

Green Chemistry: Sustainable Chemical Practices in Education

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Abstract:

This study examines Sustainable Chemical Practices in Education (SCPE), how chemical practices in education are understood, applied, and promoted among chemistry students in university-level academic settings. Through a structured questionnaire-based survey, the research assesses students' awareness and application of key green chemistry principles such as prevention of waste, safer solvents, atom economy, energy efficiency, and use of renewable feedstocks. These principles are examined in terms of their incorporation into laboratory experiments and curriculum content. The study highlights that while theoretical knowledge of SCPE is moderately present among Tripura University and ICFAI University Tripura students, practical application in laboratories remains limited due to curriculum gaps and resource constraints. The study also found, after a statistical t-test, that ICFAI University students are more knowledgeable of green chemistry awareness and application than Tripura University students. Findings reveal that integrating green chemistry practices directly supports Sustainable Development Goals (SDGs), especially Goal 12: Responsible Consumption and Production, by minimizing hazardous chemical use and fostering eco-friendly scientific habits in future professionals. The paper recommends curriculum reforms that mandate green chemistry modules, investment in sustainable laboratory infrastructure, and the inclusion of digital tools for simulating green practices for both teachers and students. Strengthening SCPE will equip students to face 21st-century global issues by integrating chemical education with environmental ethics, innovation, and sustainability. The study concludes that integrating green chemistry into mainstream education is essential for developing environmentally conscious chemists and achieving long-term sustainability in science and industry.

Keywords: Green Chemistry, Sustainable Chemical Practice

1. Introduction

Green Chemistry, also known as sustainable chemistry, is a revolutionary method in chemical science focused on creating products and processes that minimize or completely remove the use and production of harmful substances. This movement arose as a reaction to increasing environmental and health issues stemming from conventional chemical methods, which frequently led to toxic waste, pollution, and unsustainable resource consumption. It aligns with the Twelve Principles of Green Chemistry, which include prevention of waste, safer solvent use, energy efficiency, and the use of renewable feedstocks. These principles have significant implications for how chemistry is taught and practiced in academic settings.

In the 21st century, there is a growing need to embed Sustainable Chemical Practices in Education (SCPE) across universities to address global environmental challenges and promote Sustainable Development Goals (SDGs), particularly SDG 12: Responsible Consumption and Production.

The following image illustrates the core concept of green chemistry by combining scientific symbols (e.g., molecular structures, test tubes, and flasks) with natural elements (e.g., leaves and recycling icons) to symbolize the integration of environmental sustainability into chemical education.



Figure 1: Representation of Green Chemistry

Over the years, Green Chemistry has transformed from an industrial or regulatory effort into an essential area of education and research. In the 21st century, integrating Sustainable Chemical Practices in Education (SCPE) into chemistry curricula at universities and higher educational institutions has become increasingly vital. Implementing green principles in laboratory experiments allows institutions to minimize chemical waste, create safer learning spaces, and promote responsible scientific practices for students.

2. Objectives of the Study

- To assess how green chemistry education contributes to achieving Sustainable Development Goals (SDGs) in students' minds.
- To recommend strategies for strengthening green chemistry teaching and laboratory practice in alignment with 21st-century educational goals.
- To assess the students' awareness of green chemistry at both Tripura University and ICFAI University, Tripura.
- To assess the students' application of green chemistry at both Tripura University and ICFAI University, Tripura.
- To assess the impact of technology on green chemistry usage at both Tripura University and ICFAI University, Tripura.
- To study the overall review by the researcher.

3. Hypotheses of the Study

- **H₀₁:** There is no significant difference in green chemistry awareness and application of Tripura University students and ICFAI University students.
- **H₀₂:** There is no significant difference in technology impact on Tripura University students and ICFAI University students.

4. Conceptual Framework

The conceptual framework illustrated in figure 2 presents the structural foundation of the research, emphasizing the integration of green chemistry principles into chemical education and its influence on student awareness and laboratory practices. This framework also aligns with the broader goals of sustainable development, particularly SDG 4 (Quality Education), 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). At the core of this framework are the 12 principles of green chemistry, which serve as the guiding philosophy for promoting environmentally sustainable practices.

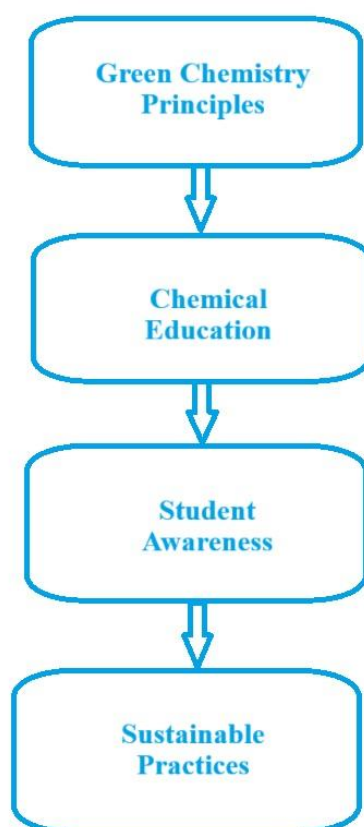


Figure 2: Conceptual Framework showing the relationship between Green Chemistry Principles, Chemical Education, Student Awareness, and Sustainable Practices.

5. Review of Related Literature

Brase [10] Conducted a study on “Digital chemistry: navigating the confluence of computation and experimentation— definition, status quo, and future perspective”. This article describes digital chemistry as the combination of computational techniques, machine learning, robotics, and automation to enhance, replicate, and refine chemical discovery and experimentation. It outlines the historical development of digital chemistry from initial quantum models to today’s AI-driven labs and highlights its effects on areas such as drug discovery, eco-friendly manufacturing, and materials research. Anticipating the future, it highlights that digital chemistry will significantly transform chemical research by fostering

efficiency, reproducibility, and environmental sustainability through the integration of artificial intelligence, quantum computing, and digital infrastructure.

Amonet et al. [12] A research was conducted on “Green chemistry and responsible research and innovation: Moving beyond the 12 principles”. The research article investigates how the combination of the Responsible Research and Innovation (RRI) framework with green chemistry can promote more sustainable and socially aware chemical research. The research presents a "responsible road mapping" approach, tested in three green chemistry initiatives, aiming to embed social, ethical, political, legal, and economic factors into preliminary R&D planning, extending beyond the conventional 12 principles of green chemistry. The results indicate that this interdisciplinary strategy enhances green chemistry's ability to significantly contribute to circular economy shifts and the achievement of Sustainable Development Goals (SDGs).

Zhang et al. [13] Conducted a study on “Research on the Impact of Green Technology Innovation in the Manufacturing Industry on the High-Quality Development of the Manufacturing Industry Under “Dual Circulation”. This study examines the impact of green technology innovation on the high-quality advancement of China's manufacturing sector within the “dual circulation” framework. Utilizing panel data from 30 Chinese provinces (2012–2022), the analysis reveals that green technology innovation significantly enhances internal economic circulation, thereby promoting high-quality manufacturing growth; meanwhile, external circulation (international trade) has a positive influence on this connection. The research ends with tailored policy suggestions aimed at fostering sustainable and innovation-oriented growth within the manufacturing industry.

Sethi et al. [14] The study named "Green Chemistry: A Review" provides an extensive summary of green chemistry, highlighting its 12 core principles intended to minimize or eradicate hazardous materials in the creation, production, and application of chemical products. It describes the development of green chemistry, tracing the journey from initial environmental consciousness to present advancements in areas like pharmaceuticals, agrochemicals, materials science, energy, water treatment, food technology, and education. The article promotes sustainable development by incorporating environmentally friendly practices, renewable resources, and life cycle evaluations, emphasizing the necessity for increased industrial dedication to fully achieve the benefits of green chemistry.

Constable [15] Conducted a study on “Green and sustainable chemistry- The case for a systems-based, interdisciplinary approach”. This article argues that for green chemistry to evolve into genuinely sustainable chemistry, chemists must adopt a systems-oriented, life-cycle aware, and interdisciplinary framework. It challenges conventional green chemistry methods, such as dependence on metal catalysis and batch processing, and highlights the importance of assessing overall environmental effects from molecular design to the final product disposal. The author urges increased cooperation among various fields to minimize chemical dangers, improve process efficiency, and address worldwide sustainability issues in line with the UN Sustainable Development Goals.

Rathi et al. [16] A research was conducted on “Green chemistry and technology for sustainable development”. This research paper highlights the significant role of green chemistry and technology in facilitating sustainable development by minimizing harmful substances and encouraging eco-friendly practices in different sectors. It outlines the 12 principles of green chemistry and showcases practical applications-such as green dry cleaning, environmentally safe paper bleaching, water purification with tamarind seed powder, and green pharmaceutical synthesis-emphasizing how these advancements minimize waste, energy consumption, and harmful substances. The study determines that the extensive

implementation of green chemistry, backed by education and interdisciplinary creativity, is crucial for a sustainable future.

Salvia et al. [11] Investigated a study on “A methodological framework for assessing regional climate efforts. Learning from its application in Italy”. This research paper presents and utilizes a detailed methodological framework to evaluate regional climate initiatives through three main dimensions- ambition, robustness, and implementation and progress- using Italy as a case example. The results show that although certain Italian regions exhibit a strong dedication and science-driven planning, the absence of quantitative adaptation goals and insufficient monitoring obstruct effective assessment and comparison of initiatives. The research emphasizes applicable best practices and offers a framework that can be scaled to enhance sub-national climate governance worldwide.

Anastas and Eghbali [17] Conducted a study on “Green Chemistry: Principles and Practice”. This foundational document describes the definition, extent, and practical significance of Green Chemistry, highlighting its importance in creating chemical products and processes that minimize or eradicate hazardous materials. It methodically examines the Twelve Principles of Green Chemistry-including waste reduction, atom efficiency, utilization of safer solvents, and catalysis-and demonstrates how they can be effectively integrated throughout the chemical life cycle for sustainable innovation. The document emphasizes effective industrial implementations and advocates for comprehensive, systems-oriented strategies and education to guarantee that future chemical design remains economically sustainable and environmentally responsible.

Anastas and Beach [18] Investigated a study on “Green chemistry: the emergence of a transformative framework”. This article showcases green chemistry as a revolutionary framework, rather than merely a collection of objectives, highlighting deliberate design that emphasizes environmental and human health from the molecular level onward. It examines two decades of advancements, featuring effective catalysis, sustainable feedstocks, safer solvents, biodegradable substances, and cutting-edge technologies such as microreactors and enzyme catalysis. The authors promote a comprehensive, innovation-focused strategy that incorporates all Twelve Principles of Green Chemistry to tackle worldwide sustainability issues via advanced chemical design.

Wardencki et al. [19] This article, "Green Chemistry-Current and Future Issues," examines the evolution, principles, and practical applications of green chemistry, highlighting its significance in minimizing environmental harm and fostering sustainable chemical practices. It explores the application of green chemistry in industries, labs, and educational settings, emphasizing breakthroughs like biodiesel creation, supercritical fluids, and solvent-free analytical methods. The authors emphasize that the main obstacle is implementing green chemistry principles in practical situations, necessitating ongoing education, technological progress, and favourable policies for broader acceptance.

Warner et al. [20] Conducted a study on “Green chemistry”. This impactful article introduces Green Chemistry as a forward-thinking, design-focused approach that aims to eradicate chemical hazards at the source instead of addressing risks after they are generated. It examines the Twelve Principles of Green Chemistry through practical examples, highlighting their impact on changing industrial practices by minimizing waste, energy consumption, toxicity, and encouraging the use of renewable feedstocks and safer solvents. The writers advocate for incorporating environmental impact assessment (EIA) instruments into the initial phases of chemical design and support reforming chemist education to embed environmental and toxicological consciousness starting from the molecular level.

Dong et al. [21] Investigated a study on “Mechanochemistry: Fundamental Principles and Applications”. This article examines the fundamental principles and diverse applications of mechanochemistry, a discipline where mechanical forces initiate chemical reactions, providing an environmentally friendly alternative to conventional techniques. It outlines how mechanochemistry improves solid-state synthesis, polymer activity, interfacial bonding, and responsive biomaterials, highlighting methods such as ball milling, twin-screw extrusion, and single-molecule force spectroscopy. The study finds that mechanochemistry has transformative potential for sustainable and green chemistry, yet challenges persist in completely grasping its molecular mechanisms for predictive design.

Curzons et al. [22] Conducted a study on “So you think your process is green, how do you know? -Using principles of sustainability to determine what is green—a corporate perspective”. This paper investigates a corporate structure to methodically assess the "greenness" of synthetic chemical processes based on sustainability criteria. Using case studies from GlaxoSmithKline, the authors suggest metrics like mass intensity, energy consumption, reaction mass efficiency (RME), and solvent choice as effective methods for evaluating environmental impact. The research highlights that although atom economy is important, wider life cycle evaluations and interdisciplinary teamwork—particularly among chemists and engineers—are crucial for progressing toward genuinely sustainable green chemistry methods.

OPR&D [23] Investigated a study on “Green Chemistry: A Framework for a Sustainable Future”. This research points out the transformation of green chemistry into a foundation for sustainable innovation, stressing the incorporation of life-cycle perspectives, circular economy objectives, and interdisciplinary methods. It highlights progress in renewable raw materials, CO₂ capture, waste reduction, and the design of low-toxicity chemicals. The authors emphasize the significance of metrics such as process mass intensity and encourage future studies to concentrate on depolymerization, eco-toxicology, machine learning, and scalable green technologies to tackle global sustainability issues.

Goyal et al. [24] A research was conducted on “Green chemistry approaches towards the design and synthesis of anti-infective fluoroquinolone derivatives”. This study investigates environmentally friendly chemistry techniques for the creation and production of anti-infective fluoroquinolone derivatives employing sustainable approaches like microwave irradiation and reusable catalysts. It highlights the benefits of these techniques—greater yields, diminished toxic substances, and quicker reaction durations—while examining recent progress in the creation of effective antibacterial and antifungal compounds. The research finds that green synthesis not only meets sustainability objectives but also provides a practical and effective pathway for creating next-generation fluoroquinolone-based treatments.

Arora and Saraswat [25] Conducted a study on “Vermifiltration as a natural, sustainable and green technology for environmental remediation: A new paradigm for wastewater treatment process”. This study introduces vermifiltration as a green, sustainable, and localized wastewater treatment method that leverages earthworms and microbial processes to eliminate organic contaminants and pathogens. The authors explain its structure, functions, and benefits, emphasizing how earthworms improve aeration, microbial activity, and contaminant degradation, while generating nutrient-dense vermicompost as a beneficial byproduct. Vermifiltration has demonstrated effectiveness in managing domestic, industrial, and clinical wastewater, standing out as an economical, environmentally friendly option compared to traditional systems, thereby aiding public health and environmental objectives.

6. Origin of Green Chemistry

The idea of Green Chemistry was officially presented in the 1990s by Paul Anastas and John Warner at the U.S. Environmental Protection Agency (EPA). Their groundbreaking efforts, especially the release of the book "Green Chemistry: Theory and Practice" in 1998, established the foundation of the discipline. In this book, they introduced the now well-known Twelve Principles of Green Chemistry, which act as a framework for chemists to create safer, more efficient, and eco-friendly chemical methods (**Anastas and Warner**) [1].

7. Green Chemistry Awareness Among Students

Awareness of green chemistry among students is important for cultivating an environmentally conscious generation of scientists and citizens. Many students possess limited knowledge about sustainable chemical practices, as traditional curricula often focus on conventional methods without emphasizing environmental impact. Increasing awareness through formal education, workshops, and practical exposure can help students understand the importance of reducing chemical hazards, conserving resources, and adopting safer laboratory techniques. When students are introduced to the 12 principles of green chemistry and their real-life applications, they become more mindful of the ecological consequences of chemical processes. Enhanced awareness not only improves their academic understanding but also encourages responsible behavior in both academic and industrial settings. Therefore, assessing and promoting green chemistry awareness among students is vital for aligning education with global sustainability goals and fostering a future workforce capable of addressing environmental challenges through innovation.

8. Recent Emerging Technologies in Green Chemistry

Recent progress in green chemistry has brought forth new methods that reduce environmental effects while improving the effectiveness of chemical processes. These techniques diminish or remove harmful substances, function at lower temperatures, and frequently employ renewable energy or biodegradable materials. Every technique corresponds with several green chemistry principles. Integrating these methods into educational programs and laboratory practices fosters worldwide initiatives aimed at attaining the Sustainable Development Goals (SDGs). There are several techniques shown in the following table.

Table 1: Modern Green Chemistry Techniques

Techniques	Environmental Benefits	Applications	Relevant Green Chemistry Principles
Mechanochemistry Arfelis et al. [3]	Solvent-free, less energy consumption, minimizes waste	Pharmaceutical synthesis, metal-organic frameworks (MOFs), and organic coupling reactions	1- Prevent Waste, 5- Safer Solvents, 6- Energy Efficiency, 9- Catalysis
Photoredox Catalysis Shaw et al. [4]	Uses visible light, avoids toxic reagents, mild conditions	CO ₂ reduction, degradation of pollutants, LED-based synthesis	3- Less Hazardous Synthesis, 6- Energy Efficiency, 1- Prevent Waste
Biocatalysis (Enzymes) France et al. [5]	Uses renewable catalysts, high selectivity, low toxicity	Drug synthesis, biodegradable plastics, food chemistry	4- Safer Products, 7- Renewable Feedstocks, 9- Catalysis

Supercritical CO₂ Fluids Prasad et al. [6]	Replaces organic solvents, non-toxic, recyclable	Extraction of oils/flavors, textile dyeing, nanomaterials	6- Energy Efficiency
Flow Chemistry Porta et al. [7]	Safer and more controlled, reduces waste, scalable production	(Active Pharmaceutical Ingredient) API synthesis, fine chemicals, continuous production	6- Energy Efficiency, 12- Safer Processes, 1- Prevent Waste
Deep Eutectic Solvents Smith et al. [8]	Biodegradable, low volatility, made from natural and renewable materials	Green extraction, biocatalysis, electrochemistry	5- Safer Solvents, 7- Renewable Feedstocks, 10- Design for Degradation
Electrochemical Synthesis Kaboudin et al. [9]	Avoids hazardous oxidants, uses renewable electricity, efficient	Organic reactions, electro polymers, sustainable redox reactions	6- Energy Efficiency, 9- Catalysis, 1- Prevent Waste
Digital Lab or Digital Chemistry Stefan Brase [10]	Reduces chemical waste by simulation, enhances safety, minimizes trial-and-error experiments	Virtual labs, predictive modelling, AI-based reaction optimization	1-Prevent Waste, 6- Energy Efficiency, 11-Real-Time Analysis, 12-Safer Processes

9. Relevance of Green Chemistry in Education

Green chemistry is crucial for fostering eco-friendly scientific thought in students, making its integration into education curricula both important and timely. Incorporating the 12 principles of green chemistry in educational settings helps students understand sustainable chemical methods that emphasize safety, resource management, and pollution reduction. It prompts students to assess the ecological effects of chemical processes critically and choose more sustainable options in experiments and industry. Education in green chemistry supports both national and international sustainability objectives, like the UN's Sustainable Development Goals (SDGs), while also training future scientists capable of creating safer materials and cleaner technologies. Thus, incorporating green chemistry into education promotes a culture of environmental responsibility, creativity, and informed decision-making from the beginning of scientific training.

Integrating green chemistry into university programs aids students in acquiring vital 21st century abilities, such as critical analysis, ethical judgment, environmental awareness, and sustainable design thinking. These skills are essential not just for scientific professions but also for cultivating responsible citizens aware of the environmental consequences of their choices. Additionally, exposure to green chemistry equips students for new career prospects in green manufacturing, clean energy, environmental monitoring, and sustainable materials science.

Nonetheless, the integration of green chemistry into Indian science education, particularly at the undergraduate level, remains constrained. Although top institutions such as IITs (Indian

Institute of Technology) and IISERs (Indian Institute of Science Education and Research) have started to incorporate aspects of green chemistry, numerous colleges and universities have not yet completely embraced these ideas in their curricula. A rising demand for curriculum reform exists, backed by educational organization like the UGC (University Grant Commission) to make green chemistry an essential part of chemistry education in various institutions.

Worldwide, nations like the United States, the United Kingdom, and Germany have established strong green chemistry education systems. Initiatives such as the Green Chemistry Education Network (GCEN) and the Beyond Benign curriculum offer freely available resources for instructing on green chemistry. India must also enhance its initiatives by advancing faculty training, affordable green experiments, and studies on green chemistry education.

10. Connecting Green Chemistry Education to Sustainable Development Goals

Linking green chemistry education with the Sustainable Development Goals (SDGs) enables students to cultivate eco-conscious scientific approaches that actively contribute to worldwide sustainability initiatives. Green chemistry promotes a greater comprehension of how science addresses actual environmental issues by aligning laboratory education with objectives like clean energy, responsible consumption, and climate action.

Table 2: Green Chemistry Principles (Anastas and Warner [1]) to relevant United Nations Sustainable Development Goals (SDGs) (UN, 2015 [2])

SL No	Green Chemistry Principle	Description	Related SDGs
1	Prevention	Avoid waste generation	SDG 12: Responsible Consumption & Production
2	Atom Economy	Maximize the incorporation of all materials into the final product	SDG 9: Industry, Innovation & Infrastructure
3	Less Hazardous Chemical Syntheses	Design safer chemicals and processes	SDG 3: Good Health & Well-being
4	Designing Safer Chemicals	Reduce the toxicity of products	SDG 3, SDG 12
5	Safer Solvents and Auxiliaries	Avoid using harmful solvents or auxiliaries	SDG 6: Clean Water & Sanitation
6	Energy Efficiency	Minimize energy requirements	SDG 7: Affordable & Clean Energy, SDG 13: Climate Action
7	Use of Renewable Feedstocks	Prefer renewable raw materials	SDG 12, SDG 15: Life on Land
8	Reduce Derivatives	Avoid unnecessary modification steps	SDG 9, SDG 12
9	Catalysis	Use selective and reusable catalysts	SDG 9, SDG 12

10	Design for Degradation	Create products that break down into non-toxic substances	SDG 14: Life Below Water, SDG 15: Life on Land
11	Real-time Analysis for Pollution Prevention	Monitor processes to prevent pollution	SDG 13, SDG 12
12	Inherently Safer Chemistry for Accident Prevention	Reduce risk of accidents and hazards	SDG 3, SDG 11: Sustainable Cities & Communities

11. Methodology

11.1 Research Design

This research was conducted based on extensive reviews and survey methods. In this research paper, two universities are considered. One is Tripura University and another is ICFAI University Tripura. Both universities are located North-East part of India. Tripura University is a government university and ICFAI University Tripura is a private university. Google forms is used to collect data from both universities.

11.2 Tool

The researcher has used a self-constructed tool for the entire research work.

Green chemistry awareness, application, and impact of technology tool developed by researcher. In this tool, there are 35 items. These items are divided into five dimensions of green chemistry, such as

- I. Awareness and Understanding of Green Chemistry Principles
- II. Practical Use of Green Chemistry in Laboratory Work
- III. Usefulness of Green Chemistry in Time and Efficiency
- IV. Role of Technology in Green Chemistry
- V. Attitude and Future Implications

The Likert-type scale of five options is used, such as Strongly Agree (SA) 5-point, Agree (A) 4-point, Undecided (U) 3-point, Disagree (DA) 2-point, and Strongly Disagree (SD) 1-point used as a scale.

11.3 Population and Sample

The population of this research was taken from Tripura University and ICFAI University Tripura. All the students from the chemistry department of both universities have been taken as the population. A stratified random sampling technique was used in this investigation.

11.4 Data Collection and Techniques of Analysis

The researcher used a Google Form to collect data from both university students. Before providing feedback, they have to inform the purpose of the study and obtain permission from all the students. In this way, complete data were collected from both university students. After the data collection, all the data were systematically put into the SPSS software for analyzing the data. Both descriptive and inferential statistics such as mean, standard deviation, and t-test, were done using SPSS software accordingly interpretation was made.

12. Data Analysis and Interpretation

Table 3 Comparison of the Green Chemistry Awareness and Application level at both University Students.

SL NO	Name of University	N	Mean	SD	df	“t” Value	Level of Significance
1	Tripura	37	141.46	12.15	75	-2.20	.031

	University						
2	ICFAI University Tripura	40	147.90	13.43			

Interpretation: An independent sample t-test was conducted to compare the green chemistry awareness and application level at both universities. Levene’s test was checked and found that “P” value is less than 0.05. So, the alternative hypothesis will be accepted. There is a significant difference between Tripura University students and ICFAI University students. In this case, ICFAI University students have better knowledge and application of green chemistry.

Table 4 Impact of Technology in Green Chemistry at both University Students.

SL NO	Name of University	N	Mean	SD	df	“t” Value	Level of Significance
1	Tripura University	37	19.46	2.50	75	-2.01	.048
2	ICFAI University Tripura	40	20.60	2.47			

Interpretation: An independent sample t-test was conducted to understand the impact of technology on green chemistry at both university students. After Levene’s test for equality of variances, it is found that “P” value is less than 0.05. So, the alternative hypothesis will be accepted. There is a significant difference between Tripura University students and ICFAI University students. In this case, ICFAI University students have better technology-friendly knowledge and usage.

13. Discussion of Results

This article discussed about green chemistry application linked with sustainable development goal in student usage. Green chemistry applies in the [Community of Inquiry \(COI\) model](#) to develop student support programs in which integrates cognitive, social, and teaching presence for effective interdisciplinary learning. Future chemical education is going to be more digitalized, it is proven by the studies of ([Brase, 2024](#)) clarify that digital chemistry is the combination of computational techniques, machine learning, robotics, and automation to enhance, replicate, and refine chemical discovery and experimentation. This study supports the chemical-free education and technology acceptance model. Furthermore, the study of ([Zhang et al., 2024](#)) proves that green technology innovation significantly enhances internal economic growth. ([Rathi et al., 2023](#)) averred that the significant role of green chemistry and technology in facilitating sustainable development by minimizing harmful substances and encouraging eco-friendly practices in different sectors. Additionally, research by ([Anastas and Beach, 2007](#)) promotes a comprehensive, innovation-focused strategy that incorporates all Twelve Principles of Green Chemistry to tackle worldwide sustainability issues via advanced chemical design. This study also clarifies that developing advanced chemical practices can reduce risk in different sectors where chemical usage is higher. Using more technology in chemical education can provide a user-friendly environment. This study also mentioned that digital chemistry education is the only education that can reduce risk in classroom chemical practices. The researcher has taken feedback from Tripura University and

ICFAI University Tripura students regarding awareness and application of green chemistry and impact of technology on green chemistry. Both university students shown positive awareness and application on green chemistry. Analysis reveal that ICFAI University Tripura students are more aware of green chemistry application and they also agreed that technology can impact green chemistry education.

14. Application of Green Chemistry

Green chemistry has many applications in higher education as well as secondary level education. Student from both levels utilize green chemistry in different ways.

● Green Chemistry Applications in Laboratory Practices

The integration of green chemistry principles into laboratory practices is essential for promoting safe, sustainable, and environmentally responsible experimentation. In educational settings, this involves replacing hazardous reagents with safer alternatives, minimizing solvent use, reducing energy consumption, and designing experiments that produce less chemical waste. For example, traditional organic synthesis reactions can be modified to use water as a solvent or conducted under solvent-free conditions through mechanochemistry. Natural dyes can be used in place of synthetic indicators, and renewable materials are preferred for practical demonstrations. These practices not only reduce health and environmental risks but also help students understand the real-world impact of chemistry. Moreover, by incorporating low-cost and eco-friendly experiments, institutions can make laboratory education more accessible and aligned with the goals of sustainable development.

● Green Chemistry Applications in Digital Laboratory Practices

Green chemistry can be integrated into digital chemical education by replacing hazardous experiments with virtual labs, leveraging online databases for reaction analysis, and using software to teach green chemistry principles like atom economy and lifecycle assessment. Green chemistry principles also apply in digital lab system where students can simulate different experiment. This digital lab system can be applicable in higher education institutions as well as secondary level institutions. Teachers from both institutions can apply digital lab system and promote green chemistry principles.

● Green Chemistry Applications in Synthesis

Green chemistry applications in synthesis focus on creating safer, more efficient chemical processes with minimal waste. It has revolutionized drug synthesis by developing shorter, less hazardous, and more efficient processes.

● Green Chemistry Applications in Catalysis

Applications include the development of eco-friendly catalysts like nano-particles, enzymes, and biocatalysts. The integration of computational methods to design more sustainable catalytic systems.

● Promote Education for Sustainable Development

Higher educational institutions are encouraged to integrate green chemistry into all aspects of their curriculum to develop a culture of sustainability among students.

15. Conclusion

Sustainable Chemical Practices in Education, especially in higher education now-a-days a burning issue. Every institution is striving to incorporate green chemistry principles into its laboratory practices. Traditional chemical reactions are more dangerous compared to sustainable chemical practices using green chemistry principles. This research tries to explore how sustainable chemical practices can help the students as well as the environment at large. Furthermore, by applying green chemistry principles, the teaching and learning process will

be more eco-friendly. Also, information and communication technology, helps to understand and utilize sustainable chemical usage in higher education as well as secondary level education. Most importantly, eco-friendly chemical usage is the only solution for the betterment of the upcoming generation.

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