



PRESERVICE TEACHERS' CONCEPTUAL UNDERSTANDING OF THE PRINCIPLES OF GREEN CHEMISTRY AND THEIR APPLICATIONS TO REAL-LIFE SITUATIONS

BY

ADEOYE, Ikeoluwa Folasade

Department of Integrated Science,
Faculty of Science Education,
Emmanuel Alayande University of Education, Oyo, Nigeria
ikeoluboye@yahoo.com & adeoyeif@eauedoyo.edu.ng | (+234) 803 823 5302

&

OKUNUGA, Rachael Olatoun

Department of Science Education,
University of Lagos, Lagos, Nigeria

Abstract

Green chemistry education plays a critical role in preparing future teachers to address sustainability challenges through informed chemical practices. This study investigated preservice chemistry teachers' conceptual knowledge and application of green chemistry and the influence of gender and their levels of study on knowledge and application of green chemistry. A descriptive survey design incorporating correlational and comparative analyses was employed, with a sample of 356 preservice chemistry teachers across 200, 300, and 400 level cohorts. The instrument adopted was validated both in conceptual knowledge and application of green chemistry. Data were analysed using descriptive statistics, Pearson's Product Moment correlation, independent samples t-test, one-way and two-way ANOVA, and regression analysis at the 0.05 significance level. Results revealed moderate levels of both knowledge and application, indicating partial integration of green chemistry concepts within teacher preparation. The finding also showed that there was a significant positive relationship between knowledge and application of green chemistry, confirming knowledge as a key predictor of sustainable practice. While gender showed no significant effect, level of study significantly influenced outcomes, with higher-level students demonstrating superior performance. It was therefore recommended that green chemistry should be introduced early and progressively across all levels of teacher education.

Keywords: Green chemistry, preservice teachers, sustainability education, conceptual understanding, application.

Introduction

Growing concerns about pollution, climate change, hazardous waste disposal, the depletion of natural resources, and unsustainable industrial and scientific practices have intensified the need for environmentally responsible scientific approaches. One major response to these concerns is green chemistry, which focuses on designing chemical products and processes that minimise or eliminate hazardous substances (Anastas & Warner, 1998). Green chemistry promotes waste prevention, safer solvents, renewable feedstocks, energy efficiency, pollution reduction and environmentally friendly chemical reactions.

In educational settings, green chemistry has become increasingly relevant because it

helps learners understand the connection between chemistry and sustainable development. For preservice teachers, the relevance is even greater, as they are future educators who will shape learners' environmental attitudes and scientific practices. Consequently, there is a need to understand how preservice teachers acquire conceptual knowledge of green chemistry and how such knowledge translates into practical applications.

The constructivist theories of Piaget and Vygotsky emphasise that learners actively construct knowledge through interaction with their environment rather than passively receiving information (Piaget, 1972; Vygotsky, 1978). Learning becomes

meaningful when new ideas are linked to prior experiences and real-life situations.

This theory is particularly relevant to green chemistry education because students often understand sustainability concepts better when connected to visible issues such as waste disposal, water pollution, and excessive energy use. Preservice teachers who relate green chemistry principles to everyday realities are more likely to develop lasting conceptual understanding.

Kolb's experimental learning theory explains learning as a cyclical process involving concrete experience, reflection, abstract conceptualisation and active experimentation (Kolb, 1984). According to this view, learners understand concepts more deeply when they engage in practical activities and reflect on those experiences. Green chemistry aligns strongly with experiential learning because many of its principles are action oriented. Students learn better when they participate in eco-friendly laboratory experiments, waste audits, recycling projects and problem-solving tasks involving real environmental challenges.

Sunday et al. (2026) found that structured green chemistry instruction significantly improved students' understanding of concepts such as waste prevention, safer chemicals and environmental responsibility. Sunday et al. also noted that students in supportive, sustainability-oriented learning environments were more willing to adopt environmentally friendly practices. United Nations Educational, Scientific and Cultural Organisation, UNESCO (2024), similarly observed that inclusive and supportive educational settings reduce barriers to participation and encourage equal engagement in STEM-related fields. Similarly, Idul and Walag (2024) reported that curriculum integration enhanced students' comprehension of sustainability-related chemistry concepts. These findings suggest that learners build stronger knowledge when green chemistry is taught in meaningful contexts. Idul et al. (2025) found that students exposed to process-oriented guided inquiry learning modules demonstrated greater ability to apply green chemistry principles to waste reduction and sustainable decision-making.

Gunbatar et al. (2025) reported that effective green chemistry teaching commonly involves inquiry, laboratory redesign and sustainability-centred activities. However, where such approaches are

absent, students often display only superficial awareness. They concluded in their systematic review that inquiry-based laboratories and hands-on learning approaches were more effective than lecture-only methods for promoting green chemistry competence. These findings imply that preservice teachers are more likely to apply green chemistry when learning experiences move beyond theory into practice.

Kusi (2026) showed a progressive increase in green chemistry knowledge with the academic level of senior high school students. However, there was no significant difference by students' gender. The study also reported a weaker understanding of advanced green chemistry concepts. Mulyanti and Kadarohman (2021) revealed students' agreement with the principles of green chemistry, but some believed that their application in real life is practically not possible.

Da Silva Junior et al. (2024) argued that students are more capable of applying chemistry concepts when learning is linked to authentic environmental and community problems. Likewise, Sunay et al (2026) found that green chemistry instruction improved students' readiness to conserve resources, reduce waste and adopt safer chemical practices. These studies suggest that knowledge and application are intrinsically connected. Conceptual understanding provides the foundation for practice, while practical engagement reinforces knowledge.

Gender differences in green chemistry learning appear less pronounced than in some traditional STEM domains. Gunbatar et al. (2025) found that collaborative and real-world learning approaches supported participation across student groups. UNESCO (2024) further emphasised that many gender disparities in science arise from stereotypes and unequal opportunity rather than innate ability. Okunuga and Adeoye (2025) found no significant gender difference in students' awareness, knowledge or perception of green chemistry among Nigerian secondary school students. Male and female students showed similar levels of engagement. This suggests that when green chemistry is taught inclusively, male and female preservice teachers may perform similarly in both knowledge and application.

In contrast, the level of study tends to show a stronger influence. Students at

higher academic levels often possess a broader chemistry background, stronger reasoning abilities, and greater laboratory exposure. Gunbatar et al. (2025) noted that advanced earners generally achieved stronger outcomes in sustainability-related chemistry education. This indicates that progressive exposure over time enhances both understanding and application of chemistry concepts.

Preservice teachers are expected to possess adequate knowledge of green chemistry and the ability to apply its principles in laboratory work, teaching practice and everyday environmental decisions. However, studies suggest that many learners hold positive attitudes toward sustainability but lack a practical understanding of green chemistry (Gunbatar et al., 2025). It is necessary to determine whether knowledge of green chemistry significantly influences its applications to real-life situations. A student may know the principles in theory but fail to apply them in practice. Therefore, this investigation examines preservice teachers' knowledge and application of green chemistry principles while considering gender and level of study.

Statement of the Problem

Despite increasing global emphasis on sustainability, many teacher education programs still give limited attention to green chemistry. As a result, preservice teachers may graduate without sufficient knowledge or practical application skills in environmentally friendly chemistry.

It appears as if preservice teachers with greater knowledge of green chemistry are more likely to apply green chemistry principles or identify them. In addition, few studies examined the conceptual knowledge and application of green chemistry together using multiple-choice items. It seems as if the study on the influence of gender and level of study on both conceptual knowledge and application among preservice teachers is limited and examined green chemistry in the Nigerian context. These were the gaps this study investigated.

Purpose of the Study

The purpose of this study is to examine preservice teachers' conceptual knowledge of the principles and applications of green chemistry, and to determine the influence of gender and level of study on these

variables and on possible misconceptions in green chemistry.

Specifically, the study seeks to:

1. Assess the levels of conceptual understanding and knowledge of applications of preservice teachers on the principles of green chemistry.
2. Find out if preservice teachers' conceptual understanding of the principles of green chemistry influences the applications of green chemistry to life situations.
3. Investigate the influence of preservice teachers' gender on the conceptual understanding of principles and applications to real-life situations of green chemistry.
4. Examine the influence of preservice teachers' level of study on the conceptual understanding of principles and applications to real-life situations of green chemistry.
5. Determine the interaction effect of gender and level of study on conceptual knowledge and application of green chemistry.

Research Question

1. What are the levels of conceptual understanding and knowledge of applications of preservice teachers on the principles of green chemistry?

Research Hypothesis

The following null hypotheses were postulated and tested at a 0.05 level of significance.

1. There is no significant relationship between preservice teachers' conceptual understanding of the principles of green chemistry and the applications of green chemistry to life situations.
2. Student gender does not significantly influence preservice teachers' conceptual understanding of principles and applications of green chemistry.
3. Levels of study do not significantly influence preservice teachers' conceptual understanding of principles and applications of green chemistry.
4. There is no significant interaction influence of gender and level of study on preservice teachers' conceptual understanding of principles and applications of green chemistry.

Methodology

A descriptive survey design with a correlational component to assess levels of conceptual understanding of green chemistry and its applications, to determine



the relationship between conceptual understanding and application and to compare gender and level of study among the samples.

The population for the study was all preservice chemistry teachers at the university in Southwest Nigeria. Gender and level of study were selected by using stratified random sampling with the participants voluntarily participating in the study from three universities, with a total of three hundred and fifty-six (356) samples. The research instrument used for the study was a Preservice Teachers' Conceptual Understanding and Application of Green Chemistry Questionnaire (PTCUAGCQ) which composed of three sections: A, B, and C. Section A was the demographic information section, in which respondents were to provide their institutional name, gender, and level of study. Section B contained twenty-four (24) structured statements on the principles of green chemistry to elicit the respondents' concept of green chemistry. The respondents were to tick right (√) or mark wrong (X) as applicable to the principles. Section C had thirty-five (35) statements on the applications of green chemistry to real-life situations. The respondents were to either mark the statements as right or wrong. This format was adopted because the study conceptualised application as the ability to correctly identify environmentally responsible actions and reject inappropriate practices. Dichotomous scoring enabled objective assessment of respondents' practical understanding and decision-making competence in real-life situations. Each correct answer attracted one (1) mark, while an incorrect answer was scored zero (0). The scoring range for level of conceptual understanding of the principles

of green chemistry was 0-11, 12-16, and 17-24 as low, moderate and high, while the scoring for application level was 0-17, 18-24 and 25-35 as low, moderate and high, respectively.

The instrument was content- and construct-validated by three science educators. The inter-rater value for the validators was 0.82, based on Cohen's Kappa. The instrument was further subjected to pilot testing with 20 preservice teachers at a tertiary institution that was not sampled for the study. The reliability coefficient was .89 as measured by Kuder-Richardson Formula 20 (KR-20). The instrument was administered on 200, 300, and 400 levels preservice chemistry teachers sampled from the three universities in Southwestern Nigeria.

Data were analysed using descriptive statistics, including simple percentages, means, and standard deviations, to assess levels of conceptual understanding and the application of green chemistry. The levels were classified as high, moderate and low. Pearson's Product Moment Correlation, r , was used to determine if knowledge relates to application. Gender differences were determined on conceptual understanding and application using an independent samples t-test and one-way Analysis of Variances (ANOVA) to compare 200, 300, and 400 levels preservice chemistry teachers for both conceptual understanding and application, and a Post Hoc (Turkey) test was used to test for significant differences by levels of study. A two-way ANOVA was used to test the interaction effect of gender and level of study on the preservice chemistry teachers' conceptual understanding and application of green chemistry.

Results of Data Analysis

Table 1: Descriptive Statistics of Preservice Chemistry Teachers' Conceptual Understanding and Application of Principles of Green Chemistry

		Variable	N	Mean	Std. Error
Understanding Principles of Green Chemistry	Male	75	15.3200	2.92778	.33807
	Female	281	15.7260	3.74829	.22360
	Total	356	15.6404	3.59106	.19033
Application of Green Chemistry to real life	Male	75	20.3333	4.27227	.49332
	Female	281	21.0890	5.05073	.30130
	Total	356	20.9298	4.90106	.25976

Table 2: Correlation Values of Preservice Chemistry Teachers' Conceptual Understanding and Application of Principles of Green Chemistry

Variable	Understanding Principles of Green Chemistry	Application of Green Chemistry to real life
Understanding Principles of Green Chemistry	Pearson Correlation	.608**
	Sig. (2-tailed)	.000
	N	356
Application of Green Chemistry to real life	Pearson Correlation	.608**
	Sig. (2-tailed)	.000
	N	356

** . Correlation is significant at the 0.01 level (2-tailed).

Table 3: The values of the Independent Samples T-Test on Preservice Chemistry Teachers' Gender on Conceptual Understanding and Application of Green Chemistry

Variables		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Conceptual Understand. Principles of Green Chemistry	Equal variances assumed	7.149	.008	-.870	354	.385	-.40598	.46689	-1.32420	.51225
	Equal variances not assumed			1.002	145.545	.318	-.40598	.40533	-1.20707	.39511
Application of Green Chemistry to real life	Equal variances assumed	4.163	.042	1.187	354	.236	-.75563	.63662	-2.00767	.49640
	Equal variances not assumed			1.307	134.558	.193	-.75563	.57805	-1.89888	.38761

Table 4: One-Way ANOVA Values for Preservice Chemistry Teachers' Conceptual Understanding and Application of Principles of Green Chemistry by Level of Study

Variable		Sum of Squares	Df	Mean Square	F	Sig.
Understanding Principles of Green Chemistry	Between Groups	506.822	2	253.411	21.973	.000
	Within Groups	4071.156	353	11.533		
	Total	4577.978	355			
Application of Green Chemistry to real life	Between Groups	1081.402	2	540.701	25.634	.000
	Within Groups	7445.842	353	21.093		
	Total	8527.244	355			

Table 5: Post Hoc Tests of Multiple Comparisons for Preservice Chemistry Teachers' Conceptual Understanding and Application of Principles of Green Chemistry by Level of Study

Dependent Variable	(I) Level	(J) Level	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Understanding Principles of Green Chemistry	200.0	300.0	-1.55640*	.41696	.000	-2.3764	-.7364
		400.0	-2.99415*	.45790	.000	-3.8947	-2.0936
	300.0	200.0	1.55640*	.41696	.000	.7364	2.3764
		400.0	-1.43775*	.47260	.003	-2.3672	-.5083
	400.0	200.0	2.99415*	.45790	.000	2.0936	3.8947
		300.0	1.43775*	.47260	.003	.5083	2.3672
Application of GC to real life	200.0	300.0	-1.00288	.56389	.076	-2.1119	.1061
		400.0	-4.36088*	.61926	.000	-5.5788	-3.1430
	300.0	200.0	1.00288	.56389	.076	-.1061	2.1119
		400.0	-3.35800*	.63913	.000	-4.6150	-2.1010
	400.0	200.0	4.36088*	.61926	.000	3.1430	5.5788
		300.0	3.35800*	.63913	.000	2.1010	4.6150

Table 6: A Two-way ANOVA Values of Preservice Teachers' Gender and Level of Study on

Conceptual Understanding of Principles of Green Chemistry

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	684.265 ^a	5	136.853	12.302	.000	.149
Intercept	57129.542	1	57129.542	5135.289	.000	.936
Gender	43.589	1	43.589	3.918	.049	.011
Level	200.039	2	100.019	8.991	.000	.049
Gender * Level	133.616	2	66.808	6.005	.003	.033
Error	3893.712	350	11.125			
Total	91664.000	356				
Corrected Total	4577.978	355				

a. R Squared = .149 (Adjusted R Squared = .137)

Table 7: A Two-way ANOVA Values of Preservice Teachers' Gender and Level of Study on

Applications of Principles of Green Chemistry

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1757.388 ^a	5	351.478	18.171	.000	.206
Intercept	102592.320	1	102592.320	5303.999	.000	.938
Gender	122.556	1	122.556	6.336	.012	.018
Level	349.350	2	174.675	9.031	.000	.049
Gender * Level	553.348	2	276.674	14.304	.000	.076
Error	6769.856	350	19.342			
Total	164475.000	356				
Corrected Total	8527.244	355				

a. R Squared = .206 (Adjusted R Squared = .195)

Answer to Research Question 1: 1. What are the levels of conceptual understanding and knowledge of applications of preservice teachers on the principles of green chemistry?

The mean score of the respondents in Table 1 on conceptual understanding was 15.64 (65.17%), which falls between the grading range of 12-16, indicating a moderate level of conceptual understanding of green chemistry. That is the preservice chemistry teachers had moderate knowledge of the principles of green chemistry. The mean score for the application of green chemistry principles was 20.93 (59.80%), indicating moderate knowledge of their application.

Testing of Hypotheses

Hypothesis 1: There is no significant relationship between preservice teachers' conceptual understanding of the principles of green chemistry and the applications of green chemistry to life situations.

Results from Table 2 of the correlation analysis indicate a correlation coefficient of $r = 0.608$, which is significant at $p = 0.000$ ($p < 0.05$) for conceptual understanding and application. The null hypothesis was rejected, and it was established that there is a significant relationship between preservice teachers' conceptual understanding of the principles of green chemistry and their applications in everyday life.

Hypothesis 2: Gender does not significantly influence preservice teachers' conceptual understanding of principles and applications of green chemistry.

The results of the independent samples t-test in Table 3 show Levene's Test of Variances for variance assumed means with p-values of 0.008 and 0.042 ($p < 0.05$), respectively, for conceptual understanding and application of green chemistry, indicating significant differences in the variables by gender. Hence, the equality of variances was not assumed, and the conclusion was $p = 0.318$ and $p = 0.193$ for conceptual understanding and application between male and female preservice chemistry teachers, indicating acceptance of the null hypothesis.

Hypothesis 3. Levels of study do not significantly influence preservice teachers' conceptual understanding of principles and applications of green chemistry.

Table 4's results of one-way ANOVA show significant differences among the preservice chemistry teachers by their study levels; F

$(_{2,353}) = 21.973$, $p = 0.000$ ($p < 0.05$) for conceptual understanding and $F_{(2,353)} = 25.634$, $p = 0.000$ ($p < 0.05$) for application. Hence, the null hypothesis was rejected.

The post hoc test results in Table 5 show that 200-level preservice chemistry teachers' conceptual understanding differed significantly from that of 300-level and 400-level preservice teachers for both dependent variables. The 200-, 300-, and 400-level had mean scores of 14.35, 15.91, and 17.35, respectively, in conceptual understanding, while the 200-, 300-, and 400-level had mean scores of 19.49, 20.50, and 23.85, respectively, in the application of green chemistry.

Hypothesis 4: There is no significant interaction influence of gender and level of study on preservice teachers' conceptual understanding of principles and applications of green chemistry.

The results of the two-way ANOVA in Table 6 show a significant interaction between preservice chemistry teachers' gender and level of study on conceptual understanding, with $F_{(2,350)} = 6.005$, $p = 0.003$ ($p < 0.05$). Hence, the null hypothesis was rejected.

For the application of green chemistry, $F_{(2,350)} = 14.304$, $p = 0.000$ ($p < 0.05$), as shown in Table 7 of the two-way ANOVA. The null hypothesis 4 was also rejected.

Discussion of the Findings

This study examined preservice teachers' conceptual knowledge and application of green chemistry, as well as the influence of gender and level of study. The findings are discussed in relation to existing literature and relevant learning theories.

The finding that preservice teachers demonstrated moderate levels of both conceptual knowledge and application of green chemistry suggests that while some awareness exists, it is not sufficiently deep to support consistent practical implementation. This outcome reflects a persistent gap between theoretical exposure and functional understanding in sustainability education.

This finding aligns with Idul and Walag (2024), who reported that students often exhibit limited initial awareness of green chemistry when it is not explicitly embedded in the curriculum. Similarly, Gunbatar et al. (2025) observed that students' understanding tends to remain moderate when instruction relies heavily on

traditional, lecture-based approaches without adequate practical engagement. However, this finding contrasts with intervention-based studies such as Sunday et al. (2026), which reported higher levels of knowledge and environmental awareness among students exposed to structured green chemistry instruction. The discrepancy may be explained by differences in instructional approaches, as targeted interventions tend to produce stronger outcomes than conventional teaching methods.

From a theoretical perspective, constructivist theory suggests that learners develop a deeper understanding when knowledge is connected to real-life experiences (Vygotsky, 1978). The moderate performance observed may therefore reflect limited opportunities for contextualised learning. Similarly, experiential learning theory posits that knowledge becomes meaningful through active engagement and reflection (Kolb, 1984), which may be insufficient in traditional instructional settings.

The study found a significant positive relationship between conceptual knowledge and application, indicating that higher knowledge is associated with better application of green chemistry principles. This finding is consistent with Idul et al. (2025), who reported that students who developed stronger conceptual understanding through inquiry-based approaches demonstrated improved ability to apply green chemistry in real-life contexts. Similarly, Sunday et al. (2026) found that increased knowledge of sustainability concepts was associated with more environmentally responsible practices. The result supports constructivist assumptions that meaningful understanding enhances application (Vygotsky, 1978) and aligns with experiential learning theory, which emphasises the role of experience in transforming knowledge into action (Kolb, 1984).

However, it is important to note that knowledge alone may not fully determine application. Factors like attitudes and values may influence it. This indicates that while knowledge is a critical predictor, it operates alongside other influencing variables.

The finding that gender did not significantly influence conceptual knowledge and application suggests that both male and female preservice teachers have comparable learning outcomes in green chemistry. This result aligns with Gunbatar et al. (2025),

who reported that learner-centred and context-based instructional approaches tend to minimise gender disparities in science education.

However, this finding contrasts with earlier traditional STEM research, which often reported male advantages in science-related performance and participation (Hill et al., 2010; Organisation for Economic Cooperation and Development, OECD, 2015). These earlier disparities have been attributed largely to sociocultural influences, stereotypes, and differences in confidence rather than inherent ability.

Recent perspectives suggest that when learning environments are inclusive and opportunities are equal, gender differences tend to diminish (UNESCO, 2024). From a social learning perspective, equal exposure to role models and learning experiences can lead to similar outcomes across gender groups (Bandura, 1977). Thus, the absence of gender differences in this study may reflect improved equity in instructional practices and learning environments.

The study revealed that the level of study significantly influenced both conceptual knowledge and application, with higher-level students outperforming lower-level students (400 > 300 > 200), indicating the progression in the knowledge and application of green chemistry principles as students learn.

This finding is consistent with Gunbatar et al. (2025) and Kusi (2026), who noted that advanced students tend to demonstrate a stronger understanding of green chemistry due to cumulative academic exposure and laboratory experience. Similarly, Idul and Walag (2024) emphasised that prior knowledge significantly influences students' ability to understand and apply sustainability concepts. The result can be explained by Piaget's cognitive development and progressive learning, as higher-level students are more likely to engage in complex problem-solving and abstraction.

The finding of a significant interaction influence between gender and academic level suggests that the influence of academic level on knowledge and application varies across genders.

Although limited studies have directly examined this interaction in green chemistry, the finding is supported by broader educational research indicating that learning outcomes are shaped by

interactions among multiple variables, including learner characteristics and instructional context (Kolb, 1984; Bandura, 1977).

This result adds nuance to the earlier finding of no gender difference, suggesting that while gender alone may not be significant, its interaction with academic progression may influence learning patterns. This underscores the importance of adopting inclusive, adaptive teaching strategies that address the needs of diverse learners.

Conclusion

This study concludes that preservice teachers possess moderate levels of knowledge and application of green chemistry, indicating a need for stronger instructional support. The significant relationship between knowledge and application highlights the importance of conceptual understanding in promoting sustainable practices.

While gender does not significantly influence outcomes, the level of study plays a critical role, reflecting the impact of academic exposure and experience. The interaction effect further suggests that learning outcomes are shaped by multiple interconnected factors.

Overall, the study emphasises the need for curriculum reform and pedagogical innovation in teacher education to enhance sustainability competencies.

Recommendations

1. Green chemistry should be introduced early and progressively across all levels of teacher education.
2. Instruction should incorporate laboratory work, real-life case studies, and sustainability projects to enhance application.
3. Educators should be trained in modern, student-centred approaches to teaching green chemistry.
4. Institutions should model sustainable practices to reinforce learning through observation.
5. Teaching strategies should remain inclusive to sustain gender equity across all levels.
6. Future studies should explore additional variables such as environmental attitudes, teaching methods, and institutional culture.

Ethical Considerations: The researchers sought permission from the authorities of the sampled institutions before

administering the questionnaire. None of the students was coerced into participating in the study

References

- Anastas, P. T., & Warner, J. C. (1998). *Green chemistry: Theory and practice*. Oxford University Press.
- Bandura, A. (1977). *Social learning theory*. Prentice Hall.
- Da Silva Júnior, C. A., Giroto Júnior, G., Morais, C., & Jesus, D. P. (2024). Green chemistry for all: Three principles of inclusive green and sustainable chemistry education. *Pure and Applied Chemistry*, 96(9), 1-12.
- Gunbatar, S. A., Kiran, B. E., Boz, Y., & Oztay, E. S. (2025). A systematic review of green and sustainable chemistry education research with pedagogical content knowledge framework: Current trends and future directions. *Chemistry Education Research and Practice*, 26, 34-52.
- Hill, C., Corbett, C., & St. Rose, A. (2010). *Why so few? Women in STEM*. AAUW.
- Idul, J. J. A., & Walag, A. M. P. (2024). Integrating green chemistry and sustainability principles into a secondary science curriculum: A mixed-methods needs assessment. *Journal of Chemical Education*, 101(7), 2765-2778.
- Idul, J. J. A., et al. (2025). Green modules: Integrating green and sustainable chemistry principles through process-oriented guided inquiry learning. *Journal of Chemical Education*, 102(3), 1104-1116.
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.
- Kusi, J. K. (2026). Assessment of senior high school students' knowledge of green chemistry principles in Winneba. *Journal of Research Innovation and Implications in Education*, 10(1), 219-231. <https://doi.org/10.59765/zxr3g8>.
- Mulyanti, S., & Kadarohman, A. (2021). Students attitude towards green chemistry and its application. *Journal of Physics Conference Series*, 1806(1), 012181-012187.



- OECD. (2015). *The ABC of gender equality in education*. OECD Publishing.
- Okunuga, R. O., & Adeoye, I. F. (2025). Green chemistry education: An assessment of awareness, knowledge and application among secondary school students in Southwest Nigeria. *KIU Journal of Education*, 5(1), 17-24.
- Piaget, J. (1972). *The psychology of the child*. Basic Books.
- Sunday, E. S., Samuel, H. S., Rickson, N. H., et al. (2026). Impact of green chemistry education on students' learning and environmental awareness in chemistry. *Discover Education*, 5, Article 44, 1-14.
- UNESCO. (2024). *Girls and women in STEM education report*. UNESCO Publishing.
- Vygotsky, L. S. (1978). *Mind in society*. Harvard University Press.