

Inclusion of Green Chemistry Insight in the Chemistry Curriculum for Sustainable World

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Abstract

Chemistry is the central science and it has pivotal role in our life and surroundings. Chemistry has a history in heavy industries and fossil fuels but now it is transforming itself by paradigm shift from conventional chemistry to green chemistry both in academia and industry for sustainable world. This study aimed to explore the scope for integration of green chemistry principles into chemistry curriculum and analyse their linkages with the United Nations Sustainable Development Goals (SDGs). The findings highlight that embedding green chemistry concepts into general chemistry learning enhances the quality of chemical science education and fosters sustainability sensitive attitudes and practices among students. The work advocates for a revision of curriculum of undergraduate major Chemistry course, ensuring that green chemistry is not treated as an optional topic but as a foundational perspective. Green Chemistry in the curriculum is a pathway to sustainable development goals through quality education.

Keywords: Green Chemistry, Quality Education, SDGs, Curriculum, Sustainability

1. Introduction:

1.1 Sustainable practice of Chemistry by Green chemistry

Chemistry is the central science having many branches; environmental chemistry, geochemistry, biochemistry, polymer chemistry, medicinal chemistry, industrial chemistry, agricultural chemistry etc. The adopted chemical processes and the chemical products affect the biotic and abiotic components of ecosystem. Chemical Science has pivotal role in addressing environmental challenges which we are facing in 21st century. Chemistry education is crucial for human existence and surroundings. Chemistry education with green chemistry insight must take the charge to help our planet by preventing environmental degradation as green chemistry is the sustainable aspect of chemistry.

Green Chemistry is the concept that encourages the design of a process or product that reduces or eliminates the use or production of hazardous substances. It is in real sense sustainable practice of chemical science and manufacturing within a framework of industrial ecology in a manner that is sustainable, safe and non-polluting, consuming minimum amount of energy and material resources while producing virtually no waste [1]. The principles of green chemistry can be applied in human attitudes and actions for sustainable lifestyle.

1.2 Sustainability through Quality Education

A new dimension of development called 'Sustainable Development' term was firstly defined in the report of "Our Common Future" of Brundtland Commission in 1987 and after that it has been important agenda in economy, polity, strategic partnership etc. According to this report sustainable development is the development that meets the needs of present without compromising the ability of future generation to meet their own needs. Sustainability focuses on the desired balance between future economic growth and environment quality [2].

Quality education can change the scenario of sustainability across the globe. It is an important key and tool for achieving a more sustainable society [3]. The crucial role of education in achieving sustainable development was firstly noted at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 through Chapter 36 of its Agenda 21. Education is recognised as critical for promoting Sustainable Development and improving the capacity of the people to address environment and development issues [4]. In the year of 2005 UNESCO launched United Nations Decade of Education for Sustainable Development which insisted the key role of education for amalgamating values that are supportive of Sustainable Development. The importance of promoting education for sustainable development was also emphasized in United Nations Conference on Sustainable Development Rio+20 in 2012. After Rio+20 Conference, Higher Education Sustainability Initiative (HESI), a unique interface between policy making and academia was created for implementing commitments from higher education institutions to teach and encourage research on sustainable development, greening campuses and support local sustainability efforts.

1.3 UNSDGs and NEP-2020

As societies moved from farming to industrial economies, the need for resources grew, causing significant harm to the environment [5]. Human environment harmony gradually deteriorated and ultimately our civilization reached at the mountain of wastes with trench of depleted resources. In order to address this adverse situation across the globe, United Nation Organisation launched 17 Sustainable Development Goals in 2015 that has to be achieved by 2030. These 17 goals (UNSDGs) for Sustainable Development are based on three interdependent and mutually reinforcing pillars; social, economic and environmental under legal and political framework which are tools for social, economic, environmental and political change on the planet. These sustainable development goals are the blueprint to achieve a better and more sustainable future for all [6].

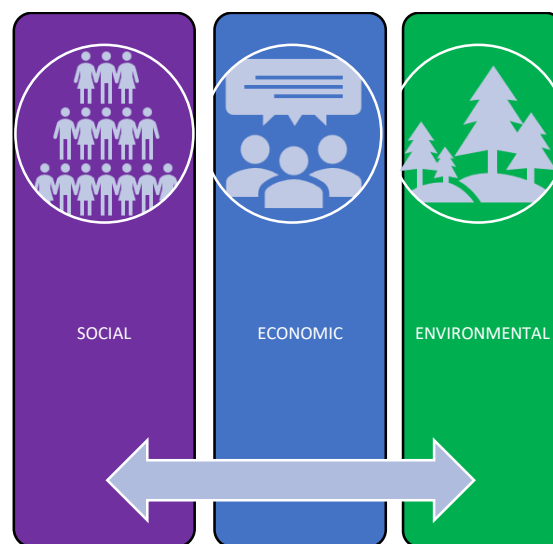


Figure: 1. Pillars of UNSDGs

Currently, Teaching and Learning in India are guided by National Education Policy-2020 (NEP-2020). This is the first education policy of this century which is aligned with the aspirational goals of 21st century education including Goal 4 of UNSDGs [7]. According to Goal 4 “ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.” It includes a set of associated targets. The target 4.7 of SDGs, ensure that all learners acquire the knowledge and skills needed to promote sustainable development including among others, through education for sustainable development and sustainable lifestyle, human rights, gender

equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development [8].

Despite of alignment of NEP-2020 with UNSDGs, there is need of more focused teaching and learning on sustainability in India as in the Environment Performance Index-2024 (EPI-2024) which is being published biennially by Yale University and Columbia University in collaboration with the World Economic Forum, India ranked 176 among 180 countries. Again, 10th Sustainable Development Report (SDR-2025) by UN Sustainable Development Solution Networks ranked India 99 out of 167 countries with a score of 67 on the scale of 0 to 100 where 100 indicates a country has achieved all 17 goals and 0 means no progress has been made. The sustainable development goals have improved millions of lives, but the current pace of change is insufficient to fully achieve all the goals by 2030. The sustainable development goals report 2025 calls for action in six priority areas: food systems, energy access, digital transformation, education, job and social protection, and climate and biodiversity [9]. So, focus on quality education is urgent to achieve SDGs 4 directly along with other 16 SDGs indirectly.

1.4 Chemistry Education and Sustainable Development Goals

A survey of Royal Society of Chemistry on how Climate Change and Sustainability are taught in science and chemistry in the year 2021 revealed that both educators and students felt climate change and sustainability are not prioritised enough in chemistry lesson or career guidance [10]. The same survey found that young people are worried about climate change and want to take action. A 2022 editorial in 'Nature' called for more rapid implementation of green and sustainability focused instruction in school and post-secondary chemistry education. Contemporary development of chemistry education focuses integration of green chemistry principles for sustainability and the real-world application of chemistry knowledge [11]. The core role of chemistry and chemical industry for sustainable development in modern societies suggests a central role of chemistry education [12].

The aim of this study was to analyse the scope for integration of green chemistry approach in teaching and learning of undergraduate students to achieve sustainable development goals through quality education in the field of chemical science. Research subjects were undergraduate students of first semester having major chemistry under Choice Based Credit System (CBCS). Research procedure involved the analysis of syllabus of undergraduate major chemistry course through the lenses of philosophy of green chemistry as a tool for achievement of UNSDGs. Understanding about environment protection insight and understanding of green chemistry principles along with their applications to the daily life in real world were assessed through questionnaires.

2. Scope of Green Chemistry and Sustainable Development in General Chemistry

Environment concern reflected around us in one of the most popular word 'green' as suffix or prefix like green economy, green chemistry, green party, green revolution, green industry, green technology, green energy, green education, green engineering, green audit, green budget, green earth, green building, green thoughts, evergreen, go green. Actually 'green' word became fascinating and this widespread usage reflects how deeply the idea of sustainability has entered daily human life. In the field of chemical science, the term Green Chemistry is now globally accepted to describe the efforts of chemist community towards the development of those chemical processes which are more environmentally acceptable. Green Chemistry is a philosophy or concept that encourages the design of a product or process that create a sustainable world. Actually, it is not a separate field of chemistry but an approach to chemistry that prioritizes the safety of human and the environment. Green chemistry is the responsible way to practice chemistry. It does not change the facts of chemistry. It just brings dimension of sustainability into our thought process for chemistry. The intention of green chemistry is to realize sustainability from atomic level.

Originating from the environmental activism of the 1960s inspired by Rachel Carson's "Silent Spring" green chemistry was formally established in the 1990s through the 12 principles [13]. The 'Twelve Principles of Green Chemistry' was proposed by professor Paul Anastas (Teresa and H. John Heinz III professor and director of Yale center of green chemistry and green engineering) and it has been widely adopted by green chemical scientists as designing rules.

Green chemistry is focused on molecular design and careful planning of synthetic pathways and therefore reducing or eliminating adverse consequences. It emphasizes the importance of all stages of chemical life cycle. The focus of green chemistry is to realize green at all the levels of chemical process that is at reactants and reagents selection, the intermediate chemical reactions and to the final products in order to reduce hazards to the minimum level. The principles of green chemistry can be applied in human attitudes and actions to save the environment. The development of green chemistry has gradually changed the public opinion towards chemistry and accepting it as a core tool for sustainability.

For making chemistry as an important tool to drive global sustainability, the application of chemistry knowledge in solving real world problems must be taught in the classrooms to shape future scientists for sustainable world. Inclusion of SDGs with green chemistry insight in chemistry learning can make this central science relevant and future oriented. This can help educators in transforming learners as next generation sustainability sensitive and responsible scientists. Thus, it is necessary to study the relationship among sustainable development, green chemistry and general chemistry learning for real action in the field of education for achievement of the SDGs.

The twelve principles of green chemistry include (1) Prevention, (2) Atom Economy, (3) Less Hazardous Chemical Synthesis, (4) Designing Safer Chemicals, (5) Safer Solvents and Auxiliaries, (6) Design for Energy Efficiency, (7) Use of Renewable Feedstocks, (8) Reduce Derivatives, (9) Catalysis, (10) Design for Degradation, (11) Real-time analysis for Pollution Prevention and (12) Inherently Safer Chemistry for Accident Prevention.

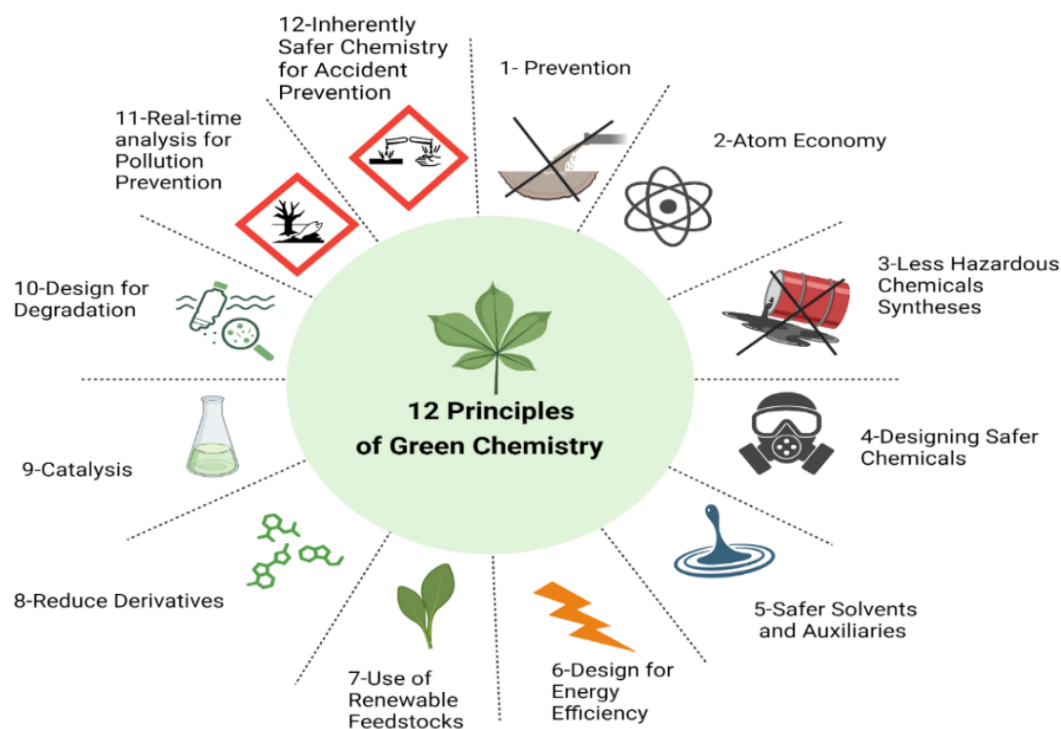


Figure: 2. Twelve Green Chemistry Principles

These green chemistry principles are interconnected and broadly categorised into “4Ps”, Planning, Process, Production and Prevention.

Sl. No.	4Ps	Green Chemistry Principles (GCPs)
1.	Planning	Designing Safer Chemicals, Design for Energy Efficiency, Design for degradation
2.	Process	Safer Solvents and Auxiliaries, Use of Renewable Feedstocks, Reduce Derivatives, Catalysis
3.	Production	Less Hazardous Chemical Synthesis
4.	Prevention	Prevention, Atom Economy, Real time analysis for Pollution Prevention, Inherently Safer chemistry for Accident Prevention

Table 1. 4Ps of Green Chemistry Principles

It is impossible to meet the requirements of all twelve principles of the process at the same time, but it attempts to apply as many principles as possible during certain stages of synthesis [14].

It has been found that due to inherent feature of sustainability in green chemistry, there is a strong connection between green chemistry principles and sustainable development goals. Out of 17 UNSDGs, several goals are directly related to the chemical science particularly those involving health, clean water, energy, responsible production and climate action while many others are indirectly interconnected through the contribution of chemistry to technology, materials and environment management [15].

The UNSDGs have exceptional value in identifying key areas of challenge that need urgent improvement if we are to move away from the unsustainable trajectory that we are on [16]. Interestingly, all of the pillars of SDGs (Social, Economic and Environmental) are directly or indirectly concern with the essence of green chemistry. Introducing principles of Green Chemistry in industrial settings have economic, social, and environmental benefits while Introducing concept and philosophy of green chemistry into academics have similar beneficial effects within the context of economic, social and environmental domains primarily at the college or the university level that must be trickle down in our society.

The 17 UNSDGs are also somewhat interconnected among themselves and also show a good connection with green chemistry principles (GCPs)

SUSTAINABLE DEVELOPMENT GOALS



Fig: 3. 17 UNSDGs to be achieved by 2030

Sl. No.	UNSDGs	Chemistry connections	GCPs
1.	SDG 2: Zero Hunger	Agricultural Chemistry, Food Chemistry	3: Less Hazardous Chemical Synthesis
2.	SDG 3: Good Health and Well being	Medicinal Chemistry, Environmental Chemistry	3: Less Hazardous Chemical Synthesis
3.	SDG 4: Quality Education	General Chemistry	All Principles
4.	SDG 6: Clean Water and Sanitation	Water Chemistry, Environmental Chemistry	1: Prevention 3: Less Hazardous Chemical Synthesis 4: Designing Safer Chemicals 10: Design for degradation 11: Real time analysis for Pollution Prevention
5.	SDG 7: Affordable and Clean Energy	Thermochemistry, Electrochemistry	6: Design for Energy Efficiency 7: Use of Renewable Feedstocks
6.	SDG 8: Decent work and Economic Growth	General Chemistry	All Principles
7.	SDG 9: Industry, Innovation and Infrastructure	Industrial Chemistry	All Principles
8.	SDG 11: Sustainable Cities and Communities	Industrial Chemistry, Environmental Chemistry	All Principles
9.	SDG 12: Responsible Consumption and Production	General Chemistry	All Principles
10.	SDG 13: Climate Action	Environmental Chemistry	All Principles
11.	SDG 14: Life below Water	Environmental Chemistry	10: Design for degradation 11: Real time analysis for Pollution Prevention

			12: Inherently Safer chemistry for Accident Prevention
12.	SDG 15: Life on Land	Environmental Chemistry	10: Design for degradation 11: Real time analysis for Pollution Prevention 12: Inherently Safer chemistry for Accident Prevention

Table 2. Connections among UNSDGs, General Chemistry and GCPs

Now, it is clear that there is a close connection among general chemistry, green chemistry and sustainable development. Therefore, inclusion of philosophy of green chemistry in general chemistry can transform the education of chemical science as an effective means for achievement of sustainable development goals.

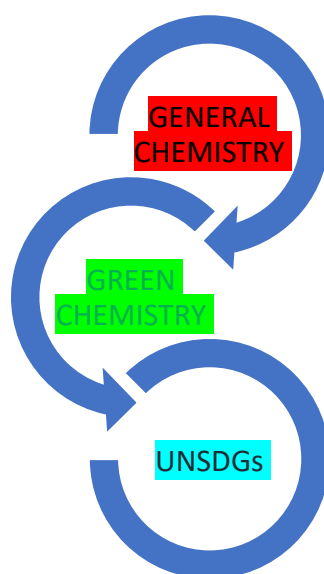


Figure: 4. Connection among General chemistry, Green chemistry & SDGs

3. Integration of GCPs in chemistry learning

Under NEP-2020, Choice Based Credit System (CBCS) is adopted in the universities of India. In this context, the state universities of Bihar, India, the syllabus of Undergraduate courses has revised and adopted in the year 2023. We analysed the new updated syllabus of UG Semester-1 Major Chemistry through the lenses of SDGs for transforming young minds to contribute in the development of sustainable world.

During the analysis of syllabus of it was found that there was very little scope of inclusion of green chemistry principles in theory classes lesson plan as the topics in theory paper includes Atomic Structure, Chemical Bonding, Fundamentals of Organic chemistry, Stereochemistry and Aliphatic Hydrocarbons. So, we focused on practical classes which includes volumetric Analysis, Detection, Purification and Separation of Organic Compounds. In all of the experiments of UG Semester-1 Major Course, there was a very good scope for inclusion of green chemistry principles especially, GCP-1, GCP-5, GCP-6 and GCP-12.

Sl. No.	Experiment	GCP integration	Implementation
1.	Preparation of solution	GCP-1 GCP-5 GCP-12	Less amount of solute/solvent Safer solvent; water Less amount & safer solvent for accident prevention
2.	Titration: Acidimetry, Alkalimetry, Permanganometry, Iodometry	GCP-1 GCP-5 GCP-12	Less amount of solute/solvent Safer solvent; water Less amount & safer solvent for accident prevention
3.	Organic Compounds: Detection of elements, Separation, Purification	GCP-1 GCP-5 GCP-6 GCP-12	Less amount of solute/solvent Safer solvent; water Less amount consumes less energy Less amount & safer solvent for accident prevention

Table 3. Integration of GCPs in Practical Lessons

Contemporary Chemical Science should include all the advanced technologies in the field along with core concept of sustainability. So, incorporation of sustainability will be one of the most important pedagogical advancements. It has been found that in UG Major Chemistry course, green chemistry is not included in the syllabus which is sustainable version of chemical science. Our research focus was to test the status of Environment Protection Insight and preparedness for acceptance of philosophy of green chemistry in general chemistry learning as well as interest in applying GCPs to the real word problem. The subjects of this research were 40 students of semester-1 Major Chemistry Course which were post higher secondary students at the entry level of university.

The questionnaire for the test of Environment Protection Insight was prepared and asked to the target group.

No.	Questions/statements	Students Response (%)			
1.	Have you ever heard of Green Chemistry ?	Y (35%)	N (65%)	CNS -	NA -
2.	Is it better to (A) treat waste (B) minimize production of waste	A (5%)	B (95%)	CNS -	NA -
3.	Is it better to perform a chemical reaction at (A) low temp and lesser consumption of electricity (B) high temp and more consumption of electricity	A (50%)	B (30%)	CNS -	NA (20%)
4.	Reactions in the (A) absence of Catalyst is good (B) presence of catalyst in good	A (15%)	B (80%)	CNS -	NA (5%)
5.	Production of a chemical is (A) good by utilizing natural resources (B) better by utilizing synthetic resources	A (55%)	B (25%)	CNS -	NA (20%)

6.	Do are you think most of the environmental problems are caused by production of toxic chemicals ?	Y (50%)	N (20%)	CNS -	NA (30%)
7.	Is it good to design and produce environment friendly chemicals ?	Y (95%)	N -	CNS -	NA (5%)
8.	Are you excited to learn chemistry through environment sensitive insight ?	Y (90%)	N (10%)	CNS -	NA -
9.	Environment protection is responsibility of (A) Government (B) Everyone	A (15%)	B (75%)	CNS -	NA (10%)
10.	Do you know Sustainable development ?	Y (85%)	N (10%)	CNS -	NA (5%)

Note: Y= yes, N= no, CNS= can't say, NA= No Answer, A= if statement one is correct, B= if statement two is correct

Table 4. Questionnaire for Mapping of Environment Protection Insight (EPI)

The result was very exciting and students were keen interested to know more about global challenges. 35% students had no knowledge of green chemistry, however 85% students had basic idea about Sustainable Development. Interestingly, 50%-95% students had already grasped the essence and philosophy of green chemistry during general chemistry learning without realizing it. 90% of young students want to learn chemistry for environment wellness and interested the curricula that emphasize environmental sensitivity.

The outcome encouraged for further inclusion of concepts of green chemistry in the practical lesson plan of UG semester-1. These concepts were embedded in the practical classes. Experiments in the laboratory were done with the application of GCPs as well as conventional methods. The difference in both green methods and conventional methods were discussed with the research group for concept clarity and environment sensitization. At the end of semester, understanding of GCPs and their applications were tested by questionnaire.

Sl. No.	Questions/Statements	Answer Key	Students response (%)
1.	Is Green Chemistry (A) same as Environmental Chemistry (B) different from Environmental Chemistry	Not same	A (40%) B (35%) CNS (25%)
2.	How many Green Chemistry principles are given by Paul Anastas ?	12 Principles	RA (70%)
3.	If you are using less amount of chemicals in the laboratory, which GCP do you apply?	GCP 1 : Prevention of Wastes	RA (65%)
4.	Utilizing natural resources for production of chemicals, which GCP do you apply?	GCP 7: Use of Renewable resources	RA (35%)
5.	Work carefully in the in the laboratory to assure safety in the workplace, which GCP do you apply?	GCP 12: Accident Prevention	RA (100%)
6.	If you prefer water instead of alcohol as solvent in a chemical reaction, which GCP do you apply ?	GCP 5: Use of Safer solvents	RA (50%)

7.	If you switch off always when electricity is not in use, which GCP do you apply ?	GCP 6: Energy efficiency	RA (80%)
8.	Do you agree that essence of principles of green chemistry is applicable in everyday life ?	Yes	Y (70%) CNS (20%) NA (10%)
9.	Do you think Green Chemistry principles were already present in Indian culture?	Yes	Y (65%) N (15%) CNS (20%)
10.	Do you think Green Chemistry principles should be included in the syllabus of UG 1 st or 2 nd semester ?	-	Y (65%) N (20%) CNS (5%) NA (10%)

Note: Y= yes, N= no, CNS= can't say, NA= No Answer, RA= Right Answer, A= if statement one is correct, B= if statement two is correct

Table 5. Questionnaire for assessment of Understanding of green chemistry

The assessment of students' understanding of green chemistry principles (GCPs) revealed a wide range between 35% and 100% of participants showing at least a basic awareness of the principles and their real-world applications. Notably, GCP 6 and GCP 12 were learnt well, with 80% and 100% of students respectively, showing strong conceptual clarity. In contrast, the remaining principles reflected more modest levels of understanding, ranging from 35% to 65%, highlighting the need for additional teaching and learning efforts. This relatively high level of appreciation for certain GCPs appears to be influenced by their prior exposure to sustainability concepts and the environment conscious values embedded in Indian cultural traditions, which emphasize ecological sensitivity and responsible resource use. Such cultural grounding seems to provide a foundation upon which their learning of green chemistry could be effectively built. Notably, a significant proportion of students, 65% expressed a clear interest in revising the curriculum to incorporate the principles of green chemistry, particularly inclusion of real-world applications. This indicates a strong learner-driven push toward curricular advancement reflecting their awareness of the importance of aligning chemical education with sustainability.

Conclusions

The research explored that students are interested to be part of the efforts for climate action and sustainable development. This study reveals that integration of the GCPs in general chemistry learning to achieve SDGs through quality education can run well. Therefore, from our work it is recommended to include concept of green chemistry in the syllabus of UG semester-1 Chemistry Major in the universities of Bihar, India as this is the entry level of higher education where young minds easily conceptualize and transform their attitude and behaviour with contemporary knowledge of chemistry required for sustainable world. Such curricular revision is essential for equipping future chemists with the mindset and skills required to contribute meaningfully to the achievement of the SDGs. By aligning chemistry education with sustainability imperatives of green chemistry, higher educational institutions can nurture responsible scientific practices and empower learners to address environmental challenges of 21st century.

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