

Research Article

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Science Teachers' Practice of Green Chemistry Principles and Its Relationship to Their Awareness of Safe Laboratory Activity Methods

Ensaf Khatatbeh , Waleed Nawafleh 

Abstract

Background/purpose. This study aimed to investigate the extent to which science teachers apply green chemistry principles and how this relates to their understanding of safe laboratory practices.

Materials/methods. Two instruments were developed and validated. The first, a 35-item scale covering ten green chemistry principles, measured teachers' practice from the perspective of 400 of their students. The second, a 35-item test spanning six safety practices, assessed teachers' awareness of safe laboratory methods and was administered to a random sample of 80 science teachers in Koura District schools during the second semester of the 2024/2025 academic year.

Results. The results showed that teachers were very effective at applying green chemistry principles, with all areas rated "high." These areas included using the least amount of material needed, starting safely, using catalysts, designing safe chemicals, using safe solvents, focusing on energy efficiency, preventing accidents, analyzing in real time to avoid pollution, reducing unnecessary byproducts, and making biodegradable materials. In comparison, teachers' awareness of safe laboratory practices was moderate. However, there was a strong positive link between how well teachers applied green chemistry principles and their awareness of safe lab practices. By contrast, teachers' overall awareness of safe laboratory practices was moderate. A positive, statistically significant correlation ($\alpha=0.01$) emerged between teachers' practice of green chemistry principles and their awareness of safe laboratory practices.

Conclusion. It can be concluded that the importance of science teachers' practice of green chemistry principles is highlighted through preparing future generations and making the environment safer, in addition to reducing waste that may result from laboratory activities.

1. Introduction

Pollution in all its forms has become one of the most serious problems threatening the sustainability and stability of planet Earth, resulting from rapid economic development and cultural prosperity across various aspects of life, including the transformation of raw materials into natural and manufactured goods. This transformation process produces waste and residues due to the incomplete conversion of inputs into products. Therefore, there is an urgent need to find sustainable solutions to reduce pollution, especially that resulting from chemical industries, and to replace them with safer materials by enhancing research activity by researchers and specialists.

At the beginning of the last decade of the twentieth century, the Environmental Protection Agency, led by scientist Instas, developed the concept of green chemistry. This concept emerged in response to environmental and health damage from traditional industrial and chemical processes, the excessive use of chemicals, and the manufacture of chemical products that minimize negative impacts on the environment and humans. (Beach et al., 2009).

The teacher is the cornerstone of the teaching-learning process. He or she bears the greatest responsibility for providing students with the latest scientific facts, theories, and laws, and for shaping students' attitudes toward adapting to modern changes and developments. This requires activating the teacher's role in achieving educational goals and mastering the teaching skills necessary for the teaching process, which help them perform their work effectively (Saleem, 2008).

Since modern science education relies on the principles of constructivist theory, which is based on the use of inquiry and open learning strategies that aim to achieve meaningful learning, and since knowledge construction is the result of social interactions between learners, science laboratory activities are the ideal tool for achieving these educational trends and an effective means of exploring the nature of science and liberating it through students' beliefs and convictions, as they are affected by how they carry out laboratory activities, their attitudes towards laboratory work, and the extent of their interaction with their fellow students during implementation (Zaytoun, 2010). The laboratory and its associated activities are essential elements that effectively contribute to achieving the goals and success of science curricula. Developing laboratory work skills among students is an essential goal of science education across educational levels, given its pivotal role in enhancing scientific understanding and fostering practical and investigative thinking (Shraifin, 2006).

Laboratory activities play an effective role in enhancing the attitudes of both teachers and students towards the educational level, and also contribute to developing social communication through teamwork, exchanging ideas, and interaction between students and teachers. They also develop attitudes and support students' intellectual progress, in addition to having an effective impact on the development of basic and integrated science process skills (Al Khataeb, 2011). They help students build abstract concepts that are difficult to understand theoretically (Andromeda et al., 2016). Despite the benefits of laboratory activities for science teachers and their students, science teachers face many risks and challenges in implementing chemical experiments and laboratory activities. These include neglecting to maintain laboratory equipment and devices, failing to ensure the validity of materials and the quantities used during laboratory activities and chemical experiments (Technical and Vocational Training Corporation, 2008), and limited laboratory equipment and facilities (Listyarini et al., 2019).

Laboratory activities generate a variety of wastes that cannot be disposed of without awareness of their risks to humans and the environment (Al-Khalili et al., 1996). In addition, improper disposal of chemical waste can lead to environmental pollution (Redhana & Merta, 2017). Science teachers must follow safe laboratory practices, including methods for storing and handling chemicals, as well as general rules for storing materials. This is necessary to reduce the risks they may face in the

laboratory, such as fires, electrical shocks, broken glass, and other hazards. This is necessary to ensure high-quality educational outcomes in a safe environment (Khatatbeh, 2011).

To raise science teachers' awareness of the negative effects of laboratory activities—and consequently encourage the adoption of safe practices that minimize these effects—it is necessary to explore a modern approach that focuses on reducing the risks and chemical waste generated by laboratory work. One such approach is the practice of green chemistry principles, which effectively help protect the environment and enhance sustainability by providing scientific and technological solutions to many environmental challenges.

Manahan (2006: 26) defined green chemistry as: “the practice of chemical science and manufacturing in a safe, sustainable, and non-polluting manner, using minimal materials and energy to produce little or no waste.” Al-Shahari (2019) also stated two primary goals of green chemistry: reducing negative environmental impacts and protecting the environment from potential environmental damage caused by industrial and technological progress.

Green chemistry aims to prepare future generations, make the environment safer and more secure for their health, highlight the benefits of its application to both the environment and society (Günter & Alpat, 2017), direct the study of green chemistry towards sustainable and healthy practices, develop technologies to achieve the desired goals of green chemistry to achieve environmental and economic objectives (Shafei, 2021), and promoting sustainable development (Al-Zaghoul, 2023). In addition, it reduces pollution and innovates solutions to eliminate it in advance, utilizes resources effectively as a better alternative to searching for strategies and methods for recycling waste, and uses natural materials while taking into account not harming others (Abu Shabana, 2005).

Cullipher (2015). Mille, 2012; Shaker, 2009) outline a set of principles upon which green chemistry is based:

- Pollution prevention: Preventing the formation of waste and chemical residues during industrial processes is more effective than treating them after they are formed.
- Atomic economy: Chemical reactions are designed to ensure the combination of the largest possible number of reactants to form the desired end products and minimize the appearance of byproducts.
- Production of highly safe chemicals to achieve chemical results with maximum efficiency, minimal loss, and minimal waste. Designing chemical reactions requires safe technologies that reduce the risks associated with reactants, intermediates, and final products.
- Use of safe solvents: These should be chosen to be harmless and biodegradable. To reduce energy consumption, it is preferable to design chemical reactions to occur under moderate conditions and to rationalize energy consumption to achieve economic efficiency.
- Use of renewable raw materials: This enhances industrial feasibility and environmental sustainability.
- Avoiding byproducts: These are unwanted surplus byproducts resulting from unnecessary chemical or physical processes. These processes require additional catalysts.
- Using catalysts: Preferably natural and recyclable.
- Biodegradable design: Chemical compounds should be designed to decompose after their functional life has ended, reducing their accumulation in the environment.
- Real-time pollution prevention: Chemical analysis techniques should be developed to enable direct and continuous monitoring of reactions, allowing for precise control of operational conditions.

- Safe chemistry to prevent accidents: Chemicals should be selected based on their structural and physical properties to reduce the potential for hazardous reactions or leaks that could lead to industrial accidents.

- Conducting less hazardous chemical reactions: It focuses on green chemical design, intending to produce chemicals that have minimal negative environmental impacts.

- Improving energy efficiency: Energy consumption in chemical processes can be reduced by limiting production and its impact on humans and the environment.

Perhaps introducing green chemistry and its principles into education enhances students' understanding of chemical concepts by employing them in environmental and societal contexts. It helps link chemistry to multiple scientific fields and daily life, supports the development of technologies necessary to achieve sustainable development goals, and enhances chemistry's pivotal role in building a more sustainable future by preparing generations capable of effectively contributing to this achievement (Abu al-Wafa, 2018). Green chemistry education has emerged in response to shortcomings in traditional chemistry education, seeking to develop learners' skills and enhance their behaviors. Despite the importance of this approach, interest in its topics remains limited (Koulougliotis et al., 2021).

When examining the aforementioned principles of green chemistry, we find that they are closely related to the safe practices that teachers should adopt when conducting scientific activities and experiments to minimize the risks posed by chemical substances and environmental pollution. A teacher's understanding of green chemistry principles may help them follow safe practices during laboratory experiments. Similarly, science teachers' awareness of safe laboratory procedures and their knowledge of the risks and hazardous waste associated with laboratory work may be reflected in their behavior and spontaneous application of green chemistry principles. Therefore, this study aims to investigate whether there is a correlation between science teachers' practice of green chemistry principles and their awareness of safe practices during scientific activities and experiments, with the goal of leveraging this relationship in the educational process, especially given the environmental pollution caused by improper chemical handling.

1.1. The Study Problem

With advances in chemistry, humans began producing numerous chemical compounds not found in nature. Most of these compounds entered the environment at high concentrations or in inappropriate forms, leading to their accumulation in the tissues of living organisms and causing damage that could even result in the extinction of some species (Salama, 2009).

Learners can only understand environmental issues by increasing their environmental awareness. This awareness can be enhanced through social media, television, and the family. Perhaps the most important source of environmental awareness is the school, where teachers play a vital role in shaping students' understanding. Therefore, there is an urgent need to prepare teachers capable of raising students' awareness and providing them with skills that enhance their understanding of environmental issues and problems resulting from human interaction with the environment. Perhaps the principles of green chemistry represent a realistic solution to these environmental problems. A teacher who practices the principles of green chemistry is expected to be more aware and cognizant of safe methods during laboratory activities, and this is reflected in students' practices, behaviors, and awareness.

Given the scarcity of previous studies in Arab environments that directly investigated the practice of science teachers of green chemistry principles in the teaching process and its relationship to the practice of safe methods in laboratory work, and in light of what some studies recommended regarding the necessity of paying attention to the topics of learning environments and laboratory

work, such as the study of Al-Omari and Nawafleh (2011), this study came to keep pace with global trends and aimed to study the correlation between the practice of science teachers in the schools of the Koura District Education of the principles of green chemistry and their awareness of safe methods for laboratory activities. The study problem was represented by the following questions:

Question 1: To what extent do science teachers in Koura District Education schools practice green chemistry principles in their teaching, from the perspective of their students?

Question 2: To what extent are science teachers in Koura District Education schools aware of safe laboratory methods?

Question 3: Is there a correlation between science teachers' practice of green chemistry principles and their awareness of safe laboratory methods?

1.2. Significance of the Study

The significance of the study emerges from both theoretical and practical perspectives, as follows:

The theoretical significance of the study stems from its response to contemporary trends and the important role of green chemistry principles in guiding science teachers' teaching practices. Such principles aim to teach environmental concepts to students and enable teachers to scrutinize their teaching activities and practices, and to address scientific and technological developments related to environmental concepts, so that these are reflected in their students' learning of environmental concepts, which may sometimes be characterized by difficulty and abstraction compared to other concepts. Also, studying teachers' practices stems from the principles of green chemistry. It links them to safe methods for laboratory activities, which may contribute to developing or rebuilding science curricula, teaching methods, and evaluating methods in line with modern global trends in addition to what this study provides in terms of framing the subject of the study by presenting the theoretical educational literature on the concept of green chemistry, its principles, characteristics, and its impact on the educational process, and the concept of laboratory activities, and enriching Arab and Jordanian libraries with the importance of green chemistry principles and their effectiveness in improving the teaching practices of science teachers and their awareness of safe methods for laboratory activities.

The practical significance of this study lies in its ability to utilize the procedures and tools developed for this study. The results can be useful to science teachers, decision-makers, and those interested in education as they explore the relationship between science teachers' practice of green chemistry principles and their awareness of safe laboratory methods. It is hoped that the study results will encourage science teachers to incorporate green chemistry principles into their teaching practices. They may also benefit educational supervisors and the educational system by offering courses for science teachers and training them in green chemistry principles for their teaching practices, thereby improving their awareness of safe laboratory methods. It is hoped that the study will serve as a starting point for future studies on the topic.

1.3. Study limitations and Delimitations

The generalizability of the study's results is limited to the green chemistry principles employed and the dimensions of the Safe Methods for Laboratory Activities tool. The study was also limited to science teachers in the Koura Education Directorate and their students during the second semester (2024/2025). The generalizability of the study's results is determined by the validity and reliability of the instruments used to collect data, as well as the accuracy of the sample members' responses to the instrument items.

1.4. Terminological and Procedural Definitions:

- Science Teachers: Refers to teachers specialized in teaching science curricula in its four branches (physics, chemistry, biology, and earth sciences) who teach ninth grade and above.
- Practice: Defined by Al Sayed et al. (2021, p. 489) as “a term used to denote any voluntary activity through which an individual seeks to achieve tangible results.”
- Principles of Green Chemistry: Defined by Al-Shahari (2019, p. 233) as “a set of techniques and principles aimed at minimizing or eliminating the use or production of hazardous materials and ensuring the safe disposal of solid and liquid waste and gaseous emissions at their source. Its philosophy is based on replacing harmful substances with organic materials that are harmless or less harmful to the environment and less energy-consuming whenever possible.”
- Operationally, science teachers’ practice of green chemistry principles is defined as the extent to which science teachers in the Koura Directorate of Education, from their students’ perspectives, apply a set of techniques and principles aimed at reducing the use or production of hazardous substances and ensuring the safe disposal of waste in all forms, in order to preserve and sustain the environment. It was measured by the score each science teacher obtained from evaluating five high-achieving students, using a scale developed specifically to assess science teachers’ practice of green chemistry principles.
- Awareness: Defined by the American Psychological Association (2018) as “the perception or knowledge of something; the state or ability of being aware, having direct cognition, perception, or sensing of events.” Shahatah and Al-Najjar (2003) defined it as an individual’s ability to perceive specific things and situations and to possess broad, comprehensive knowledge across various fields.
- Laboratory Activities: Defined by Zaytoun (2000) as a set of activities used to achieve the aims and objectives of science teaching, implemented through the handling of materials, tools, and equipment to collect data through observation.
- Safe Practices: Defined by Al-Jabali (2006) as an integrated system of procedures, rules, and legislative regulations designed to preserve equipment from loss or damage and to protect humans from hazards.
- Operationally, awareness of safe laboratory practices is defined as the set of procedures and rules followed by science teachers in the Koura Directorate of Education aimed at preventing risks during laboratory activities and preserving laboratory property and equipment. It was measured by each teacher's score on a test designed for this purpose. These procedures were classified into the following dimensions:
 - Isolation: Physical separation and protection measures to limit the spread of hazards such as dangerous chemicals or fires. This includes using chemical-resistant cabinets, isolating hazardous areas during emergencies to prevent escalation, isolating light- or heat-sensitive materials, separating fire from oxygen, and keeping materials away from moisture.
 - Disposal: A set of procedures used by the science teacher to safely dispose of unwanted reaction residues, including liquids, gases, and solids, in environmentally safe ways.
 - Destruction: Procedures used by the science teacher to safely eliminate expired chemicals in ways that do not harm the environment.
 - Prevention: A set of procedures and behaviors carried out by the science teacher before and during laboratory experiments to avoid risks associated with materials and laboratory equipment before they occur.

- Protection: Precautionary measures taken by the science teacher to avoid exposure to danger or the effects of chemicals.
- Crisis Management: A set of practical procedures the teacher must follow to deal with expected and unexpected incidents in the laboratory—such as fires, chemical spills, or explosions—in order to minimize damage and restore normal conditions as quickly as possible. This process requires prior planning, effective response, and post-crisis recovery.

2. Literature Review

A review of previous studies on the principles of green chemistry reveals that some examined science teachers' attitudes toward the application and practice of green chemistry; others addressed the impact of teaching it on students' and teachers' attitudes toward chemistry; and still others examined various variables. On the other hand, some studies have addressed general laboratory safety procedures. Ali (2013) aimed to determine the level of understanding of science teachers' awareness of laboratory safety and security rules. The laboratory safety and security test was applied to a sample of 170 male and female teachers from Algerian schools. The results showed that science teachers' knowledge of laboratory safety and security rules did not reach the desired level, and was even lower when dealing with experiments within their specialization.

Seid et al. (2022) conducted a study aimed at identifying perceptions and practices shifting towards evaluating laboratory activities and identifying the factors influencing their implementation. The study was conducted with a sample of 400 students and 16 teachers from the North Wollo area, selected through a stratified random sampling method. To achieve the objectives of the study, questionnaires, observations, and interviews were used to collect data from the study sample. The results showed that both teachers and students are aware of the importance of laboratory activities for student learning, yet their implementation is very low. The factors affecting the implementation of laboratory activities were also identified, including a lack of equipment in the school laboratory, limited time, and low student participation.

Jusniar et al. (2023) aimed to describe the green chemistry principles that can be integrated into chemistry instruction for grades 10 and 11, as well as to describe the perceptions and understanding of green chemistry principles among science teachers and their students. The study was conducted on a sample of 230 students and 40 chemistry teachers in South Solwezi. To achieve the study's objectives, the researchers used a questionnaire to elicit perceptions and conducted interviews with teachers and students to assess their understanding of green chemistry. The study results showed that green chemistry principles can be integrated into chemistry instruction in general and that teachers have a good appreciation for green chemistry principles.

Cannon et al. (2023) sought to understand the impact of teaching green chemistry in high schools on students' and teachers' perceptions and attitudes toward chemistry. The study sample consisted of 244 teachers in New York State who were trained in the principles and practices of green chemistry through a professional development program held for high school teachers. The results showed that the trained teachers applied the skills acquired from the program and shared them with parents, administrators, and fellow teachers. The results also indicated that the professional development program used was effective in promoting the implementation of green chemistry in classrooms.

The study by Zafer and Abdul Rab (2023) aimed to determine the effectiveness of an educational program based on the principles and applications of green chemistry in developing awareness of renewable resources among third-year secondary school students in the city of Ibb. The study employed a descriptive approach to develop the educational program and a quasi-experimental design for a single group. The study sample consisted of 35 third-year secondary school students. To achieve the study objectives, a list of green chemistry principles was prepared. Based on this, the

educational program was developed using the global model. To collect study data, a knowledge test on renewable resources and an attitude scale towards renewable resources were administered to the study group. The study results showed statistically significant differences between the average scores of the study group in the pre- and post-tests of the knowledge test on renewable resources and the scale of attitudes towards renewable resources, in favor of the post-test. Furthermore, there was a direct correlation between the scores of the study groups in the post-test of the knowledge test on resources.

Jack and Shidawa (2024) focused on determining the attitude of chemistry teachers towards green chemistry. The study was applied to 70 chemistry teachers selected from chemistry teachers working in public and private secondary schools in Jalingo. To achieve the objectives of the study, the Teachers' Attitudes towards Green Chemistry Scale (TAGCS) was used. The results showed that chemistry teachers have a positive attitude towards green chemistry, and they are ready to achieve sustainable development of the environment. The results of the study also revealed that chemistry teachers with a master's degree or higher and with five years of experience in teaching chemistry or more had higher average attitudes towards green chemistry.

Al-Rasheed's study (2024) sought to develop sustainable environmental awareness across its three dimensions (cognitive, skill-based, and affective) among female middle school students in Riyadh through an educational unit grounded in the principles of green chemistry. The study was conducted with a sample of 26 female students selected from the third middle grade at a government school. To achieve the study's objectives, the researcher prepared a test to measure sustainable environmental awareness in its two dimensions (cognitive and skill-based). The researcher also used the environmental awareness scale in its affective dimension. The study results demonstrated the effectiveness of the proposed unit in developing environmental awareness in its three dimensions (cognitive, skill-based, and affective).

Baskaran et al. (2024) aimed to reveal elementary science teachers' awareness of the importance of science laboratory management. To achieve the study's objectives, the researchers developed a questionnaire to collect data, which was administered to a sample of 116 teachers in the Manjong area. The results showed that science teachers had a high level of understanding and knowledge in all areas. The highest level was in the first domain, teachers' awareness of maintenance and purchasing, and the lowest average was in handling chemicals.

Faghihi's study (2018) sought to reveal the level of awareness of general safety procedures followed in school laboratories among pre-service science teachers at Najran University. A 43-item scale was administered to a sample of 49 students. The results showed that awareness of general laboratory safety procedures was low, with statistically significant differences in awareness attributable to specialization and grade.

By reviewing previous studies related to the subject of the study, which were conducted in various educational contexts, researchers' interest in studying the use of green chemistry in the educational process, how teachers and students practice it, and its impact on many variables became clear. On the other hand, some studies examined science teachers' awareness of general safety procedures in school laboratories and of the importance of laboratory management. The studies differed in their instruments, populations, samples, and methodologies. Some previous studies aligned with the current study in addressing green chemistry and its principles, while others focused on safe methods for laboratory activities. This study supports the results of previous studies and complements them by emphasizing the need to keep pace with developments in a safe and environmentally sustainable manner, and by highlighting the necessity of studying science teachers' practice of green chemistry and its principles. However, this study differs from other studies in that

it examines the correlation between science teachers' practice of green chemistry principles and their awareness of safe laboratory methods, a gap that previous studies did not address.

3. Methodology

3.1. Research Method

This study employed the descriptive correlational method. The descriptive aspect involved describing the extent to which science teachers practice the principles of green chemistry from their students' perspectives, as well as describing their level of awareness of safe laboratory practices. The correlational aspect aimed to identify the relationship between science teachers' practice of green chemistry principles, as perceived by their students, and their awareness of safe laboratory practices.

3.2. Participants

The first study population consisted of all male and female teachers in the schools of the Koura District Education Directorate, totaling 193 teachers, according to the Koura District Education Directorate's records. These included 87 male teachers and 106 female teachers. The second study population comprised all students in the schools of the Koura District Education Directorate, totaling 32,172 male and female students, according to records from the Koura District Education Directorate. These included 15,621 male students and 16,551 female students.

The first study sample consisted of 80 science teachers (40 males and 40 females) who taught ninth grade and above, representing 41% of the total teacher population. They were selected using the stratified random sampling method from schools affiliated with the Directorate of Education in the Koura District, taking into account the variables of gender and teaching experience. Teachers with more than five years of teaching experience were included.

The second study sample consisted of 400 students (male and female) taught by those science teachers from the ninth grade and above. The students were randomly selected from among high-achieving students to ensure their proper understanding of the scale, with five students assigned to evaluate each teacher.

3.3. Study tools

3.3.1. Scale of Science Teachers' Practice of Green Chemistry Principles

The scale for measuring science teachers' practice of green chemistry principles was developed by referencing previous related studies, including Zafer & Abdul Rab (2023) and Al-Rasheed (2024). The scale, in its initial form, consisted of (42) items distributed over (12) dimensions, with a different number of items for each dimension. (starting from a safe starting point, using the least amount of materials to achieve the desired result, using catalysts, designing safe chemicals, using safe solvents, designing for energy efficiency, using accident-preventing chemistry, real-time analysis to prevent pollution, reducing derivatives, creating biodegradable materials, using renewable materials, and reducing the risk of chemical synthesis processes.

Validity of the Scale

The content validity of the scale of science teachers' practice of green chemistry principles was verified by presenting its initial form to 12 judges with expertise and experience from among the faculty members in the field of science curricula and teaching methods in a number of Jordanian universities, several science teachers and educational supervisors in the Ministry of Education, and several experts in measurement and evaluation, with the aim of expressing their opinions on measuring the dimensions and paragraphs of the principles of green chemistry and their clarity, and writing their notes on the soundness of its formulation and its adherence to the rules for formulating paragraphs of psychological and educational scales. All their suggestions were taken into

consideration, as two of the main dimensions were deleted, namely the use of renewable materials and reducing the risk of chemical synthesis processes, and some paragraphs were modified to be clearer, and a number of paragraphs similar to other paragraphs in their content and substance were deleted, or there was a lack of accuracy in their formulation, so that the scale in its final form became composed of 35 items, distributed over ten principles, which are starting from a safe starting point (prevention policy) and using the least amount of materials to obtain the result. Required: Use of catalysts, design of safe chemicals (products), use of safe solvents, design for energy efficiency, use of accident-preventing chemistry, real-time analysis to prevent pollution, reduction of byproducts, and creation of biodegradable materials.

The scale was applied to a pilot sample drawn from within the study community and from outside the study population, comprising 57 male and female students in schools under the Koura District Education Directorate. Correlation coefficients were calculated for each item with its dimension and with the overall scale. The values of the corrected correlation coefficients for the item's correlation with the dimension to which it belongs ranged between 0.34 and 0.86, and the values of the corrected correlation coefficients for the item's correlation with the total scale score ranged between 0.32 and 0.87. All of these are statistically significant and acceptable indicators of the construct validity of the Green Chemistry Principles Practice Scale for Science Teachers, as indicated by Awda (2014).

Reliability of scale

To verify the reliability of the scale, the questionnaire was administered to the survey sample (students) and re-administered two weeks later. Pearson correlation coefficients were calculated between scores on each dimension of the scale for both applications and for the combined scale. Internal consistency reliability coefficients were also calculated using Cronbach's alpha equation. It was found that the internal consistency reliability coefficients for the scale dimensions ranged from 0.78 to 0.91, and for the combined scale items, they reached 0.94. These values are appropriate and acceptable for the current study. The retest reliability coefficients for the scale dimensions ranged from 0.75 to 0.89, and for the combined scale items, they reached 0.89. These values are appropriate and acceptable for the purposes of the current study, as indicated by Awda (2014).

The scale items were responded to according to a five-point Likert scale, where the response "always" was given a score of (5), the response "often" was given a score of (4), the response "sometimes" was given a score of (3), the response "rarely" was given a score of (2), and the response "never" was given a score of (1). To assess the degree of science teachers' practice of green chemistry principles, as well as to assess the score of each dimension of the scale and each of its items, the following statistical standard was adopted: 1.00 - less than 1.80 (very low), 1.80 - less than 2.60 (low), 2.60 - less than 3.40 (medium), 3.40 - less than 4.20 (high), and 4.20 - 5.00 (very high).

3.3.2. Testing Science Teachers' Awareness of Safe Laboratory Methods

The science teachers' awareness test of safe laboratory methods was developed based on theoretical literature on safe laboratory methods, including Shaheen (2006), Khataibah (2011), and Zaytoun (2000). The test, in its initial form, consisted of 30 items divided into six methods: isolation, disposal, destruction, prevention, protection, and crisis management.

Validity of the test

The content validity of the science teachers' awareness test of safe laboratory methods was verified by presenting its initial form to (12) judges with expertise and experience from faculty members specializing in science curricula and teaching methods in a number of Jordanian universities, a number of science teachers and educational supervisors in the Ministry of Education, and a number of experts in measurement and evaluation, they were asked to express their opinions

about measuring the paragraphs for safe methods for laboratory activities, and their clarity, and to write their notes on the soundness of their formulation, and their compliance with the rules for formulating multiple-choice test items, as all their suggestions were taken into consideration, most of which revolved around deleting some paragraphs and modifying the linguistic formulation of some items to be clearer, and the researchers made the necessary amendments and approved the test to appear in its final form consisting of 25 multiple-choice items, each item having four alternatives, distributed over six methods, as follows: (isolation (3), exchange (3), destruction (3), prevention (6), protection (4), and crisis management (6).

Reliability of the test

To verify the test's reliability, it was administered to a survey sample of 15 teachers. And re-administered two weeks later. Pearson's correlation coefficients were calculated between the scores on each method for both applications and for the combined methods. Internal consistency reliability coefficients were also calculated using Cronbach's alpha equation. It was found that the internal consistency reliability coefficients for the test methods ranged between 0.76 and 0.85, and for the combined test items, they reached 0.90. These values are appropriate and acceptable for the purposes of the current study. The retest reliability coefficients for the test methods ranged between 0.73 and 0.81, and for the combined test items, they reached 0.86. These values are appropriate and acceptable for the purposes of the current study.

The test items were scored with 1 mark for a correct answer and 0 for an incorrect answer. Thus, the teachers' total marks on the test ranged from 0 to 25. To assess the degree of science teachers' awareness of each of the safe laboratory activity methods and their combined awareness, the statistical criterion was adopted after converting the arithmetic averages of the teachers' marks for each method into a percentage, due to the difference in the number of items in each dimension as follows: less than 50% (low), 50.00% to less than 75.00% (medium), and 75.00% to 100.00% (high).

3.4. Study variables

The current study included the following variables:

- Science teachers' practice of green chemistry principles, both individually and collectively.
- Science teachers' awareness of safe laboratory methods, both individually and collectively.

3.5. Data collection

To collect study data, the Awareness of Safe Laboratory Practices Test was administered to a sample of 80 science teachers who taught grades 9 and above. Additionally, the Science Teachers' Practice of Green Chemistry Principles Scale was administered to the teachers' students to evaluate their respective teachers.

Students completed the scale in the absence of their teachers, and each group of five students was asked to assess their science teacher anonymously, without writing their names. Each teacher was assigned a unique identification number, which students were instructed to record on the scale. The extent to which each teacher practiced the principles of green chemistry was determined by averaging their students' ratings.

3.6. Study Procedures

The study procedures were implemented according to the following steps:

- Defining the study problem and related questions.
- Reviewing previous educational literature and previous studies related to the study topic.
- Preparing and developing the study tools in their initial form.

- Verifying the validity and reliability of the study tools and producing them in their final form.
- Defining the study population in which the study was conducted, represented by male and female science teachers and their students.
- Selecting the study sample from the study population, represented by several male and female science teachers and a number of their students.
- Obtaining research ethics approval to conduct the study, and obtaining a letter facilitating the task from the Deanship of the College of Education at Yarmouk University to the Directorate of Education for the Koura District.
- Applying the awareness test of safe methods for laboratory activities to a sample of teachers, and applying the scale of science teachers' practice of chemistry principles to student teachers to evaluate their practice.
- Correcting tools and performing statistical processing of data
- Discussing the results and drawing recommendations.

3.7. Data Analysis

The following statistical methods were used to answer the study questions:

- To answer the first question: Means and standard deviations were calculated for students' ratings of their teachers on each dimension of the scale measuring science teachers' implementation of green chemistry principles, as well as for each item and the scale as a whole.
- To answer the second question: Means and standard deviations were calculated for the study sample's performance (teachers) on the items of the test related to science teachers' awareness of safe practices in laboratory activities.
- To answer the third question: A Pearson correlation matrix was calculated between the students' responses on each dimension of the scale measuring science teachers' implementation of green chemistry principles and the overall score, and the science teachers' scores on each dimension of the awareness test of safe laboratory practices and the overall score. This test was conducted after verifying the assumptions of the correlation test between the two variables: a linear relationship, normal distributions, both variables quantitative, and no extreme values.

4. Results

4.1. Result related to the first question:

The first research question stated: "To what extent do science teachers in the schools of the Koura District Directorate of Education implement the principles of green chemistry in the teaching process from their students' perspectives?" To answer this question, means and standard deviations were calculated for the study sample's responses (students) on each dimension of the scale measuring science teachers' implementation of green chemistry principles. These dimensions include real-time analysis to prevent pollution, starting from a safe base guided by prevention policies, and the use of safe solvents and chemicals to minimize harm. Additionally, creating biodegradable materials and reducing the use of derivatives are essential aspects. Practitioners also emphasize using the minimum amount of materials necessary to achieve desired results, employing catalysts to improve efficiency, designing processes for energy conservation, and applying accident-preventing chemistry to enhance safety. Together, these principles contribute to more sustainable and safer chemical practices. Means and standard deviations were also calculated for the total score across all dimensions. Table 1 presents these results.

Table 1. Descriptive Statistics for Green Chemistry Principles by Dimension and Overall

No.	Dimension	Rank	Mean	Standard Deviation	Level of Practice
8	Real-time analysis to prevent pollution	1	3.29	1.04	Moderate
1	Starting from a safe starting point (prevention policy)	2	3.22	0.97	Moderate
5	Using safe solvents	3	3.01	0.97	Moderate
4	Designing safe chemicals (products)	4	2.97	0.88	Moderate
10	Creating biodegradable materials	5	2.96	1.09	Moderate
9	Reducing derivatives	6	2.95	0.98	Moderate
2	Using the minimum amount of materials to achieve the desired result	7	2.92	0.96	Moderate
3	Using catalysts	8	2.90	1.04	Moderate
6	Designing for energy efficiency	9	2.88	0.99	Moderate
7	Using accident-preventing chemistry	10	2.83	0.95	Moderate
	Overall score		2.99	0.78	Moderate

Table 1 shows that science teachers practice green chemistry principles at a moderate level, with an overall mean of 2.99 and a standard deviation of 0.78. All dimensions of the scale were rated as moderate, in the following order: real-time analysis to prevent pollution, starting from a safe starting point (prevention policy), using safe solvents, designing safe chemicals (products), creating biodegradable materials, reducing derivatives, using the minimum amount of materials to achieve the desired result, using catalysts, designing for energy efficiency, and using accident-preventing chemistry.

4.2. Result related to the Second question

The second question stated: "What is the level of science teachers' awareness of safe practices for laboratory activities in the schools of the Koura District Directorate of Education?" To answer this question, means and standard deviations were calculated for the study sample's performance on the test items related to science teachers' awareness of safe laboratory practices.

Table 2. Means and Standard Deviations of the Science Teachers' Lab Safety Awareness Scores

No.	Practices	Number Of items	Rank	Mean	Standard Deviation	Percentage of the Mean Score (%)	Level of Awareness
3	Destruction	6	1	2.01	0.89	67.00	Moderate
5	Protection	3	2	2.63	1.04	65.75	Moderate
6	Crisis Management	3	3	3.85	1.55	64.17	Moderate
2	Disposal	4	4	1.85	0.84	61.67	Moderate
4	Prevention	3	5	3.05	1.29	50.83	Moderate
1	Isolation	6	6	1.30	0.82	43.33	Low
	Overall score	25		14.69	3.87	58.75	Moderate

* The maximum attainable score for the entire test was 25, allocated across the dimensions as follows: Isolation (3), Disposal (3), Destruction (3), Prevention (6), Protection (4), and Crisis Management (6).

** Percentage of the Mean Score = Mean of dimension \times Highest score on dimension/100

Table 2 indicates that science teachers exhibit a moderate level of awareness of safe laboratory practices overall, with a mean score of 14.69 and a standard deviation of 3.87. All dimensions were at a moderate level, while one dimension, "isolation," was at a low level.

4.3. Result related to the third question

The third question stated: "Is there a statistically significant correlation at ($\alpha = 0.05$) between science teachers' practice of green chemistry principles and their awareness of safe practices for laboratory activities in the schools of the Koura District Directorate of Education?"

To answer this question, a Pearson correlation matrix was calculated between the students' evaluations of each dimension of the scale measuring science teachers' practice of green chemistry principles—both individually and as a whole—and the teachers' own evaluations on each dimension of the scale measuring their awareness of safe laboratory practices—both individually and collectively. Table 3 presents the results of this analysis.

Table 3. Pearson Correlation Matrix between Students' Ratings of Teachers' Practice of Green Chemistry Principles and Teachers' Awareness of Safe Laboratory Practices

Dimensions of Practicing Green Chemistry Principles	Dimensions of the Awareness Scale for Safe Laboratory Practices						Overall Awareness of Safe Laboratory Practices
	Isolation	Disposal	Destruction	Prevention	Protection	Crisis Management	
Real-time analysis to prevent pollution	.409**	.379**	.503**	.423**	.347**	.517**	.726**
Starting from a safe starting point (prevention policy)	.336**	0.196	.413**	.468**	.483**	.514**	.700**
Using safe solvents	.298**	.351**	.430**	.359**	.362**	.544**	.673**
Designing safe chemicals (products)	.330**	.335**	.473**	.438**	.489**	.524**	.738**
Creating biodegradable materials	.408**	.269*	.329**	.315**	.450**	.560**	.670**
Reducing derivatives	.393**	.338**	.370**	.518**	.352**	.558**	.732**
Using the minimum amount of materials to achieve the	.395**	.264*	.385**	.397**	.456**	.491**	.680**

desired result							
Using catalysts	.384**	.302**	.365**	.439**	.366**	.498**	.675**
Designing for energy efficiency	.421**	.359**	.466**	.458**	.392**	.525**	.742**
Using accident-preventing chemistry	.298**	.280*	.357**	.327**	.386**	.479**	.610**
Overall Practice of Green Chemistry Principles	.462**	.386**	.514**	.515**	.511**	.651**	.869**

*Statistically significant at $\alpha = 0.05$

**Statistically significant at $\alpha = 0.01$

Table 3 shows a positive and statistically significant correlation at the $\alpha=0.01$ level between science teachers' practice of green chemistry principles and their awareness of safe laboratory practices. The Pearson correlation coefficient was 0.869, indicating that as science teachers' application of green chemistry principles increases, their awareness of safe laboratory practices also increases, and vice versa.

5. Discussion

5.1. Discussion of the first question:

The results of the first question may be attributed to science teachers having an acceptable but still limited awareness of green chemistry principles and a need for greater effort and intensive practical training to enhance their implementation in educational settings. It may also be due to a focus on theoretical knowledge over practical skills, insufficient resources and laboratory equipment, and limited awareness of the importance of sustainable development. The partial implementation of these principles in classrooms may lead to limited student understanding, which negatively affects their ability to apply them effectively. The lack of targeted training programs and teaching materials further hinders the application of green chemistry principles; Cannon et al. (2023) indicated that subjecting teachers to training on these principles is reflected in their teaching practices.

This finding contrasts with the findings of Jack and Shidawa (2024), who reported that chemistry teachers hold a positive—not moderate—attitude toward green chemistry, indicating their readiness and active efforts to achieve environmental sustainability. This result also differs from that of Jusniar et al. (2023), which indicated that science teachers understand the principles of green chemistry.

Table (1) shows that, of all the dimensions measuring science teachers' practice of green chemistry principles from the students' point of view, the least applied was the seventh—using inherently safer chemistry to prevent accidents—recording a mean of 2.83; this highlights the need to choose chemicals according to their physical and chemical properties to reduce the likelihood of incidents such as explosions, toxic gas emissions, or fires, for instance by opting for low energy, low vapor pressure substances (solids or non volatile liquids) rather than volatile liquids or gases that may become hazardous during reactions; this result may stem from teachers' limited scientific and professional experience in handling chemicals and a lax application of general safety rules, a

conclusion that aligns with Fagih's (2018) study, which found low awareness of laboratory safety procedures.

In contrast, the eighth dimension—real-time analysis to prevent pollution—recorded the highest mean score among all principles, at 3.29, indicating it was the most frequently practiced by science teachers. This may be attributed to the fact that such practice represents a pivotal step in preparing students for lessons, as the development of chemical analysis techniques that enable real-time monitoring of reactions allows for early detection of hazardous compound formation and immediate control of reaction conditions.

5.2. Discussion of the second question:

Table 2 suggests that, while teachers possess an acceptable baseline understanding of safety procedures, they still require substantial effort and intensive practical training to enhance their awareness. Contributing factors include limited training opportunities in the use and management of laboratory equipment, insufficient funding for purchasing scientific materials, weak coordination between schools and support agencies in supplying laboratories, and laboratory spaces that are either too small or overcrowded, hindering orderly and safe experimentation. In addition, the scarcity of class periods dedicated to science limits the effective delivery of practical components, so we find that the majority of teachers are not inclined towards laboratory work due to numerous obstacles.

This finding is consistent with the results of Seid et al. (2022), who found that both teachers and students recognize the importance of laboratory activities for student learning. However, despite their significance, the actual practice of such activities remains very limited. The study also highlighted several factors affecting the implementation of laboratory activities, including a lack of equipment in school laboratories, time constraints, and limited student participation in lab-based work. This result is also consistent with Ali's (2013) study, which indicated that science teachers' knowledge of security and safety rules did not meet the required level.

Table 2 also reveals that five of the six safety practices were rated as moderate by science teachers. These, in descending order, were destruction, protection, crisis management, disposal, followed by prevention, with percentage scores ranging from 50.83% to 67.08%. In contrast, only one practice—Isolation—was rated low, with a percentage score of 43.33%.

The emergence of the “disposal” dimension in the first rank, at a moderate level, may be attributed to the Ministry of Education's annual field visits to schools to inspect expired laboratory materials, tools, and equipment for safe disposal. Science teachers are usually part of the disposal committees formed at schools, which has enabled them to gain practical experience in this area.

As for the “isolation” dimension, which ranked last and at a low level among science teachers, this may be attributed to a lack of knowledge resulting from weaknesses in teacher preparation programs. Such programs often fail to emphasize training teachers on general safety precautions that science teachers should be aware of. A science teacher may understand the chemical and physical properties of substances and the potential hazards arising from them, yet may not have received sufficient training on how to handle laboratory equipment, tools, and chemicals, or on proper methods of storage, organization, and maintenance to ensure safety and minimize risks. This lack of training likely led to the teachers' low performance in this dimension.

Additionally, this result may be attributed to limited practical experience in laboratory settings, which restricts teachers' awareness to only basic preventive measures. Furthermore, the lack of institutional support in organizing training workshops reduces the dissemination of the culture of isolation. Consequently, science teachers may prefer simpler alternatives, such as ventilation and the use of personal protective equipment, rather than implementing isolation procedures.

This finding contrasts with the study by Baskaran et al. (2024), which showed that science teachers demonstrated a high level of understanding and knowledge across all domains. In that study, the highest scores were in teachers' awareness of maintenance and procurement, while the lowest were in handling chemicals.

5.3. Discussion of the third question:

This positive relationship can be explained by the fact that green chemistry principles emphasize designing chemical processes and experiments in ways that minimize the use of hazardous substances and reduce toxic impacts on humans and the environment. Accordingly, teachers who apply these principles are naturally more likely to develop a deeper understanding of chemical safety concepts. These concepts are foundational to achieving sustainability in laboratory practices, as adherence to safe procedures reduces chemical waste and minimizes the risk of environmental or health-related incidents.

Applying green chemistry principles in the classroom directly strengthens safe laboratory practices and bolsters both theoretical and practical awareness of chemical hazards and safe handling procedures. The interplay between practice and awareness fosters professional competence in chemical safety. Because science teachers serve as key role models for conveying knowledge and values related to safety and sustainability, their mastery of green chemistry principles and commitment to safe procedures instill these values in their students, thereby increasing students' awareness of environmental safety.

Moreover, science teachers' awareness of safe practices in conducting laboratory activities requires an understanding of scientific concepts, chemical substances, their hazards, and their relationship to the environment and environmental sustainability. It also involves reducing pollution through approaches such as using safe materials, renewable resources, and biodegradable substances—all of which are fundamental principles of green chemistry.

This result is reinforced by Al-Rasheed (2024), who indicated that practicing the principles of green chemistry contributes to the development of sustainable environmental awareness. Similarly, Zafer and Abdul Rub (2023) noted that practicing these principles enhances awareness of renewable resources.

Table 3 also indicates that every individual green chemistry principle practiced by science teachers is positively and significantly correlated with their overall awareness of safe laboratory practices. The lowest significant correlation ($r = 0.610$, $p < 0.01$) was found between the principle of using accident-preventing chemistry and teachers' combined awareness of safe practices. This suggests that designing inherently safer chemicals and processes deepens teachers' understanding of chemical hazards, prompting them to adopt safer laboratory routines irrespective of a substance's intrinsic danger. The most significant correlation ($r = 0.742$, $p < 0.05$) was observed between the principle of designing for energy efficiency and overall awareness of safe practices. This may be because green chemistry protocols that maximize the incorporation of reactants into desired products and minimize side products naturally reinforce teachers' attentiveness to safe laboratory procedures, thereby elevating their overall safety awareness.

Table 3 further shows a positive, statistically significant relationship between science teachers' overall practice of green chemistry principles and each dimension of the awareness scale for safe laboratory practices. The lowest correlation was 0.386 ($p < 0.01$) between teachers' overall practice of green chemistry principles and their awareness of the disposal practice, while the highest correlation was 0.651 ($p < 0.01$) between their overall practice of green chemistry principles and their awareness of crisis management. This pattern may be explained by the fact that implementing green chemistry principles requires regular review of laboratory practices to minimize risks and improve

efficiency; such ongoing reflection prompts teachers to continually refine their laboratory methods, thereby increasing their adherence to safe procedures and strengthening a culture of safety and crisis management in educational settings.

6. Conclusion

Based on the findings of this research regarding the positive relationship between science teachers' practice of green chemistry principles and their awareness of safe laboratory activity techniques, the importance of applying green chemistry principles by science teachers becomes evident through preparing future generations, making the environment safer, and reducing waste that may result from laboratory activities.

Despite the limited sample size and the study's time frame, it is hoped that the findings will benefit educational supervisors and the educational system by informing the organization of training courses for science teachers to incorporate green chemistry principles into their teaching practices, thereby enhancing their awareness of safe laboratory practices.

7. Suggestion and Recommendations

In light of the study's findings, the study recommends the following:

- Design and develop training programs tailored for teachers, based on the principles of green chemistry, to enhance their professional performance and promote effective teaching practices that support the integration of instructional strategies aimed at reinforcing green chemistry principles among learners.

- Encourage curriculum development authorities to incorporate the principles, domains, and practical applications of green chemistry into science curricula across various educational stages, due to their vital role in fostering environmental and scientific concepts and enhancing students' awareness of contemporary environmental issues and challenges.

- Organize workshops and training sessions for teachers to introduce them to safe laboratory practices grounded in green chemistry principles, ensuring meaningful impact on students' behavior and awareness regarding safety and environmental responsibility.

- Conduct future research focusing on green chemistry principles and their effects on other variables such as creative thinking, positive thinking, habits of mind, and concepts of environmental sustainability, in order to broaden the scope of inquiry and deepen understanding in this vital field.

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