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Bridging Green and Sustainable Chemistry and Classroom Practice: A Mixed-Methods Inquiry of Secondary Science Teachers in SDO San Juan City, Philippines

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ABSTRACT

This sequential explanatory mixed-methods study evaluated secondary science teachers' (N = 30) awareness, perceived curricular integration, classroom implementation, and systems-thinking alignment with Green and Sustainable Chemistry (GSC) principles in SDO San Juan City, Philippines. Quantitative survey data (α = 0.971) revealed high general GSC awareness (M = 2.740) alongside extremely low confidence in formal training (M = 2.266). Critically, correlational analysis showed no significant relationship between teachers' GSC awareness and actual laboratory implementation (r = 0.072, p = 0.844), proving cognitive knowledge alone is insufficient to drive sustainable practice. Actual lab practices did not vary significantly by gender (p = 0.175) or level taught (p = 0.825). Qualitative thematic analysis of semi-structured interviews clarified this decoupling, exposing a division-wide "institutional ceiling" shaped by technical, financial, pedagogical, and cultural barriers (e.g., lack of fume hoods, congested curricula, and student expectations of "visual theater"). To bridge this translational gap, the study proposes the "Lab Beyond the Classroom" professional development program and a localized, division-wide implementation plan

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INTRODUCTION

Modern society faces a triple planetary crisis namely climate change, biodiversity loss, and severe environmental chemical pollution which directly threatens human health and ecological stability (United Nations Environment Programme [UNEP], 2023). To address these complex challenges, the chemical industry requires a fundamental paradigm shift from traditional hazardous methods to sustainable design. Paul Anastas and John Warner first articulated Green Chemistry in 1998 as the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. This science-based strategy relies on twelve principles that promote waste prevention, maximize atom economy, utilize renewable feedstocks, employ catalytic systems, design for energy efficiency, and prevent laboratory and industrial accidents.

At the secondary and vocational education levels, chemistry serves as a foundational science that directly shapes the environmental literacy and professional values of future citizens and industry professionals (Auliah et al., 2018; Kusi, 2026). Integrating Green Chemistry Principles (GCP) early in the science curriculum equips students with the necessary content knowledge to practice environmentally friendly science, transforming traditional chemistry instruction into a proactive environmental safeguard (UNEP, 2023). The United Nations Decade of Sciences for Sustainable Development (2024–2033) explicitly advocates incorporating sustainability education into formal school systems, highlighting chemistry education as a critical channel for achieving Sustainable Development Goal (SDG) 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).

However, chemistry education research consistently documents a significant translational failure between teachers' and students' theoretical endorsement of sustainability and their actual classroom and laboratory habits (Auliah et al., 2018; Kusi, 2026). During practical school science laboratory sessions, students often exhibit behaviors that directly contradict sustainable principles such as using disproportionately large glassware and containers, generating excessive toxic waste, and leaving heating apparatuses and water baths on indefinitely after use (Auliah et al., 2018). This gap is heavily driven by a lack of pedagogical content knowledge (PCK) among science educators, congested curriculum structures, and a complete absence of localized instructional scaffolds and administrative guidelines.

In the Philippines, the Schools Division Office (SDO) of San Juan City in Metro Manila represents a compact, highly urbanized division comprising various public and private secondary schools. Currently, empirical research diagnosing the Green Chemistry competencies of secondary science teachers within SDO San Juan City is lacking. To establish a rigorous baseline, this study evaluates local educators' level of green chemistry awareness, perceived curricular integration needs, classroom and laboratory implementation practices, and alignment with systems thinking and environmental policies. By addressing this empirical gap, the study provides SDO administrators with a diagnostic framework to design professional development interventions that align classroom activities with global sustainability standards.

THEORETICAL REVIEW

The integration of Green and Sustainable Chemistry (GSC) into secondary education is underpinned by four key educational theories and frameworks that collectively enhance teaching, diagnose learning gaps, and address systemic barriers.

Technological Pedagogical and Content Knowledge (TPACK), Emphasizes teachers' professional readiness to deliver technology-enhanced instruction. Delgra and Domingo (2025) found a strong correlation (r = 0.698) between teachers' technological awareness and classroom readiness, highlighting the need for specialized pedagogical content knowledge to bridge theoretical green concepts and practical lab applications. Capacity-building programs are essential for equipping educators with digital and hands-on competencies.

Conceptual Change Theory, paired with the Certainty of Response Index (CRI), improves diagnostic accuracy by distinguishing deep-seated misconceptions from lucky guesses. Delgra and Domingo (2026) demonstrated that CRI—evaluating confidence alongside answers—helps identify true misconceptions, enabling targeted remediation. This is critical in GSC, where students often memorize terminology like "Design for Degradation" but misunderstand underlying chemical principles.

Cognitive Self-Regulation Theory, Addresses student-centered skills in digital environments. Balbastro, Dela Peña, and Domingo (2025) found that frequent digital platform use enhances perceived usefulness, but success depends on students' self-regulation and critical discernment. In GSC, these competencies enable safe engagement with cheminformatics tools like QSARs for toxicity prediction without hazardous experiments.

Finally, the ***Four-Barrier Taxonomy—***categorized by Victorino and Tamayo (2025) into technical, pedagogical, financial, and cultural barriers explains systemic resistance to GSC integration. Even motivated teachers face constraints such as crowded curricula and limited professional development, highlighting the operational challenges of implementing sustainable practices in classrooms.

Conceptual Framework

The conceptual framework of this study, adapted from Victoriano and Domingo (2026), examines Green and Sustainable Chemistry (GSC) integration in San Juan City's Schools Division through a tri-lateral dynamic of teacher attitudes, adoption factors, and tool effectiveness. Independent variables encompass teachers' cognitive and affective drivers: GSC Awareness (spanning definitions, 12 Principles, UNEP's Ten Objectives, and LCA concepts), attitudes toward curricular integration, and TPACK competence (Delgra and Domingo, 2025). Mediating technological tools include computational chemistry databases and virtual laboratories, though their efficacy depends on student cognitive self-regulation and ethical discernment (Balbastro et al., 2025). Virtual labs provide waste-free pre-lab scaffolding but must complement hands-on physical skills. Systemic constraints operationalize Victorino and Tamayo's (2025) Four-Barrier Taxonomy: technical/financial (absent fume hoods, microscale glassware), pedagogical (congested curricula), and cultural (student expectations of dramatic chemistry). Bridging requires two interventions: a professional development program and the SDO San Juan City Green Chemistry Implementation Framework, which is a proposed administrative policy establishing shared laboratory hubs, safety rubric reforms, and GSC-aligned assessment metrics.

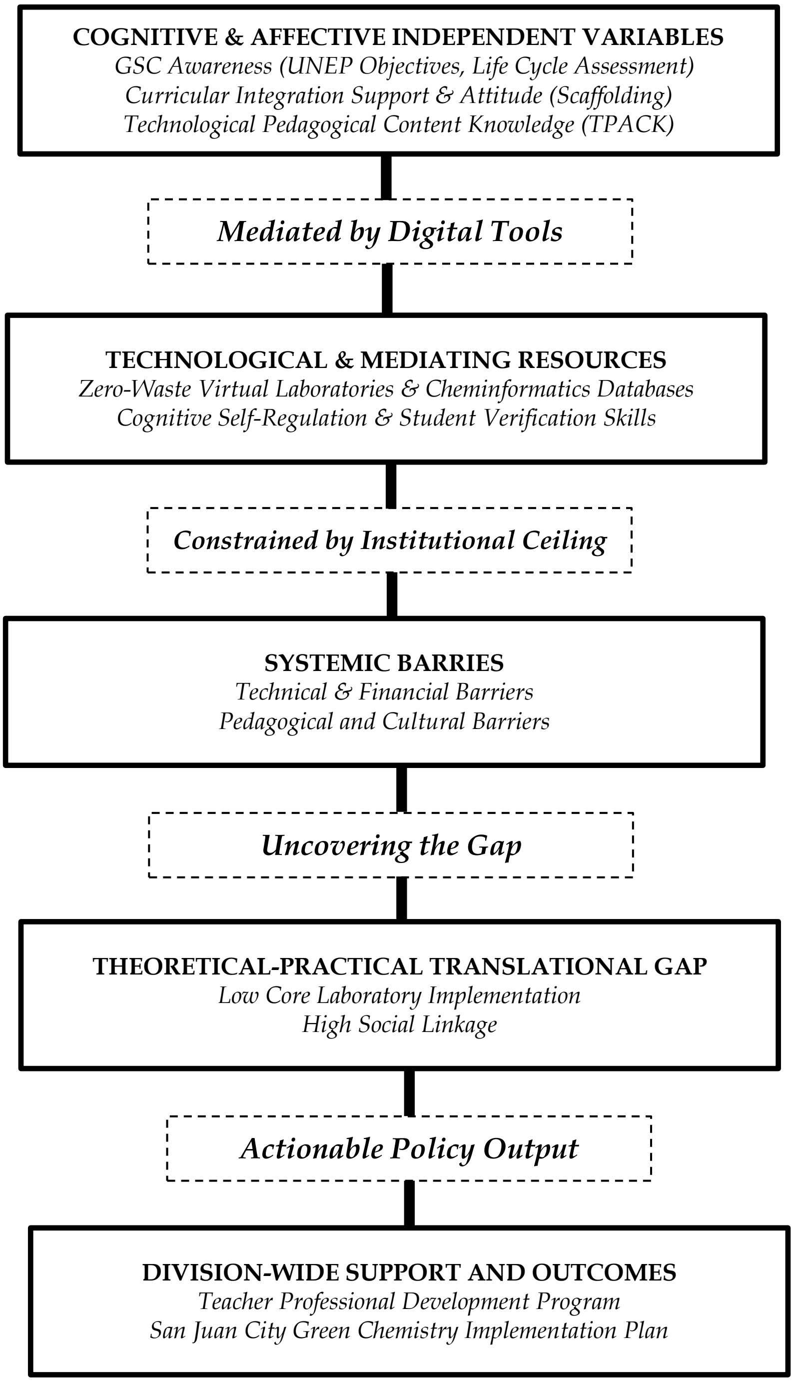

Figure 1. Conceptual Framework of the Study

METHODOLOGY

This study employed a sequential explanatory mixed-methods research design (Creswell and Creswell, 2023). Mixed methods are essential in chemistry education research to answer both "what" and "why/how". (Herrington and Daubenmire, 2014; Towns, 2008). The study was conducted in two distinct, sequential phases: a quantitative survey phase using a validated questionnaire to establish broad divisional trends, followed by a qualitative, semi-structured interview phase with a selected subset of teachers to explore and contextualize the quantitative results.

The target population comprised all secondary science teachers currently teaching within the Schools Division Office (SDO) of San Juan City, Philippines. Because SDO San Juan City is a compact division, the study used census sampling, yielding 30 science teachers who participated fully. This census approach ensures high division-level data representation and avoids sampling bias.

The study utilized two primary validated instruments: (1) Survey Instrument: A 40-item Likert-scale questionnaire. It has four parts (10 items each): Part 1: GSC Awareness (4-point awareness scale: 1 = Not at all aware, 2 = Slightly aware, 3 = Very aware, 4 = Extremely aware); Part 2: Curricular Integration and Perceptions (4-point confidence/readiness scale: 1 = Not confident, 2 = Low confidence, 3 = Confident, 4 = Highly confident); Part 3: Classroom and Laboratory Implementation (4-point frequency scale: 1 = Never, 2 = Seldom, 3 = Often, 4 = Always); and Part 4: Systems Thinking and Policy Alignment (4-point frequency scale: 1 = Never, 2 = Seldom, 3 = Often, 4 = Always). (2) Semi-Structured Interview Protocol: Comprising open-ended questions based on Patton's classification of qualitative questions, exploring background, experiential behaviors, values, motivations, and real-world failure prompts regarding laboratory constraints.

The instrument underwent a rigorous validation process, beginning with content review by subject-matter experts in science, mathematics, and reading education. Following expert feedback, it was pilot-tested on a sample of 30 secondary science teachers across four schools division offices: SDO Manila, Bulacan, Pangasinan II, and Quezon Province. The subsequent reliability assessment, measured via Cronbach's alpha, returned a value of 0.971, confirming that the instrument possesses excellent internal consistency and is highly dependable for the intended population.

Quantitative data were analyzed using Jamovi. Descriptive statistics (weighted means, standard deviations, and percentages) summarized teachers' scores. Inferential statistics, including One-Way Analysis of Variance (ANOVA) and t-tests, determined if significant differences existed when teachers were grouped by demographic profiles. Pearson's correlation evaluated the relationship between awareness and implementation practices. The researchers transcribed and analyzed qualitative audio recordings using thematic analysis guided by the four-barrier taxonomy (technical, pedagogical, financial, and cultural) from Victorino and Tamayo (2025).

RESEARCH RESULTS

The study involved 30 active secondary science teachers in SDO San Juan City. Table 1 details their demographic characteristics. The sample was heavily dominated by female educators (80%), and 67% taught at the Junior High School level. In terms of educational attainment, only 10% held a completed Master's degree and 3% a Doctorate, while 50% were taking Master's units. Years in service were distributed, with 30% teaching for fewer than 5 years and 34% teaching for 15 or more years.

Table 1. Demographic Profile of SDO San Juan City Secondary Science Teachers

Variable	Groups	Frequency (f)	Percentage (%)
Gender	Male	6	20%
	Female	24	80%
Civil Status	Single	13	43%
	Married	15	50%
	Widow/Widower	2	7%
Age	26-30	9	30%
	31-35	4	13%
	36-40	3	10%
	41-45	3	10%
	46-50	5	17%
	51-55	3	10%
	56-60	3	10%
Level Taught	Junior HS	20	67%
	Senior HS	10	33%
Educational Attainment	Bachelor's Degree	9	30%
	with Master's units	15	50%
	Master's Degree	3	10%
	with Doctoral units	2	7%
	Doctorate Degree	1	3%
Years in Service	Below 5 years	9	30%
	5-9 years	5	17%
	10-14 years	5	17%
	15-19 years	4	13%
	20-24 years	4	13%
	25-29 years	1	3%
	30-34 years	2	7%

Table 2 outlines the indicators and weighted means for each of the four survey parts. Under GSC Awareness, teachers reported high general awareness of basic definitions (M = 2.661) and the 12 principles (M = 2.740), but scored extremely low on technically demanding metrics such as UNEP's Ten Objectives (M = 2.163, Slightly Aware) and Life Cycle Assessment concepts (M = 2.458). Under Curricular Integration, teachers expressed strong support for early integration (M = 3.151) and sustainability orientation (M = 3.140), but reported very low confidence in their formal training (M = 2.266, Low Confidence). In Laboratory Implementation, teachers frequently practiced simpler safety practices like minimizing physical accidents (M = 3.132) and turning off water baths (M = 2.849), whereas they rarely implemented advanced green concepts like Atom Economy calculations (M = 2.138, Seldom) and catalytic substitution (M = 2.239). Lastly, in Systems Thinking, teachers reported connecting chemistry to food and energy (M = 2.985) but rarely utilized advanced quantitative tools like E-factors (M = 2.428) or cheminformatics molecular databases (M = 2.302, Seldom).

Table 2. Selected Weighted Means and Verbal Descriptions of Survey Parameters

Part and Selected Indicator	**Mean**	**Verbal Interpretation**
Part 1: GSC Awareness		
1. The fundamental definitions and goals of Green Chemistry	2.661	Very Aware
2. The traditional 12 Principles of Green Chemistry	2.740	Very Aware
3. UNEP's Ten Objectives and Guiding Considerations	2.163	Slightly Aware
6. Life Cycle Assessment (LCA) concepts	2.458	Slightly Aware
Part 2: Curricular Integration		
5. Sufficient pedagogical content knowledge from current training	2.266	Low Confidence
6. Need for regular professional development in green chemistry	2.930	Confident
9. Integrating concepts early with progressive scaffolding	3.151	Confident
Part 3: Laboratory Implementation		
4. Emphasizing "Atom Economy" in stoichiometric calculations	2.138	Seldom
6. Choosing experiments to minimize chemical accidents and fires	3.132	Often
8. Advocating for catalytic reagents over stoichiometric reagents	2.239	Seldom

Part 4: Systems Thinking and Policy Alignment		
1. Encouraging students to evaluate reactions using "Life Cycle Thinking"	3.074	Always
5. Comparing environmental efficiency of reactions using E-factor	2.428	Seldom
7. Utilizing cheminformatics or online molecular databases	2.302	Seldom

To test Ho_1, One-Way Analysis of Variance (ANOVA) was executed. Table 3 presents the ANOVA results when grouping teachers by Civil Status, Age, Educational Attainment, School, and Years in Service. The null hypothesis was rejected at the 0.05 level of significance across almost all demographics. Civil Status ($p < 0.001$), Age ($p < 0.001$), School ($p < 0.001$), and Years in Service ($p < 0.001$) showed highly significant differences across all four parameters. Educational Attainment showed highly significant differences for GSC Awareness ($p < 0.001$), Lab Implementation ($p = 0.011$), and Systems Thinking ($p = 0.007$), but was not significant for Curricular Integration perceptions ($p = 0.960$).

Table 3. One-Way ANOVA Summary Table for Demographic Groups

Demographic Factor	Parameter	df	F-value / Mean Sq	p-value	Interpretation
Civil Status	GSC Awareness	2, 27	9.355	<0.001	Significant
	Curricular Integration		10.321	<0.001	Significant
	Lab Implementation		0.104	<0.001	Significant
	Systems Thinking		0.119	<0.001	Significant
Age	GSC Awareness	6, 63	0.108	<0.001	Significant
	Curricular Integration		0.181	<0.001	Significant
	Lab Implementation		0.177	<0.001	Significant
	Systems Thinking		0.158	<0.001	Significant
Educational Attainment	GSC Awareness	4, 45	0.095	<0.001	Significant
	Curricular Integration		0.229	0.960	Not Significant
	Lab Implementation		0.193	0.011	Significant
	Systems Thinking		0.192	0.007	Significant
School	GSC Awareness	6, 63	0.074	<0.001	Significant
	Curricular Integration		0.140	<0.001	Significant

	Lab Implementation		0.181	<0.001	Significant
	Systems Thinking		0.143	<0.001	Significant
Years in Service	GSC Awareness	6, 63	0.126	<0.001	Significant
	Curricular Integration		0.157	<0.001	Significant
	Lab Implementation		0.215	<0.001	Significant
	Systems Thinking		0.151	<0.001	Significant

To explore variations by Gender and Level Taught, independent t-tests were conducted (Table 4). Gender was a highly significant differentiator for GSC Awareness (Female Mean = 2.660 vs Male Mean = 2.120, $p < 0.001$), Curricular Integration (Female Mean = 2.960 vs Male Mean = 2.400, $p < 0.001$), and Systems Thinking (Female Mean = 2.850 vs Male Mean = 2.350, $p < 0.001$). However, actual Classroom and Lab Implementation did not differ significantly by gender (Female Mean = 2.630 vs Male Mean = 2.430, $p = 0.175$). Level Taught (Junior HS vs Senior HS) yielded no statistically significant differences across any parameter, with p-values ranging from 0.078 to 0.825.

Table 4. t-Test Comparisons of Mean Scores by Gender and Level Taught

Grouping Factor	**Parameter**	**Mean 1**	**Mean 2**	**df**	**p-value**	**Interpretation**
Gender (Male vs Female)	GSC Awareness	2.120	2.660	18	<0.001	Significant
	Curricular Integration	2.400	2.960		<0.001	Significant
	Lab Implementation	2.430	2.630		0.175	Not Significant
	Systems Thinking	2.350	2.850		<0.001	Significant
Level Taught (JHS vs SHS)	GSC Awareness	2.570	2.550	18	0.825	Not Significant
	Curricular Integration	2.900	2.730		0.241	Not Significant
	Lab Implementation	2.670	2.430		0.121	Not Significant
	Systems Thinking	2.830	2.600		0.078	Not Significant

To test Ho_2, Pearson's r correlation coefficient was calculated between the four core parameters of the study: GSC Awareness, Curricular Integration, Classroom and Laboratory Implementation, and Systems Thinking and Policy Alignment. As shown in Table 5, the correlation analysis revealed no statistically significant relationships among the variables. Specifically, the relationship between teachers' GSC Awareness and actual Classroom and Laboratory Implementation was extremely weak and non-significant (r = 0.072, df = 8, p = 0.844; df = 8, p = 0.919). Similarly, there was no significant correlation between GSC Awareness and Curricular Integration (r = -0.116, df = 8, p = 0.750) or Systems Thinking (r = 0.023, df = 8, p = 0.950). Curricular Integration perceptions did not significantly correlate with Lab Implementation (r = 0.041, df = 8, p = 0.910) or Systems Thinking (r = -0.325, df = 8, p = 0.359). Finally, Classroom and Laboratory Implementation was not significantly related to Systems Thinking (r = -0.076, df = 8, p = 0.836). Because no significant relationship was found between teachers' Green Chemistry awareness and their actual laboratory practices, the study fails to reject the null hypothesis (Ho2).

Table 5. Inter-Correlation Matrix of Green and Sustainable Chemistry Parameters

Parameter	**Measure**	**GSC Awareness**	**Curricular Integration**	**Lab Implementation**
Curricular Integration	Pearson's r	-0.116 *(p = .750)*	— —	— —
Lab Implementation	Pearson's r	0.072 *(p = .844)*	0.041 *(p = .910)*	— —
Systems Thinking	Pearson's r	0.023 *(p = .950)*	-0.325 *(p = .359)*	-0.076 *(p = .836)*

This part presents the qualitative thematic analysis of secondary science teachers' perceptions, behaviors, and institutional barriers regarding Green and Sustainable Chemistry (GSC) within the Schools Division Office (SDO) of San Juan City, Philippines. Rooted in the qualitative methodology of John W. Creswell (Creswell & Creswell, 2023), this study deeply explores the 'why' and 'how' behind SDO San Juan City's quantitative trends, focusing on Participants 1 through 11 representing diverse backgrounds across junior, senior, and technical-vocational science programs.

The qualitative themes reveal a significant "sustainable vocabulary" vs. technical implementation gap, where educators' high abstract awareness of green terminology is systematically bounded by low confidence in their formal preparation and physical laboratory constraints. Systemic barriers, structured around the four-barrier taxonomy (technical, pedagogical, financial, and cultural) of Victorino and Tamayo (2025), establish a division-wide "institutional ceiling" that limits green laboratory practices, regardless of teacher demographics, gender, or grade level. These findings provide SDO San Juan City administrators with an empirical basis to implement target-driven professional d The following section presents a detailed, rich narrative analysis of the six themes generated from the thematic analysis of SDO San Juan City science teachers' interview responses, systematically integrated with the division's quantitative survey data.

Theme 1: The "Sustainable Vocabulary" vs. Technical Implementation Gap

The qualitative data reveals a profound cognitive-behavioral gap among science educators, characterized by a superficial command of environmental terminology that lacks deep technical integration. While SDO San Juan City teachers are highly familiar with general "sustainability" buzzwords and the broad definitions of Green Chemistry, they experience severe conceptual deficits when asked to apply technically demanding green metrics in lecture or laboratory settings. This directly matches the quantitative GSC Awareness (parameters, where teachers reported being "Very Aware" of basic definitions (M = 2.661) and general principles (M = 2.740), but scored as only "Slightly Aware" of complex, chemically defined constructs such as UNEP's Ten Objectives (M = 2.163) and Life Cycle Assessment (LCA) concepts (M = 2.458).

"*These principles can be more difficult to teach because they require a deeper understanding of chemical reactions, calculations, and reaction design. Concepts like atom economy and reducing derivatives may also be less familiar to teachers and students and can be harder to demonstrate using simple laboratory activities. In contrast, preventing waste is more practical and easier to observe and apply directly.*" *(Participant 1)*

"*Honestly, I have limited knowledge about Life Cycle Thinking or Life Cycle Assessment (LCA). I would first learn more about the concept and then explain it to my students using simple, real-life examples, such as examining the environmental impact of a product from the production of its materials to its use and disposal.*" *(Participant 6)*

"*I would say that my confidence is still developing when it comes to more advanced aspects of Green Chemistry and green chemical design. Since my teaching experience in Chemistry has mainly focused on Consumer Chemistry at the Junior High School level, I recognize that I still need to deepen my knowledge and gain more exposure to the 12 Principles of Green Chemistry.*" *(Participant 9)*

Analysis shows that teachers' cognitive schema remains anchored to basic environmental protection rather than sustainable chemical engineering. This "sustainable vocabulary" creates a false sense of preparedness. It aligns with the findings of Army Auliah et al. (2018), where teachers claimed overall familiarity with green chemistry but lacked the conceptual understanding to translate jargon into structured classroom instruction.

Theme 2: The Classroom Conundrum: Congested Curricula and Rigid High-Stakes Assessments

Curricular integration is heavily constrained by the structural limits of the national education system. Science teachers face severe pedagogical and cultural barriers, characterized by congested curriculum outlines, highly restricted contact hours, and administrative pressure to prepare students for rigid, division-wide standardized exams. Although teachers express near-unanimous quantitative agreement on the need to integrate green chemistry early with progressive scaffolding (Part 2: M = 3.151), they report that the current academic structure actively penalizes instructional deviation.

"*From a senior high school science teacher perspective, advanced principles like atom economy and avoiding derivatives face resistance because they demand complex multi-step organic math and theoretical concepts that go beyond our standard introductory syllabus. In contrast, simpler principles like preventing waste seamlessly fit our curriculum and budget through straightforward, practical habits that every student can quickly grasp.*" *(Participant 2)*

"*Limited time since we only have 45 minutes for consumer chemistry, the need to supervise students closely during experiments can also make it challenging to implement more elaborate green laboratory activities.*" *(Participant 9)*

This theme illustrates the tension between teachers' positive affective beliefs and the systemic, traditional demands of high-stakes testing. This curricular congestion results in what Victorino and Tamayo (2025) categorized as pedagogical and cultural barriers, where teachers default to conventional, high-hazard lectures to guarantee student success on traditional evaluations, effectively sidelining modern sustainable education.

Theme 3: The "Institutional Ceiling" and Laboratory Infrastructure Scarcity

The lack of statistically significant differences in teachers' actual laboratory implementation across Gender ($p = 0.175$) and Level Taught ($p = 0.825$) is qualitatively explained by a common, physical "institutional ceiling." Science teachers in SDO San Juan City are bound by the same under-resourced physical facilities, severe budget limitations, lack of microscale glassware, and complete absence of non-toxic green reagents. This infrastructure deficit makes advanced green chemistry implementation structurally impossible, forcing teachers to run traditional, hazardous experiments regardless of grade level or personal teaching philosophy.

"*An ideal green laboratory experiment would use small amounts of safer chemicals, produce minimal waste, and use simple, reusable materials. However, some constraints may include limited laboratory equipment and supplies, budget limitations, availability of safer chemical alternatives, and lack of proper waste-disposal facilities. Time constraints and large class sizes can also make it difficult...*" *(Participant 1)*

"*If I were to design an ideal green chemistry experiment, severe public school budget limitations would prevent me from acquiring dedicated microscale glassware, eco-friendly kits, and safer chemical substitutes. Additionally, large class sizes and overcrowded lab spaces make it physically difficult to supervise complex sustainable setups safely and effectively.*" *(Participant 2)*

"*We don't have a laboratory room or any science laboratories, I create their own laboratory which were the field that we always used and the classrooms. I think of an idea how may I implement the science laboratory even though we don't have much materials and place for laboratory.*" *(Participant 4)*

The qualitative analysis reveals that physical infrastructure scarcity overrides personal teacher agency. While female teachers scored higher in general awareness and curricular support ($p < 0.001$), their lab implementation scores did not differ significantly from males ($p = 0.175$). SDO San Juan City schools face a common technical and financial barrier (Victorino & Tamayo, 2025), requiring institutional capital investment before any curricular reforms can be physically implemented.

Theme 4: Pedagogical Resistance and the "Visual Engagement" Trade-off

A major, unexpected pedagogical barrier to green lab integration is the cognitive association between traditional, high-hazard chemistry and "exciting" science. Traditional laboratory experiments are historically designed around highly visible, dramatic, and instantaneous qualitative results—such as intense color changes, rapid gas evolution, or large precipitate yields. Science teachers report that green chemistry alternatives (such as using microscale setups or substituting toxic reagents with milder, organic plant extracts) are often slow, subtle, and visually underwhelming, leading to initial student confusion, boredom, and a perceived pedagogical failure.

"*I would prioritize safety and sustainability while helping students understand that clear results are not the only measure of a successful experiment. If a greener alternative produces less results, I would guide students to focus on careful observation, data collection, and analysis.*" *(Participant 1)*

"*When a greener alternative gives less dramatic visual results, I use it as a teachable moment to show students that sustainable science prioritizes safety and environmental impact over flashy reactions. I supplement the experiment with digital simulations or video demonstrations of the traditional reaction so students still grasp the core chemical concepts without the unnecessary hazard.*" *(Participant 2)*

"*The key is to reframe the learning experience so that clarity comes from conceptual understanding and careful observation, rather than dramatic visual changes... Clarify the learning objective, emphasize the scientific principle, not the spectacle.*" *(Participant 5)*

This finding highlights a unique cultural barrier: the expectation of visual theater in science education. Teachers frequently practice simpler, standard safety habits like turning off water baths (Part 3: M = 2.849) or preventing accidents (M = 3.132), but actively resist technically advanced green modifications (such as reducing chemical derivatives: M = 2.503) because they do not yield the obvious qualitative signposts that students associate with a successful laboratory experience.

Theme 5: Technological Mediation: The Potential and Pitfalls of Virtual Laboratories

Consistent with the literature, virtual laboratories (VLs) and digital platforms represent a powerful, zero-waste, and safe alternative to overcome physical resource constraints in local high schools. However, science teachers report that while virtual labs successfully eliminate chemical waste and safety hazards, their integration is hindered by the loss of tactile, hands-on motor skills, unstable school internet connections, and the critical need for advanced student digital self-regulation and verification strategies.

"*The main constraints would be limited laboratory resources, budget, and access to proper equipment and materials. However, I would maximize what is available by using recyclable or discarded materials and transforming them into useful, sustainable materials for experiments. This allows students to see that even what we consider garbage can be given new purpose through Chemistry and creativity.*" *(Participant 3)*

"*In my experience, I would prioritize the safety and learning objectives of the students rather than simply choosing an experiment based on how dramatic the results are... If a greener alternative produces less visible or immediate results... I could use videos, demonstrations, or other visual materials to supplement the activity if necessary.*" *(Participant 9)*

This qualitative finding provides depth to the quantitative survey analysis, showing that while teachers are "Slightly Aware" of Life Cycle Assessments (Part 4: M = 2.458), they are hesitant to integrate computational cheminformatics databases (Part 4: M = 2.302, Seldom). It confirms the theoretical models of Delgra and Domingo (2025) and Balbastro [Balasoto] et al. (2025), emphasizing that technology-mediated science labs are only effective when paired with stable infrastructure and active cognitive self-regulation.

Theme 6: Socio-Environmental Motivation vs. Professional Development Deficit

The final theme highlights a sharp contrast between SDO San Juan City science teachers' high affective motivation to resolve local environmental crises and their severe lack of pedagogical content knowledge (PCK). Teachers report a deep-seated desire to connect chemistry lectures to immediate, local issues—such as the heavy metal pollution of the San Juan River, municipal solid waste management, and household carbon footprints (Part 4: M = 2.985). However, this environmental drive is systematically blocked by a complete absence of structured, sustained teacher training in green chemistry (Part 2: M = 2.266, Low Confidence).

"*As a former coordinator of Enviro Teens, local environmental issues give me a strong sense of concern and motivation to promote environmental responsibility among students. Seeing problems such as pollution and improper waste disposal reminds me that students need to understand how their actions affect the environment. This motivates me...*" *(Participant 1)*

"*Hearing about local environmental crises, especially severe flooding and urban pollution in San Juan City and across the Philippines, triggers a deep sense of urgency and responsibility in me as an educator. This reality strongly motivates me to teach Green Chemistry, as it transforms abstract environmental issues into actionable, scientific solutions for my students.*" *(Participant 2)*

This theme illustrates that SDO San Juan City science educators possess extremely high environmental and social consciousness but are pedagogically and content-wise deficient due to institutional omissions. It strongly supports the need for a division-wide, hands-on, context-specific professional development program (such as the proposed "Lab Beyond the Classroom" framework) to bridge the gap between affective motivation and cognitive pedagogical competence development programs and localized science curricula.

To achieve empirical convergence, we construct a joint display matrix below. This visual display systematically maps the six qualitative themes against the corresponding quantitative survey parameters (weighted means and verbal descriptions), underlying qualitative codes, and Victorino and Tamayo's (2025) systemic four-barrier taxonomy.

Table 6. Joint Display Matrix: Quantitative & Qualitative Integration

Qualitative Theme	Mapped Quantitative Parameter & Mean (M)	Underlying Inductive Codes	Representative Verbatim Quote Summary (Participants 1-11)	Mapped Systemic Barrier
Theme 1: Sustainable Vocabulary Gap	Part 1: GSC Awareness - definitions: M = 2.661 (Very Aware) - UNEP objectives: M = 2.163 (Slightly Aware)	Conceptual deficit, textbook jargon, surface-level awareness, theoretical vs. physical chemistry.	"These principles can be more difficult to teach because they require deeper understanding... Concepts like atom economy are less familiar to teachers..." (Participant 1)	Pedagogical Barrier
Theme 2: Curricular & Exam Congestion	Part 2: Curricular Integration - early scaffolding: M = 3.151 (Confident) - PCK training: M = 2.266 (Low Confidence)	Curricular pressure, contact hours, college entrance exams, quarterly tests, standardized rote learning.	"Advanced principles like atom economy and avoiding derivatives face resistance because they demand complex multi-step organic math that go beyond standard introductory syllabus..." (Participant 2)	Pedagogical & Cultural Barriers
Theme 3: Laboratory Resource Scarcity	Part 3: Laboratory Implementation - Atom Economy: M = 2.138 (Seldom) - accident minimization: M = 3.132 (Often) - no gender differences (p = 0.175)	Fume hood absence, physical resources, budget deficit, empty lab rooms, division standard package.	"If I were to design an ideal green chemistry experiment, severe public school budget limitations would prevent me... large class sizes..." (Participant 2)	Technical & Financial Barriers
Theme 4: Visual Appeal Trade-off	Part 3: Laboratory Implementation - catalytic substitute: M = 2.239 (Seldom) - standard safety habits: M = 2.849 (Often)	Visual expectations, qualitative color change, student boredom, microscale limits, active pedagogical resistance.	"Clarify the learning objective, emphasize the scientific principle, not the spectacle... encourage students to look for small but significant indicators..." (Participant 5)	Pedagogical & Cultural Barriers
Theme 5: Technology Mediation Hurdles	Part 4: Systems Thinking - database tools: M = 2.302 (Seldom) - E-factor metric: M = 2.428 (Seldom)	Virtual lab acceptance, zero-waste benefits, digital self-regulation, tactile loss, connection stability.	"I would prioritize safety and learning objectives... If a greener alternative produces less visible results... use videos, demonstrations..." (Participant 9)	Technical & Pedagogical Barriers

Theme 6: Motivations vs. Training Gaps	Part 4: Systems Thinking - environmental linkage: M = 2.985 (Always) - Part 2 Sufficient PCK: M = 2.266 (Low Confidence)	Environmental drive, San Juan River trash, training deficit, hands-on workshops, localized PBL demand.	"Hearing about local environmental crises, especially severe flooding and urban pollution in San Juan City... triggers a deep sense of urgency... strongly motivates me..." (Participant 2)	Pedagogical & Technical Barriers

As a result of this study, this Green Chemistry Implementation Plan (GCIP) is designed to break the division-wide physical 'institutional ceiling' by institutionalizing microscale chemistry kits, shared central laboratory hubs, and assessment reforms. This framework aligns directly with the MATATAG Science Curriculum Framework's three interrelated content strands: (1) Performing scientific inquiry skills, (2) Understanding and applying scientific knowledge, and (3) Developing and demonstrating scientific attitudes and values. In doing so, it ensures that environmental protection, resource efficiency, and sustainable chemical practices are not taught in isolation but are woven directly into K-10 Content Domains (Materials, Science of Materials, and Life Science).

Table 7. Green Chemistry Implementation Plan (GCIP)

Activities	**Specific Objectives**	**Science K-10 Curriculum Alignment (MATATAG Framework)**	**Timeline**	**Resources Required**	**Budget Allocation**	**Success Indicator**
Microscale Laboratory Standardization	To replace standard macro-scale chemistry procedures with safe, low-volume, drop-wise setups, reducing hazardous laboratory sink waste and school supply expenditures.	• Strand Alignment: Performing scientific inquiry skills; Developing scientific attitudes & values. • Grade Levels: Grades 3-6 (Materials Domain), Grades 7-10 (Science of Materials Domain). • Competency Mapping:	Year 1 Q1 - Q2	Laminated drop-wise reaction grid sheets, micro-well plates, plastic pipettes, household-grade green substitutes (vinegar, baking soda, plant extracts).	PHP 150,000 (SDO MOOE / Science Equipment Fund)	100% of public secondary high school's transition general chemistry labs to microscale; total SDO-wide hazardous sink waste volume drops by 90%.

		Grade 3 Q1 LC 6 & 7 (changes in materials can be harmful... demonstrate proper handling and disposal); Grade 4 Q1 LC 5 (minimize harmful changes, restrict burning of waste).				
Establishment of SDO Shared Green Science Lab Hubs	To designate SDO central high school laboratories as division-wide resource centers, providing smaller integrated schools with equitable access to advanced safety gear and green reagents.	• Strand Alignment: Performing scientific inquiry skills. • Framework Concept: Science-Technology-Society (STS) Approach & STEM engineering design processes (EDP). • Competency Mapping: Key Stage 3 Standard (Grade 10) - applying science inquiry skills in addressing real-world environmental problems; Grade 7 Q1	Year 1 Q2 - Q3	SDO central laboratory inventory list, central school schedules, university partnership templates, safety kits (protective eyewear, spill absorbents).	PHP 250,000 (Division Science Capital Outlay)	San Juan NHS and San Juan City Science HS designated as active hubs; at least 5 peripheral integrated schools schedule and utilize central labs per quarter.

		LC 12 (proper use and handling of science equipment).				
Curricular Scaffolding & Mapping Workshops	To integrate green chemistry metrics (Atom Economy, E-factors, bioremediation, Reducing Derivatives) directly into the standard high school chemistry syllabus.	• Strand Alignment: Understanding and applying scientific knowledge. • Crosscutting Concepts: Systems and system models; Flows, cycles, and conservation of matter and energy. • Competency Mapping: Grade 8 Q1 LC 8 (explain roles of plants/animals in biogeochemical cycles); Grade 9 Q4 LC 2 (chemical bonding and reaction mass changes); Grade 10 Q3 LC 6 & 7 (atoms rearrange, apply conservation of mass to balance equations).	Year 1 Q3 - Q4	Supplementary green worksheets, localized lesson plans, DepEd MATATAG K-10 curriculum guides.	PHP 50,000 (CID Science Department Funds)	Approved GSC-integrated curriculum guides published in the SDO Portal; teachers weave green calculations into regular lesson plans.

Overcoming Pedagogical Resistance & Re-engineering Rubrics	To reframe laboratory worksheets and grading criteria to reward students on process safety, atom economy, and green chemical design rather than high-hazard 'visual theater'.	• Strand Alignment: Developing scientific attitudes and values. • Pedagogical Approach: Problem-based learning (PBL) and Applications-led learning. • Competency Mapping: Grade 4 Q1 LC 7 (apply science process skills and attitudes in conducting a guided survey about environmental issues, open-mindedness); Grade 10 Q3 LC 8 (factors affecting rate of reactions, food preservation, pollution control).	Year 1 Q4	Revised grading rubrics, modified laboratory sheets, free open-access virtual laboratory suites (e.g., PhET simulations) for visual pre-lab bridging.	PHP 80,000 (ICT / Instructional Materials Fund)	Modified assessment rubrics distributed SDO-wide; student feedback (Theme 4) confirms high engagement in safe, analytical, and non-hazardous experiments.
Division-wide Standardized Exam Reform	To integrate Green Chemistry calculations and systems thinking directly into official secondary science	• Strand Alignment: Balanced integration of content knowledge and 21st-century skills.	Year 2 Q1	TOS (Table of Specifications) templates, test bank development workshops, SDO Testing	PHP 60,000 (SDO Testing Board Funds)	At least 15% of chemistry test items in SDO Secondary Science Quarterly Exams explicitly

	quarterly tests.	• Framework Concept: Cognitive Process Dimensions (DepEd Order 31, s. 2020). • Competency Mapping: Key Stage 3 Standard - making rational choices on socio-scientific issues; Grade 10 Q1 LC 11 (identify local impacts of global climate change, suggest conservation solutions).	Committee guidelines.	evaluate GSC principles, atom economy, or local environmental systems thinking.

Further, to address the local training deficit and build teachers' Pedagogical Content Knowledge (PCK) (weighted mean: M = 2.266, interpreted as Low Confidence), this 4-week hybrid capacity-building blueprint aligns directly with the Philippine Professional Standards for Teachers (PPST). This alignment ensures that participating science teachers do not merely receive theoretical content but are actively supported in developing, implementing, and assessing developmentally sequenced learning resources that stimulate critical, creative, and higher-order thinking skills, utilizing positive ICT, and engaging the local community.

Table 8. 'Lab Beyond the Classroom' Professional Development Program Aligned with the PPST

Activities / Modules	Specific Objectives	PPST Alignment (Domains & Strands Mapping)	Schedule	Persons Involved	Persons In-charge	Budget Allocation	Success Indicator
Module 1: GSC Foundations & CRI-Based Misconception Diagnostics	To raise SDO teachers' content knowledge on UNEP's Ten Objectives and Life Cycle Assessment (LCA) concepts, and utilize a Certainty of Response Index (CRI) diagnostic test to isolate and remediate personal conceptual GSC misconceptions.	• PPST Strand 1.1: Content knowledge and its application within and across curriculum teaching areas. • PPST Strand 1.2: Research-based knowledge and principles of teaching and learning. • PPST Strand 5.1: Design, selection, organization, and utilization of diagnostic, formative, and summative assessment strategies.	Week 1 (8 Hours: 4h Face-to-Face, 4h Asynchronous)	All Secondary Science Teachers (Junior High School, Senior High School) (N ≈ 30+).	Education Program Supervisor (EPS) - Science; University Chemistry Professor (Resource Speaker).	PHP 30,000 (Division HRD / INSET Fund Allocation)	100% teacher attendance; pre-to-post diagnostic test scores show statistically significant conceptual gains ($p < 0.001$); average teacher CRI score drops below 2.0 on alternative conceptions.
Module 2: Microscale and Solvent-Free Chemistry	To train science teachers to design and set up low-volume (0.1 mL), drop-wise reaction cards and solvent-free qualitative test	• PPST Strand 1.5: Strategies for developing critical and creative thinking, as well as other higher-order thinking skills. • PPST Strand 4.1: Planning and management of the teaching	Week 2 (8 Hours: 4h On-site Lab, 4h Asynchronous)	Secondary Science Teachers; School Laboratory Technicians / Assistants.	Science Master Teachers (JHS & SHS); Divisional Science Focal Person.	PHP 45,000 (In-Service Material Procurement Fund)	Each teacher will successfully construct and validate 3 localized microscale laboratory worksheets and accompanying non-toxic, eco-friendly

	matrices, bypassing physical laboratory resource constraints.	and learning process. • PPST Strand 4.5: Selection, development, organization, and use of appropriate teaching and learning resources.					reagent protocols.
Module 3: Cheminformatics, AI Integration, and Virtual Labs	To train teachers to utilize computational chemical databases (ChemSpider, PubChem) to predict molecular toxicity in silico, and establish classroom protocols for student digital self-regulation.	• PPST Strand 1.3: Positive use of ICT to facilitate the teaching and learning process. • PPST Strand 4.5: Teaching and learning resources, including ICT, to address specific learning goals. • PPST Strand 7.4: Professional reflection and learning to improve practice.	Week 3 (8 Hours: 4h ICT Lab, 4h Asynchronous)	Secondary Science Teachers; School ICT Coordinators.	Divisional Information Technology (IT) Specialist; Senior Science Master Teachers.	PHP 25,000 (SDO ICT Training Fund)	Teachers use molecular databases and publish a validated classroom protocol to ensure student self-regulation and cognitive verification during AI activities.
Module 4: Problem-Based Learning (PBL) Exemplar Design	To guide science teachers to map the 12 Principles of Green Chemistry onto localized urban environmental issues in San Juan City, creating validated, peer-reviewed	• PPST Strand 4.3: Relevance and responsiveness of learning programs to the needs of all learners. • PPST Strand 6.1: Establishment of learning environments that are responsive to community contexts. • PPST Strand 7.3: Active	Week 4 (8 Hours: 4h Peer Review, 4h SDO Colloquium)	Secondary Science Teachers; Barangay Environmental Officers / LGU Representatives.	CID Science Department Chief; Education Program Supervisor (EPS).	PHP 40,000 (CID Instructional Material Fund)	A collaborative SDO repository of 15 peer-reviewed, validated green chemistry lesson exemplars is finalized, uploaded, and made open-access for all division teachers.

	lesson plans.	participation in professional networks to share knowledge and enhance practice.

DISCUSSION

The empirical findings reveal a critical interplay between quantitative measurements and qualitative insights, exposing systemic challenges in integrating Green Chemistry in SDO San Juan City. Quantitatively, teachers demonstrate superficial "sustainable vocabulary" (terminology awareness M=2.661) but severely deficient technical mastery (E-factors M=2.428; UNEP objectives M=2.163; atom economy M=2.138). This gap is qualitatively corroborated through teacher interviews, where participants consistently expressed frustration about their inability to translate positive environmental attitudes into classroom practice due to a lack of Pedagogical Content Knowledge (PCK) training (M=2.266). The quantitative lack of implementation differences across gender (p=0.175) and level taught (p=0.825) aligns with qualitative accounts of uniform institutional ceilings physical resource constraints that bind all teachers regardless of background.

The Four-Barrier Taxonomy emerges from this mixed-method synthesis: quantitative resource deficits (absent fume hoods, microscale glassware) mirror teachers' narrated experiences of financial and technical constraints. Pedagogical barriers—quantified through low implementation scores are enriched by interview narratives revealing congested curricula and rigid schedules that preclude green modifications. Cultural barriers appear quantitatively through traditional laboratory practices that prioritize high-yield, hazardous reactions, while qualitative data show student expectations of dramatic chemistry spectacles that microscale experiments fail to satisfy.

Crucially, quantitative CRI-based diagnostics exposed teachers' alternative conceptions (e.g., equating "natural" with "safe"), which interviews confirmed as active pedagogical misconceptions requiring targeted remediation. The quantitative acceptance of virtual laboratories as conceptual scaffolds (Victoriano & Domingo, 2026) is qualitatively nuanced by teachers' insistence on blended models preserving tactile skills. Digital cheminformatics adoption quantitatively mediated by cognitive self-regulation metrics is qualitatively verified through teacher concerns about student distraction and uncritical AI use. This synthesis directly informs the proposed interventions: "Lab Beyond the Classroom" PD, localized PBL exemplars, and reformed assessment rubrics that quantitatively measure and qualitatively reward green chemistry competencies.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that secondary science teachers in SDO San Juan City hold positive Green Chemistry beliefs yet lack the technical competence and pedagogical content knowledge to translate awareness into practice. Quantitative findings confirm no significant correlation between GSC Awareness and actual Laboratory Implementation ($r = 0.072$, $p = 0.844$), showing that cognitive knowledge alone is insufficient to drive pro-environmental behaviors amid systemic physical bottlenecks.

Furthermore, qualitative analysis unpacks this decoupling, revealing identical technical, financial, pedagogical, and cultural barriers that create a division-wide implementation ceiling overriding individual teacher agency. Laboratory practices remain confined to intuitive safety habits while advanced green principles (atom economy, E-factors) remain untouched. Bridging this translational gap requires institutionalized interventions: sustained "Lab Beyond the Classroom" professional development, localized PBL modules addressing San Juan City's environmental crises, and reformed assessment rubrics rewarding green design. Only through systemic paradigm shifts moving from aspirational rhetoric to operationalized, technology-mediated frameworks can the division cultivate environmentally responsible educators and students.

The following recommendations are proposed:

1. Launch sustained "Lab Beyond the Classroom" training replacing one-day webinars with hands-on microscale green chemistry and virtual lab workshops for all science teachers.
2. Create localized green chemistry modules connecting the 12 Principles to San Juan City's environmental issues (river waste, energy footprint) for immediate classroom use.
3. Integrate PubChem and ChemSpider databases into lessons with built-in digital literacy and self-regulation activities to ensure critical data use.
4. Allocate funds for microscale glassware and green reagents, and revise lab rubrics to reward atom economy and waste reduction over percent yield alone.
5. Future studies may include larger samples, respondents and participants from different educational settings
6. Conduct longitudinal studies tracking PD effectiveness on actual implementation and validate CRI-based diagnostic tools for green chemistry misconceptions in different school divisions.

FURTHER STUDY

Future studies may expand the scope of this research by including larger, more diverse samples from multiple educational settings across the Philippines to enhance generalizability. Longitudinal investigations are strongly recommended to track the sustained effectiveness of the "Lab Beyond the Classroom" professional development program on actual classroom implementation and student learning outcomes over time.

Additionally, future researchers should develop and validate CRI-based diagnostic instruments specifically tailored to measure teachers' and students' alternative conceptions in green chemistry, extending beyond basic terminology to complex principles such as atom economy, E-factors, and toxicity prediction. Comparative studies across different school divisions would help determine whether the Four-Barrier Taxonomy holds consistently across varying socio-economic contexts.

Finally, experimental designs examining the mediating role of cognitive self-regulation and digital literacy in AI and cheminformatics tool adoption would significantly advance understanding of technology-enhanced green chemistry education.

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