Deep Science Publishing, 2025
https://doi.org/10.70593/978-93-7185-662-1_14

Chapter 14: From Green Chemistry to Sustainable Citizenship: Transformative Teaching Approaches

Joel Osei-Asiamah

Department of Science and Technology Education, College of Education, University of South Africa (Unisa), South Africa.

Corresponding Author E-Mail Id: *droseiasiamah@gmail.com*

Abstract: Amid increasing global issues of climate change, environmental degradation, and pollution, chemistry education is being recognized as an important instrument for promoting sustainable development and environmental consciousness. In this chapter, we reflect on the nature of developments occurring in educational practices in chemistry, i.e., from the traditional inscriptions of technical knowledge to a much fuller, wide-ranging and transformative engagement of students in becoming holistic sustainable citizens. It is a critique of content-oriented, traditional pedagogies, and raises new issues and arguments for the integration of green chemistry and the most basic competencies, including ethical reasoning, systems thinking and socscientific argumentation. Chapter 5 is informed by international educational theory and evidence base supporting sustainability policy frameworks, and examines new and emergent pedagogies including curriculum transformation, inquiry and problem based learning, and socio-scientific issue (SSI) approaches, as well as community engaged service learning and interdisciplinary learning. Using extensive case studies of both secondary and tertiary students, the book provides clear insight into how such an approach supports the deep learning that is needed to have a significant impact on students' lives. They contribute to the production not just of scientific literacy, but of critical thinking, moral understanding, and self-confidence to act for social justice and environmental sustainability. Finally, this chapter provides a road map of change for those educators, policymakers, and curriculum designers committed to reshaping our chemistry classrooms toward fostering a cadre of environmental innovators and maruchalas4 for the world. It only strengthens the argument that proper training in chemistry is inherently tied to the larger task of educating people who will help us all live in a more sustainable, more just world.

Keywords: Water Treatment, Chemical Processes, Emerging Contaminants, Coagulation–Flocculation, Advanced Oxidation Processes (AOPs), Adsorption, Ion Exchange, Electrochemical Methods, Water Quality Management.

Introduction

Being the source of innovations and the cause of environmental concerns at the one hand, chemistry also plays a crucial role in defining sustainable solutions, and instructing students, on the other hand, to solve complex issues of the real world (Broman & Parchmann, 2014; Lancaster, 2016).

Green chemistry is an area that has transformed chemical production and management over the last 20 years and it is based on the twelve principles that have been developed by Anastas and Warner (1998). Nevertheless, with the amount of sustainability challenges increasing as well as becoming more diverse across the world, educators have come to the conclusion that it is not just enough to disseminate technical knowledge anymore. Learners should be amplified with the skills, values and civic aptitudes necessary to be what the writer decided to call a sustainable citizen, through education (Burmeister et al., 2012). This kind of vision recasts learning chemistry as a means of critical thinking, systems thinking, ethical inquiry, and sustainable contribution to democratic decisions concerning science and society (McCright et al., 2013; Clark, 2015).

1. Evolving Concepts: From Green Chemistry to Sustainable Citizenship

1.1 The Green Chemistry Foundation

Green chemistry includes twelve principles that represent the fundamentals of sustainable thought in the field of chemistry that center on toxicity, waste, renewable starting materials, atom economy and safer processes (Anastas & Warner, 1998; Lancaster, 2016). This is also how they become included in curricula, giving them their technical origin and simultaneously creating an accessible rational idea for the learners. Fewer people have studied how students like these respond to green chemistry content, but those who have find that math/science averse and less analytical learners find green chemistry real and directly linked to environmental and health concerns, and they are motivated to work towards more sustainable solutions (Clark, 2015).

University professors have developed hands-on activities, case studies and project activities (redesign of synthesis of drugs and everyday items, etc.) that show the principles of green chemistry and emphasize the gap between theory and application (Lancaster, 2016; Blonder et al., 2014).

Even the technical content on its own leaves a lot of the elements of sustainability to be uncovered. Such complexity of environmental problems requires a more inclusive set of instruments that take into consideration social, economic, unethical, and political spheres (Burmeister et al., 2012).

1.2 Defining Sustainable Citizenship

This type of sustainability as developed in education research describes a set of skills, principles, and motivations such as scientific literacy, ethical judgments, individual responsibility, and engagement in collective problem-solving (Juntunen & Aksela, 2014; Wiek et al., 2011). Instead of learning being passive receivers of information, it is envisaged that students can identify themselves as purposeful change agents who can influence the decisions they make both personally and at a societal level which affect operations of the global systems.

The UNESCO paper Education for Sustainable Development Goals (2017) has identified competencies in sustainable citizenship that include systems thinking, anticipatory (futures) thinking, normative (values) competence, strategic (action) competence and critical self-reflection. All these can be tapped by chemistry education through a combination of content learning and the practise of using the knowledge, critiquing dilemmas, and civic discussion of problems such as plastics, energy, food security, and pollution (Burmeister et al., 2012; Zeidler et al., 2009).

2. Transformative Teaching Strategies

2.1 Inquiry-Based and Problem-Based Learning (PBL)

Inquiry-Based Learning Inquiry-Based Learning (IBL) takes the role of scientists: questioning, planning investigations, evidence gathering and explanation building. The studies have shown that the IBL and PBL methodologies elicit a better comprehension of the chemical concepts, the augmentation of student motivation, and the development of the learning to apply knowledge in novel situations (Blonder et al., 2014; Wiek et al., 2011).

Practically, teachers bring to students sustainability-oriented projects like: exploration of the chemistry of pollutants in their local rivers; creation of biodegradable products based on green chemistry principles; or evaluate the life cycle effects of such consumer products. The activities teach students to connect chemistry with the current environmental issues but also to be team-friendly, communicate effectively and manage projects (Clark, 2015).

Journals or group discussions can help to reveal the reflective components: the students can consider the trade-offs, point of view of different stakeholders, and the unforeseen consequences of the solutions (Blonder et al., 2014).

2.2 Socio-Scientific Issues (SSI)

Socio-scientific issues (SSI) teaching puts chemical concepts into socially compelling, frequently debatable situations, (they could be issues in pesticide security, the ethicality of climate engineering or the legitimacy of nanotechnology control (Levinson & Turner, 2001). The pedagogy is useful in assisting students:

- Examine and discuss actual news and case studies (Sadler, 2004; Zeidler et al., 2009)
- Appraise data and conflicting arguments to bolster evidence-based arguments
- Think of the set of ethical, political and economic consequences of chemical innovations

More than being pedagogical, SSI frameworks foster critical thinking since they are also proven to make students more interested in science and better in argumentation as well as development of confidence in discussing matters of general interest (Juntunen & Aksela, 2014).

Students can be assessed by being required to write their position papers, role-playing out as stakeholders or coming up with scientifically based policy endorsement (Sadler, 2004).

2.3 Interdisciplinary and Systems Thinking

A lot of sustainability issues are known as a wicked problem, meaning that they are multidimensional, and there are no ready-made solutions (Broman & Parchmann, 2014). To solve them, one needs systems thinking: the ability to identify patterns, feedback loops, and emergent behaviors not limited to one domain.

Teachers can layout cross-curriculum courses between chemistry and biology (ecosystems, biogeochemical cycles), physics (energy).

The students learn about designer thinking (environmental science), history (technological change), or economics (life cycle cost analysis) (Broman & Parchmann, 2014). Modeling in the form of cause and effect diagrams (also known as causal loop diagrams) and life cycle analysis software enables students to see the chain of effects that chemical production and use have.

Some ideas of group projects could be to assess green technologies with the help of multi-criteria analysis, to design a supply chain emissions model, or to study the effects of chemical waste regulations by sector (UNEP, 2022).

2.4 Service Learning and Civic Engagement

Service learning puts chemistry learning in the context of their communities- students have the power to utilize the knowledge they learn at the real social level (Ferguson et al., 2017). Partnerships with the NGOs, local agencies or business enable the students to:

- Monitor quality of the water, soil, or air and inform stakeholders about it
- Support the development or the creation of waste reduction programs
- Inform the population about safe application of chemicals and green consumer behaviors

There is some evidence that community-based projects can increase scientific literacy and bring civic awareness, as well as enable students to perceive their learning as relevant to practical change (Ferguson et al., 2017).

The student reflection also matters in this case: personal development, contribution to the community, and the things the student learns during their collaboration add value to the service experience, and the long-term dedication to sustainability develops.

2.5 Assessment for Sustainable Competencies

The evaluation practices should go beyond simple memorizing to analyze more advanced abilities: the degree of critical thinking, the ability to map systems, the quality of arguing, teamwork and morality (UNESCO, 2017). Good instruments are:

- Project report, lab, and reflective writing portfolios
- Argumentation and system thinking rubrics
- Inclusion of peer and self-evaluation with regard to collaborative work and civic contributions

Gauging the change in sustainability attitudes and behaviors over a period of time, or longitudinal assessment, this was able to provide a suggestion on a curriculum improvement (Clark, 2015).

3. Case Studies and Implementation Insights

3.1 University Green Chemistry Modules

Green chemistry instruction is also comprehensively approached at the undergraduate level in the University of York by including hands-on laboratory courses, design challenges on a team-based approach, and interdisciplinary projects (Clark, 2015). As an example students may be asked to optimize the synthesis of a pharmaceutical to make it greener, to make it less toxic and to consider alternative solvents. Analyses carried out after the modules show that students do not only learn technical ideas, but also increase sensitivity to the ethical and environmental drawbacks of their designs.

Moreover, the cooperation of York with industry partners will expose the students to the issues of a real world and means diverse careers in the sphere of green chemistry and sustainability.

3.2 High School Socio-Scientific Issues Curriculum

In the work of chemistry majors at the North Carolina State University, the students were involved in collaboration between the local government and students to test water samples at the local neighborhoods suspected of having contamination in the water (Ferguson et al., 2017). Teams formulated sampling plans, carried out experiments, analyzed the outcome, and published the findings both in science and in the open press.

Reflections found that students acquired professional scientific competencies as well as stronger inspiration and feelings of individual relevance to the potential impact of their chemistry education on the greater society.

3.3 Community-Based Service Learning

In North Carolina State University, the chemistry students worked with the local government, in which the students analyzed municipal water in neighborhoods sent by the local government in suspected contamination areas (Ferguson et al., 2017). Teams constructed sampling plans, carried out experiments, and analyzed and published results in science and popular forms of publication. Reflections pointed to students acquiring scientific professionalism e.g. rigorous data analysis, communicating science to the general population and such things as working as a team, but also expressed to be more personally motivated to do science and have a better sense that their chemistry education could deliver a good to society.

Conclusion

The pieces of evidence that are collected in this chapter pedagogical research, classroom experiments, systemic curriculum innovation make a clear argument that breakthrough instantiations of teaching have potent outcomes. Those students who undergo inquiry based, SSI, interdisciplinary, and service learning models, come to form a more complex idea about the concepts and processes of chemistry, and at the same time, are on the way to have a properly developed value-driven competency, which allow taking responsible action. Among them are systems thinking, ethical deliberation, argumentation, and team-based problem solving, and all of them are requisite not only in a scientific profession, but also in being a well-informed world citizen (Burmeister et al., 2012; Wiek et al., 2011). Also in this chapter, it is demonstrated that relevant evaluation techniques, such as paying attention to process, collaboration, and reflective skill are vital in the assessment and reinforcement of these new priorities in competencies.

References

Anastas, P. T., & Warner, J. C. (1998). *Green Chemistry: Theory and Practice*. New York: Oxford University Press.

Blonder, R., Mamlok-Naaman, R., Hofstein, A., & Rosenfeld, S. (2014). Learning about water quality using complex systems analysis: Forming the basis for understanding global environmental problems. *Chemistry Education Research and Practice, 15*(3), 325-335.

Broman, K., & Parchmann, I. (2014). Students' application of chemical concepts when addressing sustainability. *International Journal of Science Education, 36*(14), 2436-2457. https://doi.org/10.1080/09500693.2014.910759

Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for Sustainable Development (ESD) and chemistry education. *Chemistry Education Research and Practice, 13*(2), 59-68. https://doi.org/10.1039/C1RP90068K

Clark, J. (2015). Integrating green chemistry into the curriculum at the University of York. *Green Chemistry Education, 3,* 22–32.

Ferguson, J., Slinger-Friedman, V., & Woelfel, J. (2017). Service-learning in environmental chemistry: The impact on student understanding and community engagement. *Journal of Chemical Education, 94*(7), 845-852.

Juntunen, M., & Aksela, M. (2014). Improving students' argumentation skills through a product life-cycle analysis-based educational module. *Chemistry Education Research and Practice, 15*(4), 639-649.

Lancaster, M. (2016). *Green Chemistry: An Introductory Text* (3rd ed.). London: Royal Society of Chemistry.

Levinson, R., & Turner, S. (2001). Valuable lessons: Engaging with the social context of science in schools. *School Science Review, 83*(302), 107-115.

McCright, A. M., Allen, S., & Dietz, T. (2013). The influence of political ideology on trust in science. *Environmental Research Letters, 8*(4), 044048.

Rockström, J., Steffen, W., Noone, K., et al. (2009). A safe operating space for humanity. *Nature, 461*(7263), 472–475. https://doi.org/10.1038/461472a

Sadler, T. D. (2004). Informal reasoning regarding socio-scientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513-536.

UNEP. (2022). Chemistry and the United Nations Sustainable Development Goals. United Nations Environment Programme.

UNESCO. (2017). Education for Sustainable Development Goals: Learning Objectives. Paris: UNESCO.

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science, 6*(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2009). Beyond STS: A research-based framework for socio-scientific issues education. *Science Education, 90*(3), 357-377.