

Assessment of Green Chemistry Implementation in Libyan University Labs Oratorical Strategies

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ABSTRACT

Green chemistry (GC) has emerged as a better experimental design reduce health and environmental risks of traditional practices. Significant gaps appear between the theoretical understanding of the GC principles and their application in higher education laboratories in Libya due to physical, living, and curricula restrictions. This paper examines the situation the GC principles implementation in the Libyan higher education laboratories using field studies and documentary reports, determines technical, administrative, and training difficulties, and proposes possible practical solutions to develop laboratory work, reduce the negative effect on the environment, and teaching capacity in the local area. It's conducted in the time between January and June 2026 and used a descriptive analytical approach. Data were collected by an electronic questionnaire sample from postgraduate students, departments heads, technicians, lab coordinators, and etc. An arithmetic means and standard deviations were carried out to analyse data; additionally, Cronbach's alpha coefficient was calculated to estimate the reliability of the tool. The appropriate statistics were used to test the difference between groups. Results showed that the participants had good awareness and that chemistry majors (especially analytical and physical) outperformed others in the level of application and awareness of the principles of GC and its importance in higher education, with there being an urgent need to strengthen the applied and training aspects. The study recommends that Libya should create a strategy to include green chemistry in its higher education.

تقييم توظيف مبادئ الكيمياء الخضراء في الخطاب التوعوي داخل مختبرات الجامعات الليبية

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المخلص	الكلمات المفتاحية
برزت الكيمياء الخضراء يؤدي إلى تقليل المخاطر الصحية والبيئية للممارسات التقليدية. وتظهر فجوات كبيرة بين الفهم النظري لمبادئها وتطبيقها في مختبرات التعليم العالي في ليبيا بسبب القيود المادية والمعيشية والمنهج الدراسية. تتناول هذه الدراسة وضع تنفيذ مبادئ الكيمياء الخضراء في المختبرات باستخدام الدراسات الميدانية والتقارير الوثائقية. وتحديد الصعوبات الفنية والإدارية والتدريبية؛ وتقترح الحلول العملية لتطوير العمل المخبري وتقليل التأثير السلبي على البيئة وزيادة القدرة التعليمية. استخدمت هذه الدراسة المنهج الوصفي التحليلي، وتم جمع بياناتها عن طريق استبيان من طلاب الدراسات العليا ورؤساء الأقسام والفنيين ومنسقي المختبرات وغيرهم. تم إجراء هذه الدراسة في الفترة مابين شهري يناير ويونيو 2026. وتحليل البيانات تم استخدام الوسائل الحسابية والانحرافات المعيارية؛ بالإضافة إلى ذلك، تم حساب معامل ألفا كرونباخ لتقدير ثبات الأداة. تم استخدام الإحصائيات المناسبة لاختبار الفرق بين المجموعات. أظهرت النتائج أن المشاركين يتمتعون بوعي جيد، وأن تخصصات الكيمياء (خاصة التحليلية والفيزيائية) تفوقت على غيرها في مستوى التطبيق والوعي بمبادئ الكيمياء الخضراء وأهميتها في التعليم العالي، مع وجود حاجة ملحة لتعزيز الجوانب التطبيقية والتدريبية. وتوصي الدراسة بأن تضع ليبيا استراتيجية لإدراج الكيمياء الخضراء في التعليم العالي.	الكيمياء التقليدية الكيمياء الخضراء الأساسيات 12 في الكيمياء الخضراء معوقات الكيمياء الخضراء المعامل الجامعية

Introduction

Traditional chemistry education in Libya higher colleges depends a lot on many dangerous chemicals and materials, for hands-on lessons. Although this helps students learn theory and practice traditional chemistry education brings health dangers for students, lab workers, teachers and the

local environment [1]. Traditional chemistry is a core subject that students learn in college laboratories; I see chemistry as essential for science education. However, the widespread use of chemicals, reagents and toxic materials is linked to health and environmental issues. Research shows that chemical usage affects all human activities with direct impacts on

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health and indirect effects, through air, water and soil raising the risk of chronic or acute poisoning and higher cancer rates [2].

Traditional chemistry experiments can be very dangerous, for people and the planet. They expose kids and workers to smells and cancer-causing things. These experiments also create waste that hurts the air and the water. To make things safer schools are using the ideas of green chemistry. The goal is to remove the dangers before any experiment starts [3].

Chemistry depends a lot on experiments. These experiments are very important for learning even though people worry about safety because of chemicals. These hazardous chemicals can be dangerous, to both people and the environment. Because of these using chemicals in experiments is a tough but necessary part of studying chemistry [4, 5].

Corrosive nitric acid is a chemical that can cause long-term health problems when you are exposed to it. Other substances, such, as chloromethyl, dichloromethene and other carcinogens can cause harm after just one exposure [6].

Green chemistry or sustainable chemistry is a way of thinking about chemicals. It focuses on making products in a way that reduces or removes dangerous things. It is a change from just trying to make chemicals less harmful. Instead, it is about making things safer and better for the planet. This way of working tries to create cleaner ways to make chemicals. It is not, about cleaning up after things go wrong or making less pollution [7-9].

Chemicals are essential for well-being and for growth. Yet Chemicals can also create health problems and damage ecosystems when mismanaged. The effect of Chemicals on human health changes, with the type of exposure the amount of Chemicals involved and how long exposure lasts [10]. Impact of Hazardous chemicals in laboratory on health and environment is serious issue which needs to be focused and acted upon. Table 1 shows materials in labs and what they can do. A careful way of dealing with these substances is very important to stop them from being used much or let out into the air. The goal is to keep the environment and people safe. Good rules and ways to handle chemicals properly at every step of their time, in use are needed [11].

Green Chemistry provides ways to make chemicals. It uses things that can be replaced like plants or other natural materials. It helps save energy and makes products that can break down easily in nature. This helps fix problems that hurt people's health and the environment [12].

Green Chemistry provides guidelines, for making chemicals. It uses materials that can be renewed. It helps save energy. It creates products that can break down easily. These steps address issues pertaining to health and the environment [9].

The lab studies started here are very important, for making processes, medicines, farm chemicals and things people use every day. When chemists use chemistry rules right from the beginning chemists can make safe products and processes that do not hurt the environment [1].

Green chemistry has had a significant impact on chemistry education, with universities and programs worldwide recognizing the need to raise awareness and implement environmentally friendly practices (Waked et al., 2019). Institutions like Westminster College and the University of California, Berkeley, have implemented such practices [13, 14]. The American Chemical Society (ACS) considers green chemistry the future of chemistry. With it come exciting potential discoveries and transformative applications [15].

The Twelve Principles of Green Chemistry, developed by Anastas and Warner, offer a guiding structure when designing products and processes with minimized inherent hazards [16]. Figure 1 shows the green chemistry framework of set of 12 principles [17].

Table 1: Hazardous Substances in Laboratories [11]

Type of Chemicals	Effect	Examples of Chemicals
Dangerous Chemicals	Harmful to the human body and environment	Acetonitrile, chloroform, formaldehyde, sodiumazide, sodium hydroxide, etc.
Oxidizer	React violently and cause fires or explosions	Nitrates, perchlorates, permanganates, chromates, peroxides, etc.
Flammable Liquids	Ignite easily and burn rapidly Release flammable or toxic gases on exposure to moisture or water	Methanol, ethanol, acetone, xylene, toluene, etc.
Water-Reactive	Spontaneously ignite in air or oxygen Cause acute or chronic toxicity to the human body or the environment	Alkali metals, metal powders, carbides, boranes, etc. Metal alkyls and aryls, nonmetal alkyls, phosphorus (white), etc.
Poisons		Acrylamide, cyanides, sulfides, mercury compounds, etc.

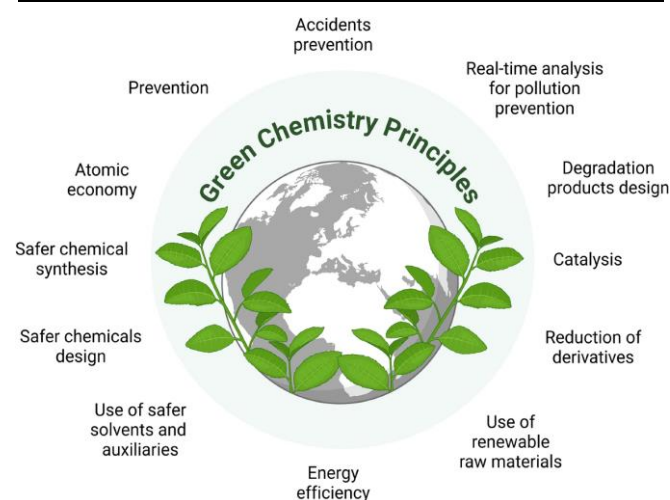


Figure 1: Principals of Green Chemistry [17]

All discussed concepts are relevant to lab environments. Can be put together into a helpful checklist for scientists. The first rule is about reducing waste by using the amounts of chemicals. The second rule, called atom economy is about using many chemicals as possible in a reaction with an emphasis on addition and rearrangement reactions to make fewer extra products. The third rule is about making chemicals that're not very harmful maybe by choosing safer catalysts. The fourth rule is about making chemicals that work well but are not harmful which is important when changing lead molecules in drug development. The fifth rule is about using liquids to mix things suggesting options like water or supercritical CO₂ instead of regular harmful chemicals. The last rule is about saving energy by doing reactions at temperatures using methods, like sound waves or microwave heating to make reactions faster [17-19].

When we work in the lab the seventh principle tells us to use feedstocks. It is better to use biomass-derived chemicals of petrochemicals. This means doing lab studies to turn carbohydrates, lignin or plant oils into things we can actually use. The eighth principle is about reducing derivatives. We should try to avoid using groups that just create more waste. The goal is to reach a state of protecting group- synthesis. The ninth principle focuses on catalysis. We want to use catalysts like enzymes or metal complexes in small amounts to make chemical processes work better. Using catalysts helps reduce waste, which's a big change, from cross-coupling reactions that usually need a lot of stoichiometric organometallic reagents [20, 21].

In laboratory practice the seventh principle encourages the use of feedstocks. This means using chemicals that come from plants of oil-based chemicals. It looks at ways to turn things like sugar, wood or plant oils into materials. The eighth principle is about cutting down on parts in chemical reactions. It suggests removing things that are not needed so that less waste is created. The ninth principle focuses on using catalysts. It says to use little as possible of these helpers like enzymes or special metals to make reactions work better. This helps reduce waste. This is especially important, in reactions where a lot of chemicals are usually needed [22].

In this study we reviewed papers carefully to see how green chemistry is used in laboratories. We looked at how green chemistry changes students' understanding of both ideas and hands-on work and how green chemistry changes their sense of caring about the planet over the ten years from 2015 to 2024. We used the DOZN 2.0 chemistry scale to measure how dangerous each chemical reaction might be. Green chemistry is very important for the green laboratory movement. Green chemistry helps organizations reach goals for sustainability and safety. Green chemistry requires teamwork, among people who work in sustainability, environmental health and safety. [23-26].

Chemists are increasingly adopting alternatives in laboratory techniques such as synthesis, purification, analysis and storage. This research paper evaluates both the benefits such as cost savings, safety improvements and regulatory compliance and the drawbacks, including limitations, ignorance and resistance to change. It highlights the necessity for research and innovation in green chemistry to address emerging challenges in the field while fostering a culture of sustainability in laboratories through ongoing training and experience sharing, among staff [27]. Table 2 shows the green chemistry laboratory practices and action that to be considered.

A study using qualitative literature analysis looked at how green chemistry can improve both environmental health in sustainable health programs and policymaking. It shows how occupational and environmental health frameworks can help plan programs and shape regulations through chemical innovation. The results suggest that adding chemistry principles to health initiatives can cut down on workplace dangers and lower the long-term costs of medical care and environmental harm. This method links chemical science with health encouraging sustainable evidence-based ways to boost health results. The research gives a framework, for putting green chemistry into everyday occupational and environmental health practices [29].

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Table 2: Green Chemistry Laboratory Practices and Action to be Considered [27]

Green Practice	Action to be Considered
Making Use of Safer Materials	Use less toxic or poisonous chemicals where ever possible. Substitute hazardous materials for more safe alternatives. Keep an up-to-date list of your chemicals to prevent duplicate purchasing. Label and store your chemicals carefully to prevent spills and accidents.
Management of Chemical Inventory	Use minimal amounts of chemical reagents in order to achieve the desired results. Minimize the quantity of chemical reagents in experiments and procedures.
Reduce the Use of Chemicals	Use greener solvents (e.g. Ethanol or water) rather than harmful or volatile organic solvents. Conserve and recycle solvents.
Selection of Solvents	Utilize energy-saving apparatus in the laboratory. Lower energy consumption by adjusting experimental parameters and switching off devices when not in use.
Efficiency of Energy Use	Reduce the waste generated. Employ techniques like microscale chemistry and recycle and reuse where possible.
Reduction of Waste	Use catalytic processes to reduce the number of reagents used and reduce the waste.
The Process of Catalysis	Use green synthesis.
Ecological Synthesis	Purchase energy efficient technology.
Green Equipment	Train staff and relevant parties in the use of green techniques and technologies.
Education and Training	Prioritize safety by following standard procedures.
Safety Procedures	

occupational and environmental health frameworks can help plan programs and shape regulations through chemical innovation. The results suggest that adding chemistry principles to health initiatives can cut down on workplace dangers and lower the long-term costs of medical care and environmental harm. This method links chemical science with health encouraging sustainable evidence-based ways to boost health results. The research gives a framework, for putting green chemistry into everyday occupational and environmental health practices [30].

Over the ten years green chemistry has become much more important for protecting our environment and helping the world grow in a healthy way. However higher education in Libya is struggling to keep up with these changes. Even though green chemistry is doing well in research groups and local labs you do not see green chemistry being used much in official university classes or standard lab work. It is very hard to find chemistry in a regular classroom setting. This happens because there are problems with money, school rules and even cultural habits. Many studies show that students and teachers do not always know enough, about chemistry and there are just not enough money or the right laws to make green chemistry a part of every lab and course [28]. This research looks at how green chemistry used in Libyan university laboratories when compared to traditional chemistry labs. It needs to find out why it is so hard to use chemistry. There are problems like rules from bosses the way classes are taught lack of materials, old facilities and a lack of training. This study also checks if postgraduate students, educators and technicians actually know about chemistry and if they are ready to use it. It was suggested ways to bring

chemistry into the labs so we can lower risks to the environment and human health. Now there is a big gap, between what people know about green chemistry and how they actually use green chemistry in Libyan labs. We really need to change things to make our research and teaching better.

This research shows what it can be expected from higher education laboratories. Now the use of green chemistry in Libyan higher education laboratories is quite low or only medium. Most people still rely on traditional experiments. There are problems holding things back. For example, there are no rules for green chemistry. The lab facilities are not good enough. There is a lack of microscale equipment. Also, the school lessons do not think much about the environment. There are not enough training classes. It's also noticed that different groups of people have levels of knowledge and habits. This happens because some people have tools and more experience than others. To fix this it was suggested that to use experiments. It also thinks there should be rules, for eco-friendly ways of working. It would be great to add chemistry modules to the classes that students already take. Finally, it needs to find ways to treat waste. These ideas are based on facts. They are meant to help the Libyan educational authorities bring green chemistry into the chemistry curriculum in a way that lasts.

Methodology

Study Design, Instrumentation, and Sampling Strategy

The present study adopted a quantitative research approach to explore how green chemistry can complement traditional chemistry. A structured questionnaire was the main instrument for data collection. The survey instrument was carefully designed to include 25 unique items to test different aspects of awareness, implementation and attitudinal behavior towards green chemistry to facilitate systematic data collection. Responses were elicited using a multiple-choice procedure.

The population of interest was composed of faculty members, laboratory technicians and postgraduate students in chemistry and related science departments of Libyan institutions so that the responders were directly or indirectly involved in chemical laboratory operations. A purposive sampling technique was applied to ensure a representative and diverse sample. Hence, the questionnaires were completed by 200 (male and female) respondents from several relevant scientific specializations.

Statistical Methods Used in Data Analysis

The study data were analysed using the Statistical Program for the Social Sciences (SPSS V27) [31], relying on a set of descriptive and inferential statistical methods in accordance with the nature of the study objectives and hypotheses. Frequencies and percentages were used to describe the demographic characteristics of the study sample, and arithmetic means and standard deviations were used to determine the level of responses of sample members to the study items. To verify the stability of the study tool, Cronbach's alpha coefficient was used to measure the internal consistency of the questionnaire items. The study also relied on a descriptive and analytical statistical methodology aimed at revealing differences between independent groups according to demographic and academic variables. Because the assumptions of normal distribution and homogeneity of variance were not met, the following nonparametric tests were used, appropriate to the nature of the data.

(i) The non-parametric Mann-Whitney U test [32] for

independent samples was used to compare the differences between males and females in the reality of applying green chemistry principles to support traditional chemistry in higher education laboratories in Libya.

(ii) A nonparametric one-way analysis of variance test (Kruskal-Wallis H) [33] was used to detect differences in the reality of applying the principles of green chemistry instead of traditional chemistry in higher education laboratories in Libya according to the variables of years of experience teaching or working in a university laboratory, academic position, type of educational institution, and specialization, at a level of statistical significance ($\alpha \leq 0.05$).

In the event that there were statistically significant differences when using the nonparametric one-way analysis of variance test, (Post-Hoc Tests) [34] were used to determine the nature of the differences between the different specializations and interpret them more precisely. Bonferroni correction was applied to adjust the level of significance resulting from multiple comparisons [35].

Results and Discussion

Validity and Reliability of the Study Tool

First: The Validity of the Questionnaire:

The validity of the study tool means that the questionnaire statements measure what they were designed to measure [36], and the validity of the questionnaire was verified through the following types of validity:

The Apparent Validity of the Questionnaire (the Veracity of the Arbitrators):

The authors were tested the validity of the study tool by using the validity method by presenting the questionnaire to a group of arbitrators with experience in the field of study. The researchers took the majority of the arbitrators' comments to finalize them.

Second: Reliability of the questionnaire

In order to test the reliability of the study tool, Cronbach's alpha test was used to test the internal consistency of the tool. Table 3 shows the results.

Table 3: Results of the Study Tool's Reliability Test (Cronbach Alpha).

Axis	Number of Items	Alpha Coefficient
Questionnaire Items as a Whole	20	0.908

The Distribution of the According to the Demographic Characteristics of the Study Sample

The Table 4, lists the distribution of the according to the demographic characteristics of the study sample:

Table 4: The Distribution of the According to the Demographic Characteristics of the Study Sample.

Variable	Characteristic	Number	Ratio (%)
Gender	Male	83	41.5
	Female	113	56.5
	Missing data	4	2.0
Years of experience teaching or working in a university laboratory	Less than 5 years	89	44.5
	From 5 to 10 years	40	20.0
	From 11 to 15 years	31	15.5
	More than 15 years	40	20.0
Academic category or position	University student	22	11.0
	Higer education student	70	35.0
	Laboratory technician	13	6.5
	Faculty member	79	39.5

Type of educational institution	Any other job related to chemical laboratories	16	8.0
	Government university	158	79.0
	Private university	7	3.5
	General chemistry	60	30.0
Specialization	Organic chemistry	23	11.5
	Analytical chemistry	18	9.0
	Physical chemistry	11	5.5%
	Medical sciences and laboratories	25	12.5
Type of educational institution	Government university	158	79.0
	Private university	7	3.5
	Higher Institute	12	6.0
	Other educational institution	23	11.5
Specialization	General chemistry	60	30.0
	Organic chemistry	23	11.5
	Analytical chemistry	18	9.0
	Physical chemistry	11	5.5%
	Medical sciences and laboratories	25	12.5
	Any other specialty related to chemical laboratories	63	31.5

The results of Table 4 showed that the distribution of sample members was similar in terms of gender, as the number of male participants reached 83 (41.5%), while the number of female participants reached 113 (56.5%), with 2.0% missing data. It turns out that the proportion of females is slightly higher than that of males, which reflects a relative balance with a tendency in favor of females. The results showed that the majority of participants had less than five years of experience (44.5%), while the rest of the sample was divided between 5 to 10 years of experience (20.0%), 11 to 15 years (15.5%), and more than 15 years (20.0%). This indicates that a large segment of the sample is newly experienced, with a significant percentage having long experience. While the academic categories were distributed as follows: graduate students (35.0%) and faculty members (39.5%) constituted the largest percentage, followed by undergraduate students (11.0%), technicians (6.5%), and any other jobs related to chemical laboratories (8.0%). This reflects the academic character of the sample with a strong representation of faculty and graduate students.

The majors were distributed as follows: general chemistry (30.0%) and other majors related to chemical laboratories (31.5%) constituted the largest percentage, followed by organic chemistry (11.5%), analytical chemistry (9.0%), physical chemistry (5.5%), and medical sciences and laboratories (12.5%). This reflects the diversity of the scientific backgrounds of the sample, with a notable concentration in general chemistry and other applied disciplines. Most of the participants belonged to public universities (79.0%), while other educational institutions (11.5%) constituted a significant percentage, while higher institutes (6.0%) and private universities (3.5%) represented small percentages. This shows that public universities are the primary source of the sample.

In general, the study sample is characterized by clear diversity in terms of gender, years of experience, academic positions, type of educational institution, and specializations. However, the majority belong to public universities, have less than five years of experience, and faculty members and graduate students constitute the largest percentage. In terms of specialization, general chemistry and other chemical

laboratory-related specializations stand out as the most represented fields, reflecting the academic and applied character of the sample.

Notes on the Statistical Analysis:

(i) Due to the small number of respondents to the following paragraphs:

- Ecology and Geography (13 respondents);
- Oil and gas (9 respondents);
- Agricultural sciences (7 respondents), it has been added to any other specialty related to chemical laboratories as well as paragraph:
- Department Head/Laboratory Coordinator (3 respondents), it has been added to any other job related to chemical laboratories.

Questionnaire Scale Test

A Likert scale of five points test [37] was adopted to determine the relative importance of each item in the questionnaire, as shown in Table 5:

Table 5: The Values and Standards for Each Weight of the Five-Point Scale Approved by the Study

Scale	Strongly disagree	Disagree	Somewhat true	Agree	Strongly agree
Degree	1	2	3	4	5

A Measure of the Relative Importance of the Arithmetic Mean

An ordinal scale was developed for the arithmetic mean according to its level of importance to be used in analyzing the results according to Table 6 and Table 7 shows the results of the relative importance measure of the arithmetic mean.

Table 6: The Values and Standards for Each Weight of the Five-Point Scale Approved by the Study.

Scale	Strongly disagree	Disagree	Somewhat true	Agree	Strongly agree
Degree	1.0 to 1.79	1.80 to 2.59	2.60 to 3.39	3.40 to 4.19	4.20 to 5.00

Table 7: The Results of the Relative Importance Measure of the Arithmetic Mean

Arithmetic Mean	Importance Measure
Very low	1.0 to 1.79
Low	1.80 to 2.59
Moderate	2.60 to 3.39
High	3.40 to 4.19
Very High	4.20 to 5.00

Second: Displaying the Results of Agreement Among Sample Members:

(i) The extent of agreement between the sample members' answers. The sample members' answers to the items related to the level of human capital are shown in Table.(8)

The results of Table 8 showed that the level of agreement was very high regarding the material and human obstacles to applying the principles of green chemistry in higher education laboratories in Libya, such as weak capabilities, lack of equipment, and weak training, as the averages ranged between (4.25 - 4.31). While the level of agreement was high, with averages between (3.45 - 4.17), between most of the paragraphs that refer to practices and policies supporting the application of green chemistry in higher education and laboratories, such as policies, regulations, practical practices in the laboratory, and paragraphs related to personal knowledge (knowledge of green chemistry and the difference

between traditional and green chemistry), which showed a good awareness of the importance of green chemistry and its practical applications. On the other hand, detailed knowledge of the twelve principles of green chemistry and following up on related research had a moderate level of agreement, as the averages ranged between (3.18 - 3.26). The item regarding obtaining training or workshops had a low level of agreement, with an average of (2.48).

Comment on the Results

The results of the statistical analysis of participants' level of knowledge and attitudes toward green chemistry showed that the overall average agreement tends to be high, which reflects a good awareness of the importance of this field in education and laboratory applications. The paragraphs showed that general knowledge of green chemistry and awareness of its importance in higher education and academic curricula were at a high level, as the averages ranged between (3.45 and 4.17). The results also showed a clear commitment to reducing chemical waste and using less dangerous alternatives, in addition to taking into account safety and sustainability standards when choosing laboratory experiments.

In contrast, detailed knowledge of the 12 principles of green chemistry and follow-up of related research were at an average level, indicating the need to strengthen the theoretical and awareness aspects. As for practical training, it represented a clear gap, as the level of obtaining workshops or specialized training was recorded at a low level.

On the other hand, the results highlighted that material and human obstacles represent the greatest challenge to the actual application of green chemistry, as the items related to weak capabilities, lack of alternative devices and materials, and weak training and qualifications were at a very high level with averages exceeding (4.25).

To compare the current research paper with another recently published research paper in the same field, the findings of a Libyan publication on green chemistry by Al-Allous and Al-

Azzoumi [38] are discussed in the study, emphasizing the absence of empirical evidence on community understanding and engagement despite the publication's requests for awareness. This is supplemented by the current study, which offers quantitative assessments of participants' attitudes and knowledge, revealing high levels between 3.45 and 4.17, but moderate knowledge of particular principles and little practical training. Although this study focuses on quantifiable human and material restrictions, both studies reveal implementation difficulties. While the new study adds empirical support to the comparative study's recommendations for improved curricula and supportive policies, it also identifies obstacles to the real-world implementation of green chemistry in educational settings. Overall, the results support the conclusions of the Libyan study and provide useful indicators for green chemistry education reform.

Hypothesis Testing

The First Hypothesis: There are no statistically significant differences between genders in the reality of applying the principles of green chemistry to support the traditional chemistry in higher education laboratories in Libya.

The Mann-Whitney U test was conducted to verify the presence of differences between genders in the reality of applying the principles of green chemistry instead of traditional chemistry in higher education laboratories in Libya. The results showed that the U value was 4343.000, while the W value was = 7829.000, with the Z value = -0.884. The level of statistical significance reached $p = 0.377$. Since this value is greater than the approved significance level (0.05), the differences between males and females were not statistically significant. Therefore, these results indicate that gender is not an influencing factor in the reality of applying the principles of green chemistry to support traditional chemistry in higher education laboratories in Libya within this sample, which reinforces the hypothesis of homogeneity of responses between the two groups.

Table 8: The Sample Responses to Paragraphs Related to the Level of in Green Chemistry Practices or Attitudes.

No.	Paragraph	Arithmetic Mean	Standard deviation	Agreement level
1	I have sufficient knowledge of GC	3.45	1.147	High
2	I have sufficient knowledge of the 12 principles of GC	3.19	0.895	Medium
3	I have knowledge of the difference between traditional chemistry and GC	3.45	0.888	High
4	I can identify practical applications of GC in the laboratory	3.18	1.123	Medium
5	I have had previous training or workshop in GC	2.48	0.979	Low
6	I believe GC can be applied in Libyan higher education	3.85	1.033	High
7	I find it important to include GC in courses	4.10	0.991	High
8	I follow research or articles related to GC regularly	3.26	1.115	Medium
9	In the laboratory, I use less hazardous chemicals and reagents whenever possible	3.87	1.084	High
10	I minimize the amount of toxic or volatile solvents in the laboratory	3.95	1.124	High
11	I consider reducing chemical waste resulting from chemical experiments in the laboratory	4.06	0.976	High
12	I implement clear recycling or reuse procedures within the laboratory	3.68	1.041	High
13	There are green alternatives to some traditional Experiments in laboratory courses	3.54	0.954	High
14	Laboratory experiments are selected according to safety and sustainability standards	3.77	0.925	High
15	I consider energy efficiency in operating laboratory instruments and equipment within the laboratory	3.75	0.869	High
16	There are clear instructions for students about the safe handling of chemicals in the laboratory	3.89	0.899	High
17	Weak financial capabilities hinder the application of GC in the laboratory	4.25	1.147	Very high
18	The lack of alternative equipment and materials limits the possibility of applying GC within the laboratory	4.28	0.895	Very high
19	Lack of specialized training or qualification is one of the most prominent obstacles to applying GC in the laboratory	4.31	0.888	Very high
20	The lack of clear university regulations or policies reduces the application of GC	4.17	1.123	High
General average		3.72	0.61	High

The Second Hypothesis: There are no statistically significant differences between academic jobs in the reality of applying the principles of green chemistry to support the traditional chemistry in higher education laboratories in Libya.

The nonparametric analysis of variance test (Kruskal–Wallis H) was conducted to detect differences between academic groups in the reality of applying the principles of green chemistry to support traditional chemistry in higher education laboratories in Libya. The results showed that the value of ($H = 8.618$, $df = 4$, $p = 0.071$) was not statistically significant. Based on this, it can be concluded that academic function does not represent an influencing factor in this context, which strengthens the hypothesis of homogeneity of responses between groups.

The Third Hypothesis: There are no statistically significant differences between specializations in the reality of applying the principles of green chemistry to support traditional chemistry in higher education laboratories in Libya.

When comparing academic disciplines, the nonparametric analysis of variance (Kruskal–Wallis H) test showed that there were statistically significant differences in the reality of applying green chemistry principles to support traditional chemistry in higher education laboratories in Libya. The test value was ($H = 19.131$) with degrees of freedom ($df = 5$) and a probability significance level ($p = 0.002$). Since the probability value is less than the approved significance level (0.05), this indicates the presence of fundamental differences between disciplines in the responses. Participants: This result confirms the rejection of the null hypothesis that there are no differences between academic specializations and the acceptance of the alternative hypothesis that there are statistically significant differences. Accordingly, it can be said that academic specialization is an influential factor in this context, which requires conducting post-hoc tests to determine the nature of the differences between the different specializations and interpret them more accurately.

In practical terms, this can be explained by the fact that some disciplines directly related to natural or applied sciences, such as chemistry, have a greater awareness of green chemistry principles and their applications, while other disciplines may show a lower level of knowledge or interest. This discrepancy highlights the need to integrate green chemistry in a balanced manner into all academic programs to ensure the spread of a culture of sustainability and environmental awareness among various disciplines.

The Fourth Hypothesis: There are no statistically significant differences between the types of educational institutions in the reality of applying the principles of green chemistry to support traditional chemistry in higher education laboratories in Libya.

The nonparametric analysis of variance (Kruskal–Wallis H) test when comparing the type of educational institution showed that the differences between the types of educational institutions were not statistically significant, as the test value was ($H = 2.570$) with degrees of freedom ($df = 3$) and a probability level of significance ($p = 0.463$). Since the probability value is greater than the approved significance level (0.05), this indicates that there are no fundamental differences between the different educational institutions in the reality of applying the principles of green chemistry to support traditional chemistry. In higher education laboratories in Libya, it can be said that the type of educational institution is not an influential factor in this

context, which reinforces the hypothesis of homogeneity of responses between groups.

In practical terms, this can be explained by the fact that the challenges and opportunities associated with the application of green chemistry in Libyan higher education are largely similar between different institutions, whether public or private universities or institutes. Therefore, policies or initiatives supporting the implementation of green chemistry should be generally directed at all educational institutions, without the need to distinguish the type of institution as a major factor.

This result supports the hypothesis of homogeneity of responses among participants, regardless of whether the institution is a public or private university or a specialized institute. Theoretically, this can be explained by the fact that the challenges associated with implementing green chemistry in Libyan higher education are similar across different institutions, as they all face similar material and human constraints, such as lack of equipment and alternative materials, weak training and qualification, and the absence of clear institutional policies. Thus, the absence of statistical differences reflects a uniform reality of challenges that limit the practical application of green chemistry.

Post-Hoc Tests to Determine the Nature of the Differences Between Different Specializations and Interpret Them More Accurately:

Table 9, shows the mean ranks of the green chemistry score practices or attitudes across the academic specialties. Figure (2) shows the multiple pairwise comparisons among six scientific specialties based on their mean ranks for the green chemistry score practices or attitudes [39]. After applying the Bonferroni correction to adjust the level of significance resulting from multiple comparisons, it was found that:

- (i) Comparison of chemistry majors vs. organic Chemistry: Chemistry majors had higher average ranks, reflecting a better reality in applying green chemistry principles and a greater willingness to adopt sustainable practices;
- (ii) Comparison of Chemistry vs. Analytical Chemistry majors: Analytical Chemistry majors outperformed with higher average ranks, indicating better reality in the application of green chemistry;
- (iii) Chemistry vs. Physical Chemistry major comparison: Physical Chemistry majors outperformed with higher average ranks, reflecting a better reality in the application of green chemistry;
- (iv) Comparison of the chemistry major versus other laboratory-related majors: The chemistry major outperformed with a higher average rank;
- (v) Chemistry major versus medical sciences and laboratory: The chemistry major outperformed with a higher average rank;
- (vi) Comparing the organic chemistry major versus analytical chemistry: The analytical chemistry major outperformed with a higher average rank;
- (vii) Comparison of the organic chemistry major versus other laboratory-related majors: the organic chemistry major outperformed with a higher average rank;
- (viii) Comparison of the organic chemistry major versus medical and laboratory sciences: The organic chemistry major outperformed with a higher average rank;
- (ix) Comparing the specialty of analytical chemistry versus physical chemistry: The results appeared in two directions, once in favor of analytical chemistry and once in favor of

physical chemistry, which reflects discrepancies in results;

(x) Comparison of the analytical chemistry major versus other laboratory-related majors: The analytical chemistry major outperformed with a higher average rank;

(xi) Comparison of the Analytical Chemistry major versus Medical Sciences and Laboratory: The Analytical Chemistry major outperformed with a higher average rank;

(xii) Comparison of the physical chemistry major versus other laboratory-related majors: the physical chemistry major outperformed with a higher average rank;

(xiii) Comparison of the Physical Chemistry major versus Medical Sciences and Laboratory: The Physical Chemistry major outperformed with a higher average rank;

(xiv) Comparison of other laboratory-related specialties vs. medical sciences and laboratories: Other chemical laboratory-related specialties outperformed with higher average ranks.

Table 9. Mean Ranks of the Green Chemistry variable across Academic Specialties.

Variable	Speciality	N	Mean Rank
Green Chemistry	Chemistry	60	114.76
	Organic Chemistry	23	92.61
	Analytical Chemistry	18	125.81
	Physical Chemistry	11	134.77
	other laboratory-related	63	82.60
	Medical sciences and laboratory:	25	85.34
Total		200	

In addition, the following graph visualizes pairwise comparisons among six scientific specialties based on their mean ranks for the Green Chemistry. Each node represents a specialty, and the connecting lines illustrate the relative differences between them.

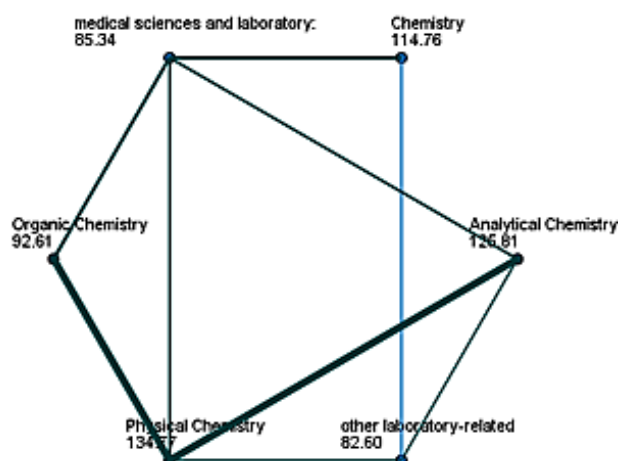


Figure 2: Analysis of Multiple Mean-Rank Differences among Six Chemistry Specialties [39]

In Figure 2, each node shows the average rank of a specialty. A higher mean rank indicates stronger engagement or higher scores in Green Chemistry practices or attitudes. The Thicker lines suggest larger differences between specialties; thinner lines indicate closer mean ranks. The relative ranking of Physical Chemistry (134.77) and Analytical Chemistry (125.81) have the highest mean ranks, implying greater involvement or awareness of green chemistry principles. Other laboratory-related fields (82.60) and medical sciences and laboratory (85.34) show the lowest ranks, suggesting less emphasis on green chemistry. Organic Chemistry (92.61) and

Chemistry (114.76) fall in the mid-range. This figure highlights that physical and analytical chemistry specialties lead in applying or valuing green chemistry principles, while laboratory-related and medical sciences lag behind. The pairwise comparison help identify where significant differences exist, guiding targeted interventions or curriculum improvements.

Conclusions

- (i) High perception of importance: Participants demonstrated good awareness of green chemistry and its importance in higher education and laboratory applications, with a practical commitment to reducing waste and using safe alternatives;
- (ii) There is a knowledge and training gap: Although general knowledge was high, detailed knowledge of the twelve principles of green chemistry and follow-up research was at an average level, while practical training was very weak, which reveals an urgent need to strengthen the applied and training aspect;
- (iii) The presence of material and human obstacles: weak capabilities, lack of alternative equipment and materials, and lack of training and qualifications represent major challenges to the actual application of green chemistry in Libya;
- (iv) Many factors are ineffective: gender, academic position, and type of educational institution did not appear as influential factors in the reality of applying green chemistry, which reflects the homogeneity of responses among these groups;
- (v) The main influencing factor: Academic specialization was the most influential factor, as chemistry majors (especially analytical and physical) outperformed others in the level of application and awareness of the principles of green chemistry;
- (vi) The need for academic integration: The disparity between disciplines highlights the need to integrate green chemistry in a balanced manner into all academic programs to ensure the spread of a culture of sustainability and environmental awareness across various fields;
- (vii) The absence of differences between educational institutions indicates that the challenges are similar, which calls for the development of general policies and initiatives that include all universities and institutes without discrimination;
- (ix) The challenges associated with implementing green chemistry in Libyan higher education are similar across different institutions, as they all face similar material and human constraints, such as a lack of equipment and alternative materials, weak training and qualification, and the absence of clear institutional policies;
- (x) The need to integrate green chemistry in a balanced manner into all academic programs to ensure the spread of a culture of sustainability and environmental awareness among various disciplines.

Recommendations

- (i) Strengthening practical training: The necessity of organizing workshops and specialized training courses to raise the efficiency of students and faculty members in applying the principles of green chemistry practically within laboratories;
- (ii) Curriculum development: Integrate the principles of green chemistry in a balanced manner into all academic programs, with an emphasis on the theoretical and practical aspects to enhance awareness and sustainability;
- (iii) Providing financial capabilities: supporting laboratories with safe alternative equipment and materials, and allocating

sufficient budgets to implement sustainable practices;

(iv) Human capacity building: Investing in training and qualifying academic and technical personnel to ensure effective and sustainable application of green chemistry principles;

(v) Unified institutional policies: developing general national strategies that include all educational institutions (public and private universities and institutes) without discrimination, given the similarity of challenges between them;

(v) Encouraging scientific research: supporting and disseminating research related to green chemistry while stimulating cooperation between different disciplines to expand the scope of knowledge and application;

(vi) Spreading a culture of sustainability: enhancing environmental awareness among students and faculty members through academic and student activities, and linking them to daily practices in laboratories;

(vii) The results confirm the need for a unified national strategy for implementing green chemistry in Libyan higher education;

(viii) Focusing on enhancing training and providing alternative resources will be more effective than trying to address differences between institutions;

(ix) Policies and procedures supporting the implementation of green chemistry should be directed at all educational institutions in general, without singling out the type of institution as a major factor;

(x) The need to develop joint training programs to enhance practical understanding of the principles of green chemistry;

(xi) The importance of formulating integrated educational policies that ensure equity in disseminating environmental knowledge among all disciplines;

(xii) The need for more comparative studies to determine the nature of the differences between specializations and explain them in more depth.

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