GREEN CHEMISTRY EDUCATION

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Introduction

Green chemistry can also be referred to as sustainable chemistry and it is the design of chemical products and processes aimed at less or less the use of hazardous substances. It's about lessening the destructive consequences on the environment and the earth's sustainability (Wale et al., 2023; Mane et al., 2023). This accommodates many principles that outline how to design safer chemical reactions as well as technology and the use of green chemicals (De, 2023; Rathi et al., 2023). Such principles include the elimination or reduction of generation, using renewable raw materials, and the production of safer substances and materials to decrease harm to human health and the environment, according to Nithya and Sathish (2023). Thus, green chemistry's goal is to bring radical changes in industries researching for effective and eco-friendly strategies for the synthesis of materials, including nanomaterials, through employing cost-efficiency and biocompatibility with the help of earth's resources (De, 2023).

Effectiveness of green chemistry education programs in promoting sustainable practices

Beginning with green chemistry education programs is vital especially in cultivating awareness of the environment, the knowledge, and skills required by the students so as to make right and sustainable decisions. Explaining green chemistry principles to curricula is not only educating students to adapt to the environmental sustainability (Etzkorn & Ferguson, 2022), but to assist the students in using industry proficient tools like DOZN 2. 0 and Life Cycle Assessment indicators to define and measure the greenness and environmental profiles of chemical reactions (Reyes et al., 2022). This way, green chemistry concepts can be introduced to students from their first academic years, and future chemists will be ready to work on sustainable development and social justice in their future careers (Marcelino et al., 2023). Current and future generations emphasize technical systems and several systems of sustainability to address the challenges of the world (Christiana, 2023). Thus, the green chemistry education programs should incorporate a number of factors to be effective in the encouragement of sustainable practices. Firstly, the main aspects of green chemistry principles and their application in the undergraduate program is essential for students' preparation for a sustainable future (Mitarlis et al., 2023). Moreover, the adoption of green metrics, which are simple and understandable, persuades the large chemistry fraternity to try and provide greener synthetic solutions. Procedures such as the use of readily available real-life tools like DOZN 2. and Life Cycle Assessment (LCA) metrics strengthen their position with regard to green and sustainable decision-making in the context of chemist's processes. It connects chemical reactions with the UN Sustainable Development Goals (SDGs). Furthermore, similarities from other disciplines like chemoinformatic and chemoinzation and the systems thinking in the design of the programs make green chemistry education programs effective in addressing global sustainability concerns (Zowada et al., 2022).

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Best practices for incorporating green chemistry principles into K-12 education

To mainstream green chemistry in K-12 education, teachers' professional development models have to be effectively incorporated, non-conventional teaching-learning activities have to be encouraged, and natural indicators have to be encouraged during the process of teaching. New York has been in a leading position in conducting introductory workshops for high school teachers on green chemistry principles and practices; coverage of this has led to adoption and use by teachers in their classes and sharing with other teachers (Cannon et al., 2023). Moreover, the literature stresses the enhancement of the approach of green chemistry in the curricula through systemic views linking it with sustainability and sustainable development as seen in learning subjects, curriculum debates, and integrative content (Marcelino et al., 2023). Additionally, implementing a green chemistry perspective in the undergraduate chemistry education programs can help to advance the Sustainable Development Goals by reducing the consumption rate and the generation of waste (Olanrewaju & Adeosun, 2023; Mitarlis et al., 2023).

Green chemistry can finally be introduced in elementary science education, with concepts such as: waste elimination, the use of safer solvents, energy conservation, and designing for safety. This integration can help contribute to Sustainable Development Goals, SDG's concern about responsible consumption and production, and climate change mitigation (Mitarlis et al., 2023). To that end, it may be possible to generate a model of curricular content for Green Chemistry School Education-based innovation with an emphasis on the following aspects. These aspects are such as Science Learning Areas/Themes, Domain Science Subjects, Disciplinary Core Ideas, Essential Skills, and Cross Cutting Concepts for Green Chemistry (González-García et al., 2023). Moreover, the ideas of green and sustainable chemistry should be introduced as early as possible in students' education. Since these concepts are rapidly advancing in research and industry – defining the approaches to making chemical processes and products more sustainable (Eilks & Linkwitz, 2022; Lembens et al., 2022).

Long-term impacts of green chemistry education on the workforce and the environment

Green chemistry education is long-term actionable, directed towards the chemical industry's skilled workforce and environment. The concept of green chemistry in educational materials and training centralizes the future scientists to adopt greener products and processes which eventually decrease energy usage, prevent harm to the environment and most importantly cannot produce waste (Rana et al., 2022). Learning green chemistry in the lower classes can influence students' attitude towards chemistry and, by extension, the experiments that they conduct. Therefore, it has produced future scientists and professionals with the mindset that experiments should embrace the use of safer chemicals that are eco-friendly (Cannon et al., 2023). The aspect of sustainability aspect of green chemistry is to attempt to not create dangerous by-products, pollute the industries where the chemicals are produced, and design green syntheses that will not harm the human personnel or the environment in the future (Reyes et al., 2022).

Summing-up

The practice of green chemistry in education has already started, and there is an emphasis on developing green chemistry for the undergraduate program with mention of future prospects (Marques et al., 2020). Several studies have examined the possible approaches for delivering the concept of green chemistry education. Besides this, proposals with specific experimental plans should include green chemistry practices to encourage responsible actions in several

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fields in an environmental and social context (Etzkorn & Ferguson, 2022). The introduction of green chemistry in students enhances the ability of the students to solve problems, assess and inquire beyond the traditional norms while practicing chemistry with an ethical framework and executing sustainable development. In light of the transition towards sustainable goals and complex systems, educators of chemistry are beginning to prepare chemistry graduates as global problem solvers, more specifically competent green chemists, to meet this world's challenges (Wang et al., 2023).

References

Cannon, A. S., Anderson, K. R., Enright, M. C., Kleinsasser, D. G., Klotz, A. R., O'Neil, N. J., & Tucker, L. J. (2023). Green chemistry teacher professional development in New York state high schools: A model for advancing green chemistry. *Journal of Chemical Education, 100*(6), 2224–2232. https://doi.org/10.1021/acs.jchemed.2c01173

De, A. (2023). Green chemistry principles and spectroscopic methods applied to nanomaterials. In *Materials research foundations* (pp. 54–91). MRF. https://doi.org/10.21741/9781644902370-3

Eilks, I., & Linkwitz, M. (2022). Greening the chemistry curriculum as a contribution to education for sustainable development: When and how to start? *Current Opinion in Green and Sustainable Chemistry*, *37*, Article 100662. https://doi.org/10.1016/j.cogsc.2022.100662

Etzkorn, F. A., & Ferguson, J. L. (2022). Integrating green chemistry into chemistry education. *Angewandte Chemie*, *62*(2). https://doi.org/10.1002/anie.202209768

González-García, P. J., Marbà-Tallada, A., & Espinet, M. (2023). A model of curricular content for the educational reconstruction of Green Chemistry: The voice of Chilean science teachers and science education researchers. *Chemistry Education. Research and Practice*, *24*(4), 1190–1203. https://doi.org/10.1039/d3rp00063j

Lembens, A., Heinzle, G., Tepla, A., Maulide, N., Preinfalk, A., Kaiser, D., & Spitzer, P. (2022). SpottingScience – a digital learning environment to introduce Green Chemistry to secondary students and the public. *Chemistry Teacher International*, *4*(2), 143–154. https://doi.org/10.1515/cti-2021-0025

Mane, N. S. R., Bais, N. S. K., & Nigadi, N. S. R. (2023). Review on green chemistry and catalysis. *International Journal of Advanced Research in Science, Communication and Technology*, 431–438. https://doi.org/10.48175/ijarsct-7993

Marcelino, L. V., Dias, E. D. S., Rüntzel, P. L., Milli, J. C. L., Santos, J. S., Souza, L. C. A. B., & Marques, C. A. (2023). Didactic features specific to green chemistry teaching in the Journal of Chemical Education. *Journal of Chemical Education*, *100*(7), 2529–2538. https://doi.org/10.1021/acs.jchemed.2c01091

Marques, C. A., Marcelino, L. V., Dias, É. D., Rüntzel, P. L., Souza, L. C. A. B., & Machado, A. (2020). Green chemistry teaching for sustainability in papers published by the Journal of Chemical Education. *Química Nova*, *43*(10), 1510-1521.

Mitarlis, M., Azizah, U., & Yonata, B. (2023). The integration of green chemistry principles in basic chemistry learning to support achievement of Sustainable Development Goals (SDGs) through education. *Journal of Technology and Science Education*, *13*(1), Article 233. https://doi.org/10.3926/jotse.1892

Nithya, K., & Sathish, A. (2023). Introductory chapter: Understanding green chemistry principles for extraction of green solvents. In *Elsevier eBooks* (pp. 193–216). https://doi.org/10.1016/b978-0-323-95156-2.00018-0

Olanrewaju, A. O., & Adeosun, N. O. (2023). Application of principles and tools in green chemistry to education using rose flower extract as acid-base indicator. *Bulletin of the Chemical Society of Nigeria*, *48*(1). https://doi.org/10.46602/jcsn.v48i1.847

Rana, R., Sharma, D., & Sharma, V. (2022). A review on Evolution and multidimensional impacts of green chemistry. *Journal of Biomedical and Pharmaceutical Research*, *11*(4). https://doi.org/10.32553/jbpr.v11i4.915

Rathi, N. P., Nausheen, N. S., & Nisha, N. (2023). Green chemistry and technology for sustainable development. *International Journal of Science and Research Archive*, *8*(2), 161–165. https://doi.org/10.30574/ijsra.2023.8.2.0225

Reyes, K. M. D., Bruce, K., & Shetranjiwalla, S. (2022). Green Chemistry, life cycle assessment, and systems thinking: An integrated comparative-complementary chemical decision-making approach. *Journal of Chemical Education*, *100*(1), 209–220. https://doi.org/10.1021/acs.jchemed.2c00647

Voutchkova-Kostal, A., Laviska, D. A., Briddell, C. (2023). ACS launches green chemistry education campaign. *C&EN Global Enterprise*, *101*(19), 30. https://doi.org/10.1021/cen-10119-acsnews2

Wale, T., Suryavanshi, S., Wavare, V., Phalke, P., & Sharmale, M. (2023). Review on green chemistry. *Journal of Drug Delivery and Therapeutics*, *13*(7), 190–193. https://doi.org/10.22270/jddt.v13i7.5919

Wang, Qian., Du, Weichao., Li, Chaowei., Chen, Gang. (2023). Green chemistry education concept transited by a comprehensive experiment of citrus peel conversion and utilization. *Education Research and Development*, *2*(1), 22. https://doi.org/10.57237/j.edu.2023.01.004

Zowada, C., Niebert, K., & Eilks, I. (2022). Perspectives on education for sustainability in chemistry teaching. *Química Nova Na Escola*, *44*(2). https://doi.org/10.21577/0104-8899.20160312

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