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Towards A Greener Cement Industry: Introducing "Green Chemistry" Into Chemistry Education and Laboratory Practices

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A B S T R A C T

The integration of green chemistry principles into the chemistry and laboratory curriculum is essential for fostering sustainable practices among future chemists. The journey towards a greener cement industry starts with education, innovation, and collective action, ensuring a more sustainable and resilient future for generations to come. This study aimed to identify the reality of green chemistry principles application and the potential benefits and challenges of implementing sustainable practices in learning and laboratories. In order to achieve the study objectives a descriptive and analytic approaches were adopted. A Questionnaire was designed and distributed to 54 respondents who are working in 5 cement factories. Results showed that integrating green chemistry into chemistry education and laboratory practices presents immense potential for transforming the cement industry towards sustainability. By embracing the principles of green chemistry, such as waste reduction, safer chemicals, and energy efficiency, the industry can mitigate its environmental impact and contribute to a greener future. However, significant challenges must be addressed, including awareness gaps, financial constraints, and regulatory barriers. It requires collaboration and commitment from educational institutions, industry stakeholders, governments, and researchers to overcome these challenges and drive the adoption of green chemistry practices in the cement industry

نحو صناعة إسمنت أكثر اخضراراً: إدخال "الكيمياء الخضراء" في تعليم الكيمياء وممارسات المعامل

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إن دمج مبادئ الكيمياء الخضراء في مناهج الكيمياء والمعامل ضروري لتعزيز الممارسات المستدامة بين الكيميائيين المستقبليين. يبدأ السعي نحو صناعة الأسمنت الأكثر اخضراراً بالتعليم والابتكار والعمل الجماعي، مما يضمن مستقبلاً أكثر استدامة ومرونة للأجيال القادمة. هدفت هذه الدراسة إلى التعرف على واقع تطبيق مبادئ الكيمياء الخضراء والفوائد والتحديات المحتملة لتنفيذ الممارسات المستدامة في التعلم والمعامل. ولتحقيق أهداف الدراسة، تم اعتماد المنهج الوصفي التحليلي. تم تصميم استبيان وتوزيعها على 54 مشاركاً يعملون في 5 مصانع إسمنت. أظهرت النتائج أن تكامل الكيمياء الخضراء في التعليم وممارسات المعامل يتيح إمكانات هائلة لتحويل صناعة الإسمنت نحو الاستدامة. من خلال تبني مبادئ الكيمياء الخضراء، مثل تقليل النفايات واستخدام المواد الكيميائية الأكثر أماناً وتحقيق كفاءة الطاقة، يمكن للصناعة تقليل تأثيرها البيئي والمساهمة في مستقبل أكثر اخضراراً. ومع ذلك، يجب معالجة التحديات الكبيرة، بما في ذلك الفجوات في الوعي، والقيود المالية، والعقبات التنظيمية. يتطلب ذلك التعاون والالتزام من المؤسسات التعليمية وأصحاب المصلحة في الصناعة والحكومات والباحثين للتغلب على هذه التحديات ودفع اعتماد ممارسات الكيمياء الخضراء في صناعة الإسمنت.

INTRODUCTION

Green chemistry, also known as sustainable chemistry, is a field that aims to design chemical processes and products in a way that minimizes their environmental impact and promotes sustainable practices. It focuses on the development of innovative solutions that are economically viable, socially responsible, and environmentally friendly. By integrating green chemistry principles into various industries, including the field of chemistry, we can strive towards a more sustainable and environmentally conscious future (Warner, 2020).

The principles of green chemistry provide a framework for guiding chemical research and development towards sustainable practices. These principles encompass various aspects of chemical processes, such as the design of safer chemicals, the use of renewable resources, the reduction of waste and energy consumption, and the development of efficient and environmentally benign synthesis methods. By adhering to these principles, chemists can minimize the generation of hazardous substances, mitigate the environmental impact of chemical processes, and promote the development of greener alternatives (Anastas, 2021).

The incorporation of green chemistry principles into the chemistry and laboratory curriculum is crucial for preparing future chemists to address global challenges in a sustainable manner. By educating students about the importance of sustainable practices and providing them with the knowledge and skills to implement green chemistry principles, we can foster a new generation of chemists who are equipped to develop innovative and sustainable solutions to real-world problems (Shri, et. al,, 2016).

This paper aims to explore the potential benefits and challenges of integrating green chemistry principles into the curriculum of chemistry and laboratory courses. By examining existing literature, case studies, and educational initiatives, we will highlight the importance of incorporating green chemistry principles in order to promote sustainable practices among future chemists. Furthermore, we will discuss the role of educators in implementing green chemistry practices and the necessary tools and resources needed to facilitate this integration successfully.

Principles of Green Chemistry:

The principles of green chemistry provide a foundational framework for incorporating sustainable practices into chemical research and development. These principles, initially proposed by Paul Anastas and John Warner in 1998, serve as guidelines for chemists to design and implement environmentally friendly processes and products. The following are the key principles of green chemistry (Anastas, et. al, 1998):

1. **Waste Prevention**: It is better to prevent waste and pollution at the source rather than dealing with them after they are generated. This principle emphasizes the importance of designing chemical processes that minimize the production of hazardous substances and waste.
2. **Atom Economy**: Chemical reactions should be designed to maximize the incorporation of all reactant atoms into the final product. This principle aims to minimize the use of excessive reagents and the generation of byproducts.
3. **Less Hazardous Chemical Synthesis**: The use of hazardous substances in chemical synthesis should be minimized or avoided whenever possible. This principle encourages the development and use of safer and less toxic chemicals.
4. **Designing Safer Chemicals**: Chemical products should be designed to be safe for human health and the environment throughout their lifecycle. This principle promotes the use of substances that are inherently less toxic, biodegradable, and do not persist in the environment.
5. **Safer Solvents and Auxiliaries**: The use of auxiliary substances, such as solvents, should be minimized, and when used, they should be selected to be non-toxic and environmentally friendly. This principle emphasizes the importance of choosing greener alternatives to traditional solvents.
6. **Energy Efficiency**: Chemical processes should be designed to be energy-efficient, minimizing the consumption of energy and reducing greenhouse gas emissions. This principle encourages the use of renewable energy sources and the optimization of reaction conditions to minimize energy requirements.
7. **Use of Renewable Feedstocks**: The utilization of renewable feedstocks is a fundamental principle of green chemistry. It entails integrating renewable, sustainable, and bio-based materials as substitutes for fossil fuel-based resources, thereby reducing reliance on limited and non-renewable resources.
8. **Reduce Derivatives**: The principle of minimizing or eliminating unnecessary derivatives in chemical processes advocates for reducing waste generation and mitigating the environmental impact associated with the synthesis and disposal of derivatives. It emphasizes the importance of streamlining chemical reactions and processes to minimize the use of unnecessary intermediate steps.
9. **Catalysis**: Catalysis plays a crucial role in green chemistry, highlighting the importance of using catalysts to improve the efficiency of chemical reactions. Catalysts enable reactions to take place under gentler conditions, resulting in shorter reaction times and reduced energy and resource consumption.

10. **Design for Degradation**: In line with the principles of green chemistry, there is a focus on designing chemical products that have the ability to undergo easy degradation after use. This approach aims to reduce the environmental impact by minimizing the presence and persistence of these products in the environment. The emphasis is placed on developing products that can decompose into non-toxic substances, highlighting the significance of sustainability and safety.
11. **Real-time Analysis for Pollution Prevention**: The principle of real-time monitoring and control emphasizes the significance of integrating advanced analytical technologies to continuously track and regulate processes. This approach underscores the importance of timely and accurate data acquisition, enabling proactive decision-making and optimization of operations techniques to prevent the formation of hazardous substances during chemical processes. It emphasizes the integration of proactive measures to identify and address potential pollution sources, ensuring the continuous improvement of process safety and environmental impact.
12. **Inherently Safer Chemistry for Accident Prevention**: The principle of inherently safer chemistry prioritizes the development of chemical processes and products that inherently possess safety features, aiming to minimize the potential for accidents and the release of hazardous materials. This principle underscores the early consideration of safety aspects during the design phase, ensuring that safety is integrated throughout the entire lifecycle of the process or product. By incorporating built-in safety features, the risk associated with these chemicals is reduced, promoting a safer and more sustainable approach.

Materials and Methods

In order to achieve the research objectives an analytic-descriptive approach was used. A questionnaire was designed which contains 3 sections (1st section is related to the twelve potential implementation of Green Chemistry principles (Waste Prevention, Atom Economy, Less Hazardous Chemical Syntheses, Designing Safer Chemicals, Safer Solvents and Auxiliaries, Design for Energy Efficiency, Use of Renewable Feedstocks, Reduce Derivatives, Catalysis, Design for Degradation, Real-time Analysis for Pollution Prevention, Inherently Safer Chemistry for Accident Prevention) with 24 items. the 2nd section is related to (The potential benefits of implementing sustainable practices in learning and laboratories) with 5 items, the 3rd section is related to (The potential challenges of implementing sustainable practices in learning and laboratories) with 5 items. A 5 Likert scale was adopted in the questionnaire for respondents as following (5-extremely agreed, 4 agreed, 3 moderate, 2 not agreed, 1 not agreed at all). The questionnaire was distributed to 26 chemistries working in cement factories among 4 factories (Zliten Cement Factory – Elmergeb Cement Factory – Lebda Cement Factory and Souq al-kamis Cement Factory). Table 1 illustrates the research sample.

Table (1): The research sample

No.	Factory	No.	%
1.	Zliten Cement Factory	16	30%
2.	Elmergeb Cement Factory	13	24%
3.	Lebda Cement Factory	14	26%
4.	Souq al-kamis Cement Factory	11	20%
	Total	**54**	**100%**

Due to small size of the sample a comprehensive survey approach has been used. That means 54 questionnaires were distributed to respondents. 51 questionnaires were received and the data were analysed using Statistcal Package for social science (SPSS.Ver.24).

Demographic Characteristics:

The following tables indicate the Demographic Characteristics according to (Gender, Qualification, Years of experience, and Number of courses attended in the sustainable development.

Table (2): Gender of the Resondents

No.	**Gender**	**No.**	**%**
1.	Male	42	82
2.	Female	9	18
	Total	51	100%

Table 1 showed that most of the respondents are males with (82%). While 18% only are females.

Table (3): Qualification

No.	Qualification	No.	%
1.	Doctorial	4	8%
2.	Master	9	18%
3.	Bachelor	28	55%
4.	High Diploma	7	14%
5.	Intermediate Diploma	3	6%
	Total	**51**	**100%**

Table 3 indicated that the majority of respondents (55%) had a Bachelor's degree, indicating a significant completion of undergraduate studies. A smaller but notable portion (18%) held a Master's degree, demonstrating further education and specialization. Only a small proportion (6%) had a diploma, suggesting a lower rate of completion in vocational or technical training programs.

Table (4): Number of training courses, Symposiums, workshops, or congresses regarding the sustainable development,

No.	Courses, Symposiums, workshops, or congresses	No.	%
1.	No courses	36	71%
2.	1 - 3	3	6%
3.	4 - 7	2	4%
4.	8 - 10	4	8%
5.	More than 10	1	2%
	Total	**51**	**100%**

Table 4 revealed that the majority of respondents, comprising 78%, did not attend any courses, symposiums, workshops, or congresses related to sustainable development. A smaller percentage, 8%, attended between 8 and 10 such events, while 6% attended between 1 and 3 events, and 2% attended between 4 and 7 events. The lowest percentage was for respondents who attended more than 10 events.

The Analysis of Questionnaire related questions:
The following tables illustrate the respondents' answers regarding the reality of green chemistry principles application in the chemistry laboratories of the studied cement factories. The potential benefits of implementing sustainable practices in learning and laboratories and the potential challenges of implementing sustainable practices in learning and laboratories were also showed. Arithmetic means, standard deviations, relative importance, and item rankings were calculated.

1. **The reality of green chemistry application:**

Table (5): The reality of green chemistry principles application

No.	Principle	μ	δ	Rank
1.	Waste Prevention	2.47	0.765	4
2.	Atom Economy	2.42	0.684	7
3.	Less Hazardous Chemical Syntheses	3.21	0.812	1
4.	Designing Safer Chemicals	2.77	0.926	2
5.	Safer Solvents and Auxiliaries	2.66	0.710	3
6.	Design for Energy Efficiency	2.44	0.627	5
7.	Use of Renewable Feedstocks	2.36	0.718	8
8.	Reduce Derivatives	2.22	0.576	10
9.	Catalysis	2.29	0.475	9
10	Design for Degradation	1.35	0.612	11
11	Real-time Analysis for Pollution Prevention	1.12	0.819	12
12	Inherently Safer Chemistry for Accident Prevention	2.44	0.618	5
	The General Mean	**2.31**	**0.707**	

The analysis of Table 5 reveals that the overall arithmetic mean for the implementation of all dimensions of green chemistry principles in the studied cement factories was 2.31, with a relative weight of 46%. This indicates that the estimated responses from the study sample generally reflected disagreement, as indicated by the general rating. The standard deviation was measured at 0.707, suggesting a moderate level of variability among the respondents' estimations.
Regarding the specific application of green chemistry dimensions, the researchers' ratings ranged from very weak to moderate. The dimension ranked highest was "Less Hazardous," with an arithmetic average of 3.21 and a moderate rating. Following closely was the dimension of "Designing Safer Chemicals," ranking second with an arithmetic average of 2.77 and a moderate rating. The fifth dimension, "Safer Solvents and Auxiliaries," secured the third position with an arithmetic average of 2.66 and a moderate rating. Conversely, the dimension with the lowest rating was the eleventh one, "Real-time Analysis for Pollution Prevention," with an arithmetic average of 1.12. It received a very weak rating, indicating a significant need for improvement in this area.

2. The potential benefits of implementing sustainable practices in learning and laboratories**:**

Table (6): The potential benefits of implementing sustainable practices in learning and laboratories

No.	Potential benefits	μ	δ	Rank
1.	Reducing the environmental impact of learning and	4.13	0.772	2

	chemical experiments			
2.	Promoting awareness of the importance of sustainability and environmental protection	3.91	0.884	3
3.	Improve laboratory safety and reduce health risks associated with harmful chemicals	3.88	0.752	4
4.	Promoting social responsibility and contributing to a sustainable society	4.23	0.871	1
5.	Providing opportunities for hands-on learning and enhancing a deep understanding of the principles of green chemistry.	3.65	0.902	5
The General Mean		**3.96**	**0.84**	

According to results shown in table 5, the overall average of the potential benefits of implementing sustainable practices in learning and laboratories was (3.96) with a relative weight (79%), which means the estimation by respondents was (agreed), and the standard deviation was (0.840), that means all the answers were very close. The item (Promoting social responsibility and contributing to a sustainable society) was ranked first by an average (4.23), with an estimation (extremely agreed), the item (Reducing the environmental impact of learning and chemical experiments) was the second ranking with an average (4.13) with an estimation of (extremely agreed), while the lowest rank was for the item (Providing opportunities for hands-on learning and enhancing a deep understanding of the principles of green chemistry) with an average (3.65) with an estimation (agreed).

3. The potential challenges of implementing sustainable practices in learning and laboratories**:**

Table (7): The potential challenges of implementing sustainable practices in learning and laboratories

No.	**Potential** challenges	μ	δ	Rank
1.	Lack of financial resources to invest in sustainable technologies and materials.	4.84	0.556	2
2.	Difficulty finding sustainable alternatives to traditional chemicals	3.88	0.681	4
3.	Restrictions of local legislation and regulations related to chemicals	3.66	0.752	5
4.	Lack of awareness and knowledge on sustainable practices and green chemistry	4.87	0.572	1
5.	Challenges of training and qualification of teachers and technicians in the field of green chemistry.	4.68	0.593	3
	The General Mean	**4.38**	**0.630**	

Table 7 presents an analysis of the potential challenges associated with implementing sustainable practices in learning and laboratories. The results indicate that the overall average for this dimension was 4.38, reflecting a high level of agreement. The standard deviation was 0.630, suggesting a moderate level of variability in responses. The item "Lack of awareness and knowledge on sustainable practices and green chemistry" ranked first, with an average of 4.87 and an estimation of "extremely agreed." This indicates a widespread consensus on the challenge of insufficient awareness and knowledge regarding sustainable practices and green chemistry.

The item "Lack of financial resources to invest in sustainable technologies and materials" ranked second, with an average of 4.84 and an estimation of "extremely agreed." This highlights the significant concern regarding the limited availability of financial resources to support the implementation of sustainable technologies and materials.

On the other hand, the item "Restrictions of local legislation and regulations related to chemicals" received the lowest rank, with an average of 3.66 and an estimation of "agreed." This suggests a comparatively lower level of agreement regarding the challenges posed by local legislation and regulations pertaining to chemicals

CONCLUSION

Integrating green chemistry into chemistry education and laboratory practices presents immense potential for transforming the cement industry towards sustainability. By embracing the principles of green chemistry, such as waste reduction, safer chemicals, and energy efficiency, the industry can mitigate its environmental impact and contribute to a greener future. However, significant challenges must be addressed, including awareness gaps, financial constraints, and regulatory barriers. It requires collaboration and commitment from educational institutions, industry stakeholders, governments, and researchers to overcome these challenges and drive the adoption of green chemistry practices in the cement industry.

By fostering a culture of sustainability and equipping future professionals with the knowledge and skills needed for green chemistry, we can pave the way for a greener cement industry that balances economic growth with environmental stewardship.

1. Gender distribution among respondents showed that 82% were male, while only 18% were female.
2. In terms of education, 55% of respondents held a Bachelor's degree, 18% had a Master's degree, and 6% had a diploma.
3. The majority of respondents (78%) did not attend any courses, symposiums, workshops, or congresses related to sustainable development. Only a small percentage attended a varying number of events.
4. The analysis of Table 4 indicated an overall arithmetic mean of 2.31 for the implementation of green chemistry principles in the studied cement factories. The responses reflected disagreement overall, with a moderate level of variability among estimations.
5. Ratings for specific dimensions of green chemistry ranged from very weak to moderate. "Less Hazardous" and "Designing Safer Chemicals" ranked highest, while "Real-time Analysis for Pollution Prevention" received the lowest rating.
6. The overall average for the potential benefits of implementing sustainable practices in learning and laboratories was 3.96, indicating agreement among respondents. The highest-ranked item was "Promoting social responsibility and contributing to a sustainable society."
7. An analysis of potential challenges in implementing sustainable practices, with an overall average of 4.38. The item "Lack of awareness and knowledge on sustainable practices and green chemistry" ranked first, highlighting the challenge of insufficient awareness and knowledge.
8. The item "Lack of financial resources to invest in sustainable technologies and materials" ranked second, emphasizing concerns about limited financial support.
9. The item "Restrictions of local legislation and regulations related to chemicals" received the lowest rank, suggesting a comparatively lower level of agreement regarding challenges posed by local regulations.

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