IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 22, April 2026
Impact Factor: 8.2

Bridging Curriculum and Practice: A Document-Based Gap Analysis of Green Chemistry in Undergraduate Chemistry Practicals across Navi Mumbai Colleges

Mrs. Priyanka Tushar More
Assistant Professor, Department of Chemistry
Sainath Education Trust's Rajiv Gandhi College of Arts, Commerce & Science,, Navi Mumbai, Maharashtra
priyankamore01074@gmail.com

Abstract: *Green chemistry has become an essential component of contemporary chemical education due to its emphasis on environmental protection and sustainable practices. Despite its inclusion in university curricula, the extent to which green chemistry principles are meaningfully applied in undergraduate laboratory teaching remains uncertain. This study conducts a document-based gap analysis to examine the level of integration of green chemistry within undergraduate chemistry practicals across selected colleges in Navi Mumbai. Given that a significant proportion of students in these institutions are first-generation learners, effective laboratory implementation becomes particularly important.*

The study systematically analyzes institutional documents, including laboratory manuals, Standard Operating Procedures (SOPs), NAAC Self-Study Reports (SSR) and IQAC records, to assess whether curriculum intentions are translated into laboratory practice. The twelve principles of green chemistry are used as an evaluative framework to examine alignment between curriculum objectives, laboratory procedures and institutional commitment. The findings indicate a pronounced gap between theoretical acknowledgement and practical execution, especially in areas such as waste minimization, selection of safer solvents, energy-efficient experimentation and pollution prevention measures. Although sustainability is frequently referenced in institutional documentation, consistent and operational laboratory-level practices are largely absent.

The study proposes feasible and cost-effective strategies to strengthen the implementation of green chemistry in undergraduate laboratories by addressing identified gaps. By relying on documentary evidence rather than perception-based inputs, the study offers a practical model for curriculum–laboratory alignment and supports institutional planning aligned with sustainable development goals. The findings underscore the need for curriculum restructuring, faculty capacity-building and stronger policy enforcement to ensure that green chemistry is embedded as a routine laboratory practice rather than remaining a conceptual aspiration.

Keywords: Green Chemistry Education, Curriculum–Practice Gap, Undergraduate Laboratories, Sustainable Chemistry, NAAC, IQAC

I. INTRODUCTION

The rapid expansion of academic laboratories and chemical industries has significantly contributed to scientific progress, yet it has also intensified environmental concerns related to hazardous chemical usage, excessive waste generation and resource-intensive laboratory practices. In response to these challenges, green chemistry has emerged as a systematic approach aimed at minimizing environmental impact while maintaining scientific efficiency. The Twelve

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Principles of Green Chemistry proposed by Anastas and Warner provide a structured framework for designing safer chemical processes, reducing waste, conserving energy and promoting sustainable practices.

Undergraduate laboratory practicals play a critical role in shaping student's scientific skills, professional ethics and environmental awareness. While green chemistry concepts are increasingly incorporated into university curricula, their practical application within routine laboratory experiments remains inconsistent. In many cases, sustainability is highlighted in curriculum documents, yet laboratory manuals and experimental protocols continue to rely on conventional methods that involve hazardous reagents, excessive solvent use and energy-intensive procedures.

Within the Indian higher education system, regulatory and quality assurance frameworks such as NAAC accreditation, Outcome-Based Education (OBE) and Institutional Quality Assurance Cells (IQACs) emphasize sustainability, experiential learning and environmental responsibility. Despite this policy-level emphasis, evidence suggests a disconnect between stated curricular objectives and actual laboratory implementation. The effectiveness of green chemistry education therefore depends not only on curriculum inclusion but also on institutional commitment and operational execution.

This study addresses this gap by undertaking a document-based analysis of undergraduate chemistry practicals across selected colleges in Navi Mumbai. By systematically examining laboratory manuals, SOPs, NAAC SSRs and IQAC reports, the study evaluates the extent to which green chemistry principles are embedded in laboratory practices. The objective is to identify areas of alignment and misalignment between curriculum intent and laboratory execution and to offer evidence-based recommendations that can support meaningful integration of green chemistry into undergraduate laboratory education.

II. REVIEW OF LITERATURE

Existing literature indicates a clear gap between the stated inclusion of green chemistry in undergraduate curricula and its actual implementation in routine laboratory practice, particularly in the Indian higher education context. While sustainability is increasingly emphasized in accreditation and quality assurance frameworks, systematic evidence demonstrating laboratory-level operationalization of green chemistry principles remains limited. Document-based evaluations focusing on laboratory manuals, SOPs and accreditation records are notably scarce, highlighting the need for evidence-driven analysis of curriculum–practice alignment.

In India, green chemistry is largely addressed at a conceptual or policy level rather than through consistent laboratory application. NAAC guidelines encourage environmentally responsible laboratory practices; however, implementation depends heavily on institutional initiative and faculty awareness rather than enforceable standards (NAAC, 2020). Studies suggest that without structured protocols, faculty training and standardized documentation, green chemistry often remains a theoretical ideal rather than a routine laboratory practice (Sheldon, 2016).

Internationally, several studies demonstrate that meaningful integration of green chemistry into undergraduate laboratories is both feasible and educationally beneficial. Dicks et al. (2016) reported that laboratory modifications such as reagent minimization and solvent substitution significantly reduce waste while maintaining learning outcomes. Similarly, Andraos (2012) showed that applying green chemistry metrics in teaching laboratories improves student's understanding of reaction efficiency and sustainability. Research on microscale experimentation further supports its effectiveness in reducing chemical hazards and resource consumption (Zhang & Li, 2019).

The theoretical foundation of these efforts is rooted in the Twelve Principles of Green Chemistry formulated by Anastas and Warner (1998), which provide a comprehensive framework for designing safer, energy-efficient and environmentally benign chemical processes. These principles continue to guide both educational and industrial approaches to sustainable chemistry.

Research Gap

Although green chemistry is widely acknowledged in undergraduate chemistry curricula and accreditation frameworks, there is limited empirical evidence examining its actual implementation in routine laboratory practices. In particular, document-based studies that systematically assess the alignment between curriculum intent, institutional documentation and laboratory execution in the Indian undergraduate context remain scarce.

III. CONCEPTUAL FRAMEWORK

The conceptual framework of this study is based on the alignment between curriculum intent, institutional commitment and laboratory practice in undergraduate chemistry education. It assumes that effective integration of green chemistry requires consistency across these three domains rather than isolated inclusion in curriculum documents.

The Twelve Principles of Green Chemistry serve as the evaluative foundation of the framework, providing standardized criteria to assess sustainability integration in undergraduate laboratories.

Curriculum intent refers to the inclusion of green chemistry and sustainability concepts within syllabi and practical course objectives. Institutional commitment is reflected through documented support mechanisms such as NAAC Self-Study Reports, IQAC records and Standard Operating Procedures (SOPs). Laboratory practice represents the actual execution of experiments, including reagent selection, waste management, energy use and safety measures documented in laboratory manuals.

A gap analysis approach is applied to identify mismatches between intended curriculum goals and their laboratory-level implementation. The degree of alignment across these components determines the effectiveness of green chemistry integration in undergraduate practical.

IV. METHODOLOGY

4.1 Research Design

The study adopts a qualitative, document-based analytical design, appropriate for evaluating curriculum implementation and institutional practices without direct laboratory intervention. This approach enables systematic assessment of policy intent, procedural documentation and reported practices related to green chemistry.

4.2 Data Sources

Institutional documents were collected from selected undergraduate colleges in Navi Mumbai. The data sources included:

- Undergraduate chemistry laboratory manuals
- Standard Operating Procedures (SOPs)
- NAAC Self-Study Reports (SSR)
- IQAC meeting minutes and activity reports
- Departmental academic records

These documents were chosen as they formally represent curriculum expectations, institutional commitments and laboratory practices.

4.3 Analytical Framework and Rubric

The Twelve Principles of Green Chemistry were used as the primary analytical framework. A structured rubric was applied to evaluate the presence and extent of integration across three dimensions: (i) Curriculum intent (ii) Laboratory execution (iii) Institutional documentation. Each criterion was categorized as fully addressed, partially addressed, minimally addressed or not addressed.

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Rubric Category	Operational Meaning (Document Evidence)
Fully addressed	Explicit, experiment-level or policy-level evidence clearly aligns with one or more green chemistry principles; procedures are specific and actionable.
Partially addressed	Principle is referenced and some procedural cues exist, but guidance is incomplete or inconsistently applied across experiments/documents.
Minimally addressed	General statements exist (e.g., safety or sustainability mentions) without clear operational steps tied to green chemistry principles.
Not addressed	No explicit evidence in manuals/SOPs/SSR/IQAC records for the assessed principle or indicator.

4.4 Scope of the Study

The study is limited to undergraduate chemistry practicals and focuses on routine teaching laboratories. Postgraduate, research and industrial laboratory practices were excluded to maintain contextual consistency.

V. INDICATORS USED FOR ANALYSIS

To systematically evaluate the extent of green chemistry integration in undergraduate chemistry laboratories, a set of clearly defined analytical indicators was developed. These indicators were derived from the Twelve Principles of Green Chemistry and aligned with the objectives of undergraduate laboratory education, institutional sustainability mandates and accreditation requirements. The indicators were selected to capture both conceptual inclusion and operational implementation of green chemistry within routine laboratory practices.

The first group of indicators focused on chemical selection and experimental design, examining whether laboratory experiments promote the use of safer reagents, less hazardous chemicals and environmentally benign solvents. This included assessing the extent to which laboratory manuals encourage solvent substitution, reduced toxicity or avoidance of substances known to pose environmental or health risks.

A second set of indicators addressed scale and resource efficiency, with particular attention to the adoption of microscale or semi-microscale experimentation. These indicators evaluated whether experiments were designed to minimize reagent consumption, reduce waste generation and limit excessive use of materials without compromising learning outcomes.

Waste management and pollution prevention formed a critical component of the analysis. Indicators under this category examined documentation related to waste segregation, disposal protocols, reuse or recovery of chemicals and measures aimed at preventing pollution at the source rather than managing it post-generation. The presence of clearly articulated waste-handling procedures in laboratory manuals and SOPs was considered an important marker of operational green chemistry practice.

Energy-related indicators were used to assess energy efficiency and process optimization within laboratory experiments. This included evaluating whether experiments were designed to operate at ambient conditions where possible, minimize heating or cooling requirements or incorporate energy-conscious procedural steps.

The analysis also considered institutional documentation and reporting, particularly references to green chemistry or sustainable laboratory practices in NAAC Self-Study Reports and IQAC records. These indicators helped assess whether green chemistry was treated as an institutional priority supported by formal reporting, internal review and quality assurance mechanisms.

Finally, indicators related to student learning and awareness were examined. These focused on whether laboratory documentation explicitly linked experiments to sustainability outcomes, environmental responsibility, or green chemistry principles, thereby reinforcing student understanding of sustainable laboratory practice.

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VI. RESULTS AND DISCUSSION

The document-based analysis reveals that the incorporation of green chemistry principles into undergraduate chemistry laboratory practices across the selected colleges in Navi Mumbai is inconsistent and largely superficial. Although sustainability is acknowledged at the curriculum and institutional levels, its translation into routine laboratory practice remains limited and uneven.

At the curriculum level, green chemistry concepts are generally referenced within syllabi and course objectives, often framed in relation to environmental awareness or sustainable development. These references indicate conceptual recognition of green chemistry; however, explicit linkage between individual laboratory experiments and specific green chemistry principles is largely absent. As a result, curriculum intent does not consistently translate into actionable laboratory guidance, limiting effective implementation.

Evaluation of laboratory manuals and experimental procedures indicates a continued reliance on conventional experimental protocols. Most practicals employ traditional reagents, solvent systems and reaction conditions, with minimal modification aimed at reducing chemical hazards or waste generation. Adoption of microscale or semi-microscale experimentation was observed only sporadically and appeared to be motivated primarily by safety or cost considerations rather than a structured green chemistry approach. Consequently, key principles such as waste prevention, atom economy and safer chemical design remain weakly embedded at the procedural level.

In terms of waste management and pollution prevention, institutional documentation demonstrates basic compliance with safety and disposal regulations. SOPs commonly include instructions for waste segregation and disposal, reflecting adherence to regulatory norms. However, proactive strategies central to green chemistry—such as waste minimization at the source, solvent recovery, reagent reuse or pollution prevention through process redesign—are rarely documented. Furthermore, real-time monitoring or control measures linked to pollution prevention are largely absent from laboratory protocols, indicating limited engagement with advanced sustainability practices.

Analysis of energy efficiency and resource utilization reveals minimal consideration within laboratory documentation. Experimental procedures rarely address energy optimization, such as conducting reactions under ambient conditions or reducing unnecessary heating and cooling. This lack of attention suggests that principles related to energy efficiency and sustainable resource use are not yet integrated into routine laboratory planning.

Review of institutional quality assurance documents, including NAAC Self-Study Reports and IQAC records, indicates that sustainability is frequently highlighted as an institutional value. However, references to green chemistry are predominantly narrative in nature and embedded within broader environmental or quality-related discussions. Concrete evidence of sustained green laboratory initiatives, standardized implementation strategies, or measurable outcomes is limited. This suggests that institutional commitment, while conceptually present, is not consistently operationalized at the laboratory level.

Overall, the findings point to a clear theory–practice gap. Green chemistry is acknowledged within curricula and institutional narratives, yet its systematic application in undergraduate laboratory teaching remains underdeveloped. Areas related to safety awareness and basic waste handling show relatively stronger alignment, while principles such as atom economy, renewable feedstocks, energy efficiency and pollution prevention are weakly addressed.

These findings are consistent with existing studies that highlight the tendency for green chemistry in undergraduate education to remain declarative unless supported by structured laboratory protocols, faculty training and institutional enforcement mechanisms. The document-based approach adopted in this study effectively captures these gaps and underscores the need for deliberate strategies to translate sustainability objectives into routine laboratory practice.

VII. RECOMMENDATIONS

Based on the findings of the document-based analysis, this study proposes a set of targeted and practical recommendations to strengthen the integration of green chemistry principles within undergraduate chemistry laboratories. These recommendations are grounded in the observed gaps between curriculum intent, institutional

DOI: 10.48175/IJARSCT-37023

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documentation and laboratory-level execution and are designed to be feasible within the existing resource frameworks of undergraduate institutions.

First, laboratory manuals should be systematically revised to explicitly incorporate green chemistry principles at the experiment level. Each practical experiment should be mapped to relevant green chemistry principles, such as waste prevention, safer solvent selection, or energy efficiency. Where feasible, conventional experiments may be redesigned using microscale or semi-microscale approaches to reduce reagent consumption and waste generation without compromising educational objectives.

Second, standardized Standard Operating Procedures (SOPs) should be developed or updated to emphasize waste minimization, segregation and safe disposal as integral components of laboratory practice rather than as compliance-driven add-ons. SOPs may also include guidance on solvent recovery, reagent reuse and reduction at the source, thereby reinforcing pollution prevention as a routine laboratory responsibility.

Third, faculty capacity-building initiatives are essential for effective implementation. Regular training programs, workshops or orientation sessions on green laboratory design, alternative experimental methods and sustainable pedagogy can enhance faculty confidence and consistency in applying green chemistry principles. Faculty engagement is particularly critical in translating curriculum objectives into meaningful laboratory experiences for students.

Fourth, institutional quality assurance mechanisms such as IQAC should play a more active role in monitoring and documenting green laboratory practices. Inclusion of specific green chemistry indicators within NAAC Self-Study Reports and internal audits can support accountability and encourage sustained implementation. Documentation of best practices, pilot initiatives and measurable outcomes would further strengthen institutional commitment.

Fifth, student sensitization and learning outcomes related to sustainability should be explicitly integrated into laboratory teaching. Pre-lab instructions, viva questions and record books may include references to green chemistry concepts, enabling students to connect experimental work with broader environmental and societal responsibilities.

Finally, the study recommends low-cost, incremental interventions—such as reagent reduction, substitution of hazardous chemicals with safer alternatives, optimized energy use and selective use of virtual laboratories—to facilitate adoption without requiring major infrastructural changes. These measures are particularly relevant for institutions with limited financial resources.

Collectively, these recommendations aim to move green chemistry from a declarative component of curriculum documents to an operational feature of undergraduate laboratory practice, thereby strengthening the alignment between educational objectives and sustainable development goals.

VIII. CONCLUSION

This study examined the extent to which green chemistry principles are embedded in undergraduate chemistry laboratory practices across selected colleges in Navi Mumbai through a structured, document-based gap analysis. By systematically analyzing laboratory manuals, Standard Operating Procedures, NAAC Self-Study Reports, and IQAC documentation using the Twelve Principles of Green Chemistry as an evaluative framework, the study provides evidence-based insight into the alignment between curriculum intent, institutional commitment and laboratory execution.

The findings indicate that while green chemistry is increasingly acknowledged within curriculum documents and institutional narratives, its practical implementation in undergraduate laboratories remains limited and inconsistent. Sustainability-related concepts are often articulated at a conceptual level; however, they are not consistently translated into experiment-level protocols, resource-efficient practices or pollution prevention strategies. The strongest alignment was observed in areas related to basic laboratory safety and regulatory compliance, whereas key green chemistry principles such as waste prevention, energy efficiency, atom economy and renewable resource use were weakly operationalized.

The study highlights a persistent theory–practice gap, suggesting that the inclusion of green chemistry in curricula alone is insufficient to ensure meaningful laboratory integration. Effective implementation requires deliberate

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institutional support, faculty engagement, standardized documentation and routine monitoring through quality assurance mechanisms. The document-based approach adopted in this study demonstrates its utility in objectively assessing institutional practices and identifying operational gaps without reliance on perception-based data.

By proposing feasible, low-cost and context-appropriate recommendations, this study contributes a practical pathway for strengthening green chemistry adoption in undergraduate laboratories. The findings are particularly relevant for institutions serving first-generation learners, where laboratory exposure plays a critical role in shaping scientific attitudes and professional responsibility.

Overall, the study reinforces the view that green chemistry must be treated not merely as a curricular theme but as an operational imperative within undergraduate laboratory education. Strengthening curriculum–practice alignment is essential for preparing environmentally responsible graduates and for aligning chemistry education with broader sustainable development goals.

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