Integrating Green Chemistry in Engineering Chemistry for Achieving Sustainable Development Goals through Education(JEET)

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***Abstract*— Integrating Green Chemistry Principles (GCP) into the engineering chemistry curriculum has proven to be highly effective in enhancing freshman students' awareness and understanding of the Sustainable Development Goals (SDGs). This research was conducted to evaluate how the incorporation of Green Chemistry Principles influences students' grasp of concepts related to key SDGs, specifically SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), and SDG 13 (climate action). To assess this, an inferential statistical analysis was carried out, including pre- and post-tests administered to a random sample of First year 120 students from an autonomous college in South India. The results were analyzed using a parametric paired t-test revealing a significant improvement in students' understanding of how green chemistry practices align with sustainable development concepts. The paired t-test confirmed that students' comprehension of these concepts notably increased after the introduction of Green chemistry Principle into their curriculum. Additionally, student feedback was overwhelmingly positive, with many reporting a deeper appreciation for how their field contributes to achieving the SDGs and a greater sense of responsibility towards sustainable practices. This study underscores the effectiveness of integrating 12 Green chemistry principles into basic education, as it not only improves technical knowledge but also fosters ethical responsibility and innovation towards sustainability. It highlights the value of incorporating sustainability concepts early in educational programs, providing a model for aligning technical education with global sustainability goals.**

***Keywords*— Sustainable Development Goals, Green Chemistry Principles, Engineering Chemistry**

***JEET Category*— Research**

I. INTRODUCTION

Green Chemistry, or sustainable chemistry, focuses on designing chemical products and processes that reduce hazardous substances, following twelve principles like renewable feedstocks and energy efficiency. These principles align with the United Nations Sustainable Development Goals (SDGs) to tackle global challenges such as climate change and pollution. Integrating Green Chemistry into Engineering Chemistry education is vital for empowering students to create innovative, sustainable solutions, fostering a generation of chemists dedicated to a more sustainable future. (Mulvihill, M. J. et al., 2011)

In recent times, there has been more focus on terms such as sustainable chemistry, green chemistry, and sustainable development (Anastas & Zimmerman, 2018; Chanshetti, 2014). Related concepts include green technology (Bhowmik & Dahekar, 2014), green industry (Bolivar, 2019), and green economy (Khoshnava et al., 2019). The term "green" has become part of everyday language as awareness of environmental issues grows and actions to address them are undertaken. The 17 SDGs address the ecological, social, and political aspects of sustainability, as highlighted by (Gupta and Vegelin ,2016).

Green chemistry promotes the design of products and processes that minimize the use and production of hazardous substances (Anastas & Zimmerman, 2018). Its principles can also guide human behavior towards environmental preservation through education, known as "green education" (Wardencki et al., 2005).

Education for Sustainable Development (ESD) and sustainable development have been extensively studied to support ESD, it is essential to incorporate sustainability-related values within the educational system. (Tarasova et al., 2018). Sustainability is often defined by three pillars: environmental, social, and economical (Purvis et al., 2019), or by up to five pillars including political and corporate aspects (Greenland et al., 2022). Achieving the SDGs requires environmental sustainability, especially through green chemistry.

Green chemistry concepts are often taught in lab andclassroom settings, sometimes inadvertently. Green chemistry encourages safe, non-polluting, sustainable chemical processesthat use less energy and resources while generating less waste.The twelve principles of green chemistry can guide human behavior towards environmental conservation. This principlesshould be incorporated at all educational levels.

Universities and colleges play a vital role in promoting environmental sustainability through eco-campus programs, which include strategic targets like urban forest success, waste management, water recycling, pollution-free air, efficient transportation, energy savings, water quality improvement, environmental education, eco-campus research, and master plan revitalization. Incorporating green chemistry principles into first-year engineering chemistry courses can support these goals and the SDGs through education.

The 17 SDGs strive to foster sustainable development by addressing present needs while ensuring future generationscan meet theirs. Efforts are ongoing to incorporate SDG and ESD ideals into curricula (Zguir et al., 2021). Research has explored the connection between sustainability, ESD, and high-quality education (Didham & Ofei-Manu, 2020); however, there is limited knowledge on how to incorporate green chemistry concepts into the classroom to help achieve the SDGs. This research aims to outline the connections and contributions of green chemistry, education, the SDGs, and engineering chemistry lesson design to environmental preservation. It also proposes a learning model focused on green chemistry to support the SDGs.

Currently, green chemistry principles are often integrated into classroom and laboratory activities, sometimes without explicit awareness. Green Chemistry is a philosophy that promotes the design of products and processes that minimize or eliminate the use and generation of hazardous materials(Manahan, 2022).

“Green chemistry is the practice of chemistry in a manner that maximizes its benefits while eliminating or at least greatly reducing its adverse impacts. Green chemistry is the sustainable practice of chemical science and manufacturing within a framework of industrial ecology in a manner that is sustainable, safe, and non-polluting, consuming minimal amounts of energy and material resources while producing virtually no wastes.” (Azizah U & Yonata B, 2023).

The 12 principles of green chemistry can be adapted to human attitudes and behaviors to protect the environment (Anastas & Warner, 1998). Environmental actions can be implemented in all levels of education.

Higher education, representing the final stage of the educational journey, holds a crucial responsibility in preserving the environment through green education. Universities can contribute significantly by implementing eco-campus programs targeting integration of environmental learning and education can be achieved through the

Engineering Chemistry course, which is part of the first-year curriculum for Chemistry Department students. Introducing green chemistry principles early in their education is crucial. Thus, designing green chemistry-oriented learning and equipment is necessary to achieve green education, supporting eco-campus targets and contributing to the Sustainable Development Goals (SDGs) through education.

This article explores how integrating green chemistry principles into engineering chemistry education can advance the environmental aspects of the Sustainable Development Goals (SDGs), specifically targeting SDGs 3, 6, 12, and 13 (Government of Sierra Leone, 2016). The study emphasizesthe practical application of green chemistry in introductory courses, allowing students to develop and apply greentechniques from the outset (Hjeresen, 2000). By incorporating green chemistry into chemical synthesis and aligning educational practices with sustainable development values, the study highlights opportunities to advance environmentaleducation through the Engineering Chemistry course.

The research aims to integrate a comprehensive module on Green Chemistry Principles (GCP) within the engineering curriculum, emphasizing the 12 principles of green chemistry, their engineering applications, and their alignment with the Sustainable Development Goals (SDGs). The proposed educational methods include lectures, discussions, practical labs, and project-based learning, with a focus on real-world GCP applications. To further promote sustainable development, the GCP frameworks most relevant to the engineering curriculum are carefully selected and mapped to the SDGs. A quasi-experimental study will be conducted, using pre- and post-tests to evaluate the effectiveness of this approach in achieving the SDGs by providing students with both foundational knowledge and practical experience in green chemistry (Mitarlis, Azizah, & Yonata, 2018; Hjeresen, Boese, & Schutt, 2000).

II. RESEARCH METHODOLOGY

This research employed a quantitative design with a pre- and post-test.(Binani, S et al., 2018) approach to analyze the impact of Green Chemistry Principles (GCP) on the understanding of 120 freshman engineering chemistry students (84 male and 36 female) from an autonomous college in South India. The study was conducted in four stages: preparing and analyzing engineering chemistry syllabus, mapping and describing the curriculum, developing learning materials incorporating GCP, and evaluating student learning. Initially, a pretest revealed confusion among students regarding real-life applications of green chemistry. GCP insights were then integrated while teaching curriculum, followed by a posttest with 20 survey questions to measure improvement.

Data collection involved using validation questionnaires, response questionnaires, and test instruments, along with practical equipment and materials commonly used in engineering chemistry courses. The effectiveness of the GCP integration was analyzed using inferential statistical methods, including a t-test, which showed significant improvement in student understanding. The study could be interpreted as a quasi-experimental study, where the educational intervention involves mapping and integrating GCP principles into engineering courses, including the development of teaching materials. This approach is designed to foster student awareness and understanding of chemical engineering in relation to the Sustainable Development Goals (SDGs), by incorporating GCP principles throughout the curriculum.

III. RESULTS AND DISCUSSIONS

A. MAPPING SUSTAINABLE DEVELOPMENT AND GREEN CHEMISTRY

Green Chemistry, often referred to as sustainable chemistry, promotes designing products and processes to minimize harmful substances. By targeting pollution at its source,it leverages innovative scientific methods to tackle environmental challenges. Its 12 principles (Anastas & Warner, 1998) can be integrated into education from an early stage to aid in achieving sustainable development goals, as outlined below.

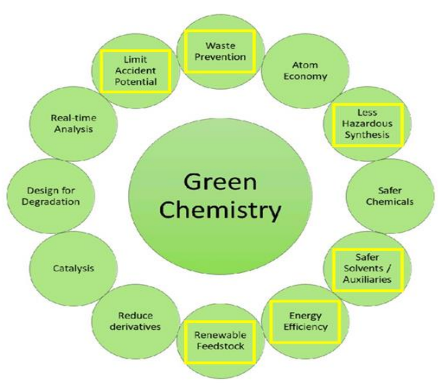

Fig 1.Green Chemistry Principles and Related targets(Yellow mark)

Among the 12 principles of green chemistry that can be implemented in education are: (1) waste prevention, (3) designing safer chemical syntheses, (5) using safer solvents and auxiliaries, (6) improving energy efficiency, (7) utilizing renewable raw materials, and (12) reducing the potential for accidents.

The six principles of Green Chemistry, as mentioned in Figure 1, can be integrated into the engineering chemistry education rogram. These principles were chosen based on their relevance to students' learning experiences, particularly during practicals in the engineering chemistry curriculum. Figure 2 illustrates the connections between the principles of green chemistry, the pillars, and the goals of sustainable development, as well as their incorporation into chemistry education.Specifically, these linkages are reflected in the formulation of SDGs targets 3, 6, 12, and 13. By 2030, the goal is to significantly decrease waste generation through prevention, reduction, recycling, and reuse, while ensuring that the community is well-informed and conscious of sustainable development and lifestyles that coexist harmoniously with nature (Alisjahbana, 2018).

Fig 2.The Role of Education in Achieving the 17 SDGs and Related Targets

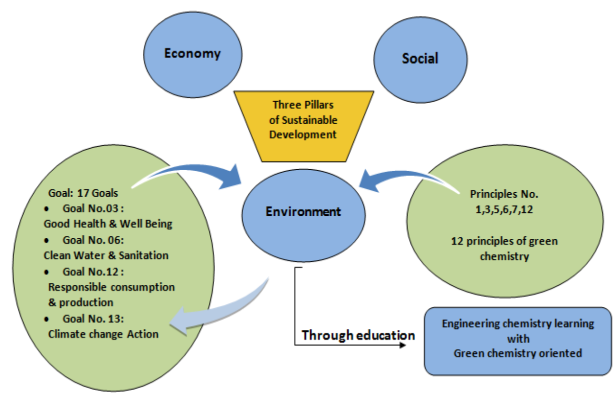

Fig 3. Integration of Green Chemistry Principles into Education for Achieving Sustainable Development Goals

Based on the results of the mapping, Fig.3 showcases a connection between green chemistry principles and engineering chemistry learning in supporting the achievement of SDGs through learning. The integration of these principles begins with the formulation in the Semester Learning Plan(SLP). By focusing on the environmental pillar of sustainable development, this approach highlights the importance of green chemistry in achieving goals such as good health and well-being(Goal 03), clean water and sanitation (Goal 06), responsible consumption and production (Goal 12), and climate action (Goal 13). Aligning these goals with green chemistry principles 1, 3, 5, 6, 7, and 12 emphasizes environmental stewardship and aims to equip future generations with the knowledge and skills needed for sustainable practices.

B. Semester Lesson Plan (SLP) of Engineering Chemistry Course

The analysis of the Semester Lesson Plan (SLP) for Engineering Chemistry courses focused on evaluating learning outcomes, learning experiences, and the teaching strategies, mod els, and methods employed. This analysis was crucial in shaping the development of learning materials that incorporate Green Chemistry Principles (GCP).

The Engineering Chemistry syllabus includes topics such as water treatment, spectroscopic techniques and applications, stereochemistry, reaction mechanisms and drug synthesis, electrochemistry and corrosion, and polymer preparation.

These subjects are addressed through various instructional methods, including discussions, assignments, and practical laboratory activities involving instrumental, volumetric, virtual, and polymer preparation techniques. The integration of GCP into these components aims to enhance student competencies by linking green chemistry insights with practical and theoretical knowledge. This approach ensures that the learning materials and activities are aligned with sustainability goals and support the broader educational objectives of the course.

The results of the SLP analysis for Engineering Chemistry courses associated with green chemistry insights are briefly presented in Table 1 & Table 2

TABLE I
ENGINEERING CHEMISTRY SEMESTER LESSON PLAN WITH GREEN CHEMISTRY PRINCIPLES AND LEARNING METHOD

Engineering Chemistry Theory(Syllabus)	Green Chemistry principles(GCP)	Strategy/Model/Method of Learning	General Learning Method
Molecular Structure and Bonding Concepts: This includes atomic and molecular orbitals, the Linear Combination of Atomic Orbitals (LCAO) method, molecular orbitals in diatomic molecules, and energy level diagrams for nitrogen (N_2), oxygen (O_2), and fluorine (F_2). It also covers π molecular orbitals in butadiene and benzene.	**GCP No. 1**. Atom Economy **GCP No. 2**. Safer Chemical Syntheses **GCP No. 6**. Energy Efficiency **GCP No. 9.** Catalysis	1. Visual Representation and Modeling 2. Interactive Simulations and Virtual Labs 3. Problem-Solving and Application Exercises 4. Collaborative Learning and Discussion	1. Flipped Classroom 2. Cooperative Learning 3. Project-Based Learning (PBL) 4. Online Courses and MOOCs 5. Interactive Workshops
Water and Its Treatment: An overview of water hardness, including its causes and the distinction between temporary and permanent hardness. Methods for expressing and measuring hardness, particularly using the complexometric method. Potable water standards and the processes involved in water treatment, including disinfection and desalination.	**GCP No. 1.**Prevention **GCP No. 5.**Safer Solvents and Auxiliaries **GCP No. 4**.Design for Degradation	1. Case Studies and Real-World Examples 2. Laboratory Experiments 3. Field Trips 4. Simulations and Modeling	1. Flipped Classroom 2. Cooperative Learning 3. Project-Based Learning (PBL) 4. Online Courses and MOOCs 5. Interactive Workshops
Electrochemistry and Corrosion: This includes electrochemical cells, electrode potentials, standard electrode potentials, and different types of electrodes. It covers the Nernst equation, the electrochemical series and its uses, as well as primary and secondary batteries. Additionally, it addresses corrosion, cathodic protection methods, including sacrificial anodes and impressed current techniques.	**GCP No. 2.**Atom Economy **GCP No. 6.** Less Hazardous Chemical Syntheses **GCP No. 7.**Use of Renewable Feedstocks	1. Hands-On Lab Work 2. Project-Based Learning 3. Guest Lectures and Seminars 4. Research and Review	1. Flipped Classroom 2. Cooperative Learning 3. Project-Based Learning (PBL) 4. Online Courses and MOOCs 5. Interactive Workshops

Stereochemistry, Reaction Mechanism, and Drug Molecule Synthesis:Introduction to the representation of three-dimensional structures, including structural and stereoisomers, configurations, symmetry, and chirality. Examination of enantiomers, diastereomers, optical activity, and absolute configuration. Conformational analysis of n-butane.	**GCP No. 2.** Atom Economy: **GCP No. 3**. Safer Chemicals Design **GCP No. 7.** Use of Renewable Feedstocks **GCP No. 9.** Catalysis	1. Concept Mapping and Visualization 2. Practice-Based Learning with Mechanistic Analysis 3. Case Studies and Pharmaceutical Applications	1. Flipped Classroom 2. Cooperative Learning 3. Project-Based Learning (PBL) 4. Online Courses and MOOCs 5. Interactive Workshops
Spectroscopic Techniques and Their Applications:This includes the principles of spectroscopy, selection rules, and the applications of electronic spectroscopy. It covers vibrational and rotational spectroscopy, fundamental concepts of Nuclear Magnetic Resonance (NMR) spectroscopy, and chemical shift. An overview of Magnetic Resonance Imaging (MRI) is also included.	**GCP No. 1**. Waste Prevention **GCP No. 5.** Safer Solvents and Auxiliaries: **GCP No. 11**. Real-time Analysis for Pollution Prevention	1. Simulation Software 2. Multimedia Resources 3.Flipped classroom	1. Flipped Classroom 2. Cooperative Learning 3. Project-Based Learning (PBL) 4. Online Courses and MOOCs 5. Interactive Workshops

TABLE II

RELATIONSHIP BETWEEN ENGINEERING CHEMISTRY PRACTICAL , AND ITS GREEN CHEMISTRY INSIGHTS WITH LEARNING METHOD.

Engineering chemistry lab	**Green chemistry principles(GCPs)**	**Strategy/Model/Method of learning**	**General Learning Methods with GCP**
Volumetric Analysis: -Estimation of Hardness Of water -Estimation of chloride content in water	**GCP No. 1:** Prevention **GCP No. 5:** Safer Solvents and Auxiliaries **GCP No. 12:** Inherently Safer Chemistry for Accident Prevention.	1. Laboratory Experiments 2. Simulations 3. Problem-Based Learning	Doing practicum with Green chemistry insight on determining hardness and chloride content of water
Instrumental Analysis: -Potentiometer -Conductometer -Viscometer -Stalagmometer	**GCP No. 3:** Less Hazardous Chemical Syntheses **GCP No. 7:** Use of Renewable Feedstocks **GCP No. 9:** Catalysis	1. Hands-On Instrumentation Training 2. Data Analysis 3. Virtual Instrumentation Labs	Doing practical with Green chemistry insights on determining the concentration of an environmentally friendly electrolyte by using instrumental analysis.
Virtual Lab: - Electric vehicle -solar cells	**GCP 1:** Prevention **GCP 4:** Designing Safer Chemicals **GCP No. 8:** Reduce Derivatives	1. Interactive Simulations 2. Virtual Reality (VR) Labs 3. Online Platforms	Doing practical work to explore the efficiency of different types of solar cells in a virtual lab and use of electric vehicles contributes to reducing greenhouse gas emissions.
Preparation of polymers: -Preparation of Bakelite -Preparation of Nylon 6,6	**GCP No. 2:** Atom Economy GCP No. 6: Design for Energy Efficiency GCP No. 10: Design for Degradation - GCP No. 11: Real-Time Analysis for Pollution Prevention	1. Laboratory Synthesis 2. Research Projects 3. Collaborative Projects 4. Case Studies	Doing Practicals on synthesize of polymers in the lab and evaluate the process in terms of energy efficiency and waste reduction

C. *Integrating Green Chemistry Principles on Engineering Chemistry*

The integration of Green Chemistry Principles (GCP) into Engineering Chemistry education was implemented using specialized learning tools and materials developed with a green chemistry focus. These materials were validated by experts and found to be effective. Student comprehension was monitored and assessed, and a questionnaire was used to evaluate their understanding of green chemistry and its role in achieving the Sustainable Development Goals (SDGs).

The implementation of GCP in the curriculum demonstrated positive results. A test instrument assessed students' knowledge of green chemistry, its application in engineering chemistry, and its relevance to everyday life. The pre- and post-test results, shown in Table 3, indicated significant improvements in understanding. The test results were presented quantitatively, highlighting the effectiveness of integrating green chemistry principles into education to support SDGs.

TABLE III
RESULTS OF QUESTIONNAIRE ON PRE AND POST TEST STUDENTS UNDERSTANDING ON GCP

			Correct Answer(%)	
Sl.No.	**Question**	**Answer**	**Pre**	**Post**
1.	As a chemistry student, do you think green chemistry and environmental chemistry are the same?	Although there is a strong relationship, they are not same	16.23	79.73
2.	Do you know how many green chemistry principles were formulated by Paul Anastas?	There are 12 principles of green chemistry	1	99
3.	Which Green Chemistry Principle are you applying when you use the minimal amount of chemicals in the laboratory?	GCP No. 1, Prevent or reduce the formation of waste	23.33	87.82
4.	Which Green Chemistry Principle are you applying when you prefer using water solvents over alcohol solvents during the natural indicator extraction practicum?	GCP No. 5, Use safe solvents or chemicals	60.03	91.59
5.	Which Green Chemistry Principle are you applying when you prefer to walk instead of driving to nearby places, thereby saving fuel?	GCP No. 6, Energy Efficiency	18.21	98.64
6.	Which Green Chemistry Principle are you applying when you prefer to bring your own drinking bottle to reduce waste production?	GCP No. 1, Prevent or reduce the formation of waste	54.63	95.11
7.	Which Green Chemistry Principle are you applying when you always turn off electrical equipment and lights that are no longer in use?	GCP No. 6, Energy Efficiency	60.02	94.24
8.	Which Green Chemistry Principle are you applying when you use natural resources for chemistry experiments and learning activities?	GCP No. 7, Uses renewable feedstock	40.41	96.77
9.	Which Green Chemistry Principle are you applying when you always replace the packaging cover or bottle cap after using substances, to maintain safe conditions in the laboratory or in daily life?	GCP No. 12. Prevent or minimize potential accidents	54.47	97.09
10	Which Green Chemistry Principle are you applying when you work carefully with materials in the laboratory to ensure safety and security?	GCP No. 12. Prevent or minimize potential accidents	40.41	95.02
11.	Which GCP should be focused for preparation of polymers?	GCP No. 3 Less hazardous synthesis GCP No. 5 Safer solvent and Auxiliaries	27.57	91.07

12.	When you focus on designing chemical processes that avoid the use of derivatives, which GCP do you apply?	GCP No. 8 Reduce derivatives	49.97	94.44
13.	After deciding to minimize energy requirements in your lab, which GCP are you applying?	GCP No.6. Energy Efficiency	38.11	86.88
14.	When you focus on creating chemical products that break down into harmless substances after use, which GCP do you apply?	GCP No. 10. Design for Degradation	53.25	92.36
15.	If you use a chemical process that eliminates the use of solvents or makes them unnecessary, which GCP do you apply?	GCP No. 5. Safer Solvents and Auxiliaries	47.59	82.11
16.	Considering the importance of safety, you design a process that uses and generates substances with little or no toxicity. Which GCP do you apply?	GCP No. 3. Less Hazardous Syntheses	59.22	87.52
17.	By implementing real-time analysis to monitor your chemical processes, which GCP do you apply?	GCP No. 11. Real-time analysis	38.21	82.03
18.	When designing a chemical reaction to maximize the incorporation of all materials into the final product, which GCP do you apply?	GCP No. 2. Atom Economy	43.83	98.32
19.	If you use a chemical process that eliminates the use of solvents or makes them unnecessary, which GCP do you apply?	GCP No. 5. Safer Solvents and Auxiliaries	53.72	82.11
20.	Ensuring that your chemical products are designed to be effective yet non-toxic, which GCP do you apply?	GCP No. 4. Safer Chemicals	39.43	79.45

An analysis of the Semester Learning Plan (SLP) for the Engineering Chemistry course was conducted, focusing on learning outcomes, experiences, and teaching strategies. The SLP aims to integrate Green Chemistry Principles (GCP) to support Sustainable Development Goals (SDGs) through learning. This integration encompasses five units of Engineering Chemistry, complemented by laboratory activities, and is delivered through dialogues, assignments, and practicals. This approach aligns student competencies with green chemistry insights.

To evaluate the effectiveness of this green chemistry-oriented learning approach, pre- and post-test assessments were administered. The pre-test results revealed that the percentage of correct answers was below 61% across all items. In contrast, the post-test results demonstrated significant improvement, with correct answers exceeding 79% for most items. Table 3 summarizes these findings, indicating a marked enhancement in students' understanding following the implementation of this teaching strategy.

The study involved 20 survey questions to gauge students' understanding. Initially, freshman students had a basic awareness of environmental issues but lacked detailed knowledge of SDGs and their connection to engineering chemistry. Post-GCP (Green Chemistry Principles) learning revealed an enhanced understanding of SDGs, with students recognizing the impact of chemical practices on global sustainability goals, such as good health and well being (SDG 3) clean water and sanitation (SDG 6) waste reduction (SDG 12) and climate change (SDG 13). This improved awareness underscores the importance of integrating green chemistry into education to foster sustainable practices.

Tables 1 and 2 present the SLP analysis results, while Table 3 displays the results of both the pre-test and post-test highlighting the effectiveness of green chemistry-oriented education in enhancing students' awareness and knowledge of sustainable practices.

Table 3 shows that the GCP insights in engineering chemistry led to an improvement in students' understanding of inferential statistics through paired t-test. The data indicates that the number of scores increased were excellent, while the number of poor and average scores decreased following the implementation of this teaching strategy.
The mean scores for the pre-test and post-test were calculated. The results demonstrate an increase in mean scores, highlighting the effectiveness of the activity in enhancing student performance.To analyze this improvement, a paired t-test was conducted.

One might formulate the alternative hypothesis as a left-tailed, right-tailed, or two-tailed test. Since it suggests that the pre-test mean score is lower than the post-test mean score, a left-tailed test is employed in this situation. According to this theory, the post-test results show improvement over the pre-test findings.

Alternative (left-tailed) Hypothesis: H1:µ1<µ2 (The means of both samples differ significantly, indicating that the pre-test score mean is lower than the post-test score mean.)

Pre-test mean value: 1 = 40.21 and Post-test mean value: 2 = 90.54

To calculate the t-test statistics, we use the following formula:

$$t = \frac{\sum d}{\sqrt{\frac{n(\sum(d^2) - (\sum d^2)}{n-1}}} \quad (1)$$

Where *d* is each paired value's difference.
n: the quantity of samples

The t-test is conducted at a 5% significance level, with p=0.05 and a degree of freedom of df=19. The significance level defines the acceptance and rejection regions for the hypothesis test. We accept the null hypothesis if the test statistic is inside the acceptance zone. The crucial t-value for a degree of freedom of 19 is 2.093.

This indicates that we accept the null hypothesis H0 if the computed t-test statistic is less than or equal to 2.093. However, if the calculated t-test statistic exceeds 2.093, we reject H0 and accept the alternative hypothesis H1.Comparing the pre-test mean of 40.21 with the post-test mean of 90.54 using a left-tailed test supports this evaluation.

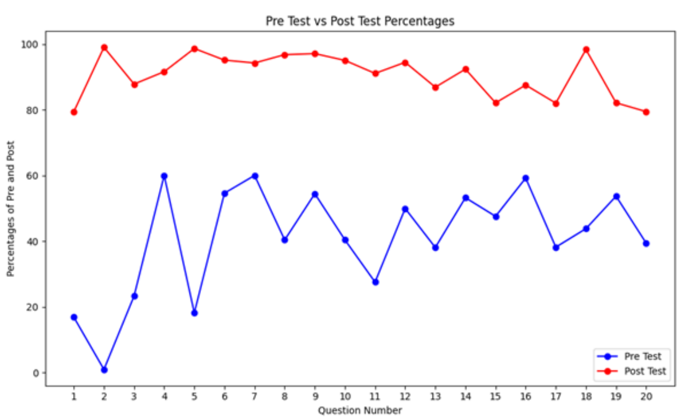

Fig. 4. Pre test and Post Test percentages.

Calculated paired t-test value for df = 19 t-test table value for df = 19

TABLE III
POST-TEST RESULTS ARE TYPICALLY GREATER THAN PRE-TEST RESULTS.

Calculated paired t-test value for df = 19	t-test table value for df = 19
12.58	2.093

The calculated t-test statistic value is 12.58, which exceeds the critical value of 2.093. As a result, we reject the null hypothesis.

IV. CONCLUSIONS

Based on the data gathered in this research, which involved incorporating Green Chemistry Principles (GCP) into the engineering chemistry curriculum and mapping them to learning objectives and experiences, it can be concluded that integrating these principles into chemistry education effectively supports the achievement of the SDGs. Among the 12 GCP principles, 5 were specifically aligned with the engineering curriculum, contributing to the achievement of 4 SDGs. These include promoting material-saving behaviors that reduce waste (GCP No. 1), encouraging less hazardous synthesis (GCP No. 3), utilizing safer solvents (GCP No. 5), enhancing energy efficiency (GCP No. 6), and employing renewable feedstocks (GCP No. 7). These principles can be applied in both laboratory and classroom contexts.Engineering chemistry education plays a significant role in raising awareness of the SDGs, particularly the environmental pillars of SDG 13 (Climate Action), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 3 (Good Health and Well-Being). Students have provided exceptionally positive feedback, with many expressing a newfound appreciation for how their field contributes to achieving the SDGs and an increased sense of responsibility toward sustainable practices. Green chemistry-oriented learning significantly contributes to these goals.Effective teaching methods for integrating GCPs include the Flipped Classroom, Collaborative Learning, and Problem-Based Learning. Incorporating Green Chemistry Principles into the engineering curriculum for freshman students is anticipated to enhance their awareness and understanding of the SDGs. This approach not only educates students about sustainable practices but also prepares them to contribute effectively to global sustainability efforts through their engineering expertise.

V.FUTURE WORKS

Future research should focus on aligning Green Chemistry Principles with specific engineering disciplines to deepen the understanding of SDGs within specialized topics. This includes developing domain-specific modules that integrate GCPs with engineering applications, assessing the impact of such modules on students' ability to address sustainability challenges in their respective fields, and evaluating how these specialized integrations enhance their preparedness to contribute to the SDGs. This approach will ensure that the integration of sustainability principles is not only broad but also tailored to the specific needs and challenges of various engineering disciplines.

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