Green Chemistry Education

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An important goal for sustainability education is to learn negotiation, problem solving and decision-making skills through discussions about ecological, social, economic, and ethical principles concerning local and global responsibility in their own life. Through memorable, experiential, and active processes, students learn to discuss their own value selection and to evaluate phenomena and sources of information critically. In this article, we aim to identify suitable pedagogical approaches to teaching and learning green chemistry among college students and preservice teachers by examining the teaching methods that have been used to promote green chemistry education (GCE) and how these methods have supported green chemistry learning (GCL).

sustainability education | green chemistry education | green chemistry teaching and learning | environmental awareness | teaching personal and social responsibility

1. Introduction

Sustainable development has been considered a major global goal since the launch of Agenda 21 in 1992 [1]. It has also been confirmed recently with Agenda 2030 and its sustainable development goals [2]. According to the report Our Common Future [3] sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Here, the long-term aspect of sustainability is emphasized, and justice is introduced as the ethical principle for achieving equity between the present and future generations [4]. To tackle the challenge from ecological and environmental crises such as "white pollution" [5][6] and "endocrine disrupting chemicals (EDCs) amplification effects" [7], sustainable development goals call for chemists, engineers and decision-makers [8][9] to take responsibility for sustainable solutions to these crisis and complex problems. However, recognizing the concept is not enough; it is also necessary to deliver results and teach the values and views of the sustainability of green chemistry to tomorrow's chemists, engineers and decision-makers during their professional studies [8] and to ensure the implementation of the sustainability based on the advance of green chemistry [10].

A main objective of green chemistry education (GCE) is to foster and improve scientific literacy in sustainability and to develop the corresponding skills among the present and future generations [11]. However, 25 years after the interdisciplinary emergence, green chemistry practices are possibly more incremental than transformative if the XII Principles [11] are not considered to be a uniform system establishing the "hows" and "whys" of these practices [12]. According to Anastas, sustainability has been little incorporated into the curricula and education of green chemists and engineers [13]. In addition to reducing waste and hazards, GCE could also address the wider societal impact of responsible technology innovation [14]. This calls for the active search for different solutions to societal challenges [15] and incorporation of additional humanistic principles such as a fair and equitable distribution of benefits based on at least one of the Sustainable Development Goals (SDGs) [16] to ensure sustainability in the broadest sense.

According to Rhoten et al. [17] and Klein and Newell [18], interdisciplinary education is understood as a mode of curriculum design and instruction in which teachers integrate information and theories from various disciplines to foster and improve students' capacity to create new solutions and approaches to existing problems. Unfortunately, to date, little attention has been paid to integrative teaching methods promoting sustainability education (SE) in higher education [19][20]. In this study, sustainability education is defined as education based on the concept of sustainability [21]. It must be interdisciplinary, collaborative, experiential, and potentially transformative. A popular way to achieve integration in a curriculum is to address a theme or topic through the lenses of different subjects [22]. Because interdisciplinarity is a complex psychological and cognitive process [23][24],, interdisciplinary pedagogy is not synonymous with a single process, method or technique; different teaching methods are needed to support and promote interdisciplinary learning outcomes [23][25] depending on a discipline's history, traditions and ways of thinking.

Thus, based on the ultimate goals of green chemistry, environmental protection and the prevention of environmental pollution [11], when teaching green chemistry integrated with sustainability education, in addition to providing high-quality content knowledge and pedagogical content knowledge, it is important to foster environmental awareness and consciousness, positive attitudes towards environmental issues [26] and behavior change motivation in a sustainable direction. Content knowledge [27] refers to the amount and organization of knowledge per se in the mind of the teacher.' Pedagogical content knowledge involves teachers' interpretations and transformations of content knowledge to facilitate student learning [11] Teaching knowledge alone cannot change people's behavior, but sustainability education, which incorporates, e.g., positive psychology [28], can effect such change. Sustainability education aims to promote education as a critical tool to prepare young people for responsible citizenship in the future [29] and to initiate and steer mainstream culture in a sustainable direction [30]. Teaching and learning green chemistry for sustainability education can fully utilize the applied learning models that connect real-world circumstances with the broader human concerns of environmental, economic, and social systems [31].

GCE also aims to achieve sustainability [32], and its task is to teach students how to make chemical and societal decisions depending on multidimensional green chemistry metrics and the consideration of social factors related to green chemistry and sustainable development [29]. Because only a few reviews on GCE exist t [33] and there is a need to elaborate on them, we investigated the integration of green chemistry with other disciplines and the teaching methods used in colleges and teacher education to find integrative ideas incorporated in the selected articles. This was expected to contribute to develop interdisciplinary curriculum and green chemistry teaching, and thus help close the gap between the interdisciplinary green chemistry teaching and single-disciplinary teaching.

2. Literature Review

The literature review begins with a brief examination of the relationship of green chemistry to other disciplines from the perspective of teaching and learning principles to promote sustainability. It then investigated the ways in which green chemistry education is taught and the features of teaching methods in supporting green chemistry learning. Figure 1 clarifies the schematic role of green chemistry teaching and learning in promoting sustainability education.

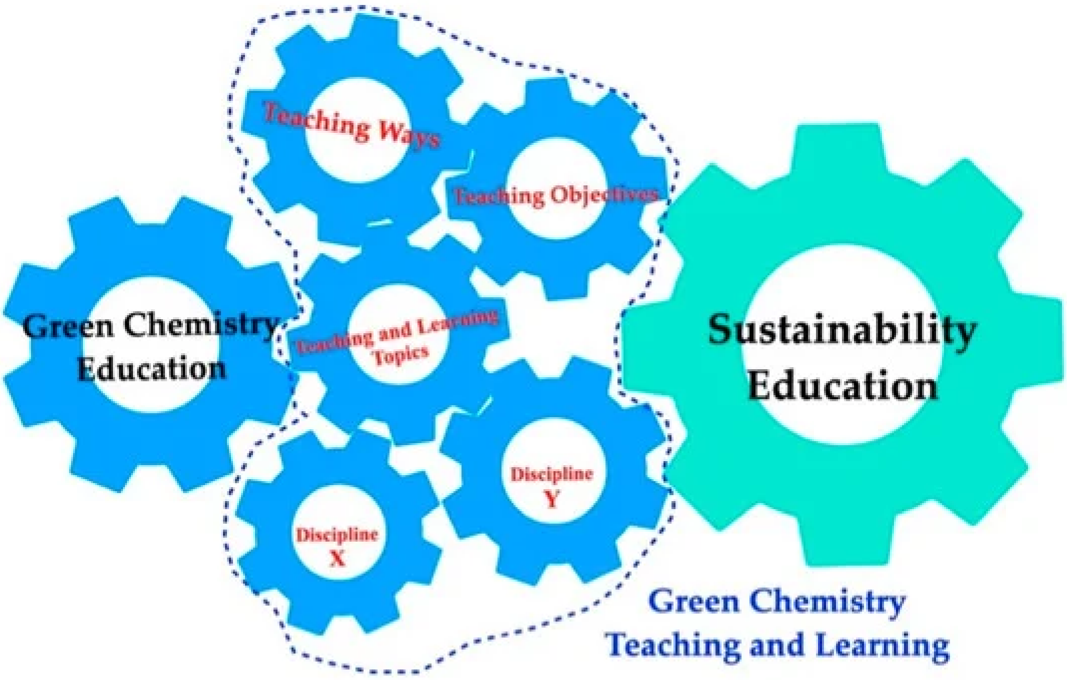

Figure 1. Schematic role of green chemistry teaching and learning in promoting sustainability education.

2.1. Integrated Teaching and Learning Topics Promoting Sustainability in Green Chemistry Education

Science and technology alone cannot solve our food, energy, environmental, and health problems. Meeting goals in these areas requires interdisciplinary science. Tripp and Shortlidge [34] define the concept ‘interdisciplinary science’ as follows:

Interdisciplinary science is the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines-leveraging various perspectives, approaches, and research methods/methodologies-to provide advancement beyond the scope of one discipline’s ability. As an interdisciplinary science [35], green chemistry aims to secure a sustainable future [32] and to promote collaboration between life scientists and social scientists to develop and implement practical solutions [10]. The knowledge and creativity of individual researchers in different disciplines [34], such as biology, mathematics, engineering, and psychology, can contribute to ecological protection [10] when developing the chemical industry [36].

The first implemented green chemistry course at the college level was created by professor Terry Collins at Carnegie Mellon University [37]. Later, this course was opened to graduate students and advanced undergraduates.

The topics of this course include issues relevant to clean chemistry, nontoxic chemistry, and biotechnology. Moreover, besides relationships of fundamental chemical concepts with the real-world impacts of chemical products and processes, sustainability ethics are also an important part of the course program.

Other important topics are interdisciplinary education [36] and sustainability education [38]. For an interdisciplinary green chemistry curriculum, it needs to be preferably integrated with other science-related courses, such as biology and artificial intelligence, and non-science-related courses, such as psychology, business, ethics, law and regulatory affairs [36]. The greatest challenge of GCT is to encourage people to adopt the idea of sustainability [32]. In this case, the individual plays a critical role [39]. Since education should be thought of as something other than just training [26], the design of this courses are intended to increase students' motivation to learn and to create attitudinal changes [40][41] towards sustainability.

In implementing these topics, integration of green chemistry with other disciplines [42][43] problem-oriented perspectives [44] included in “real-world” case studies and laboratory work have been seen to be effective approaches in GCE [36][45]. These studies offer an important chance for students to develop their holistic and global knowledge [46] and practical skills for their careers.

2.2. Teaching Objectives and Strategies in Green Chemistry Education for Sustainable Development

Previous studies show that the sustainability and ecological (environmental), economic and social dimensions of sustainable development need to be designed in GCE curricula [47] and included in teaching, studying and learning processes. Therefore, an interdisciplinary framework, an interdisciplinary curriculum and interdisciplinary methods [42][48] should be considered when integrating the sustainable development goals into the GCE.

An important objective in GCE is to learn to participate in societal debate and in the societal processes of democratic decision-making about issues concerning applications of chemistry and chemical engineering technology [48][49]. To achieve this objective, a useful approach is student-centered pedagogy, where teaching and learning take place in the field, in interaction with stakeholders, and through participation in civic activities or student-led research [50]. In this way, in addition to cognitive skills, students also learn transferable skills, i.e., the ability to work in teams, to create and to think critically, to communicate and to collaborate when reflecting on complex problems and look for solutions to these problems [51]. If the skills are grounded in a base of knowledge to be mastered [52], green chemistry students learn sustainability competence. They will be able to work in an interdisciplinary manner [46] using collaborative work [40] and problem-based learning (PBL) [53] concerning green chemistry principles and sustainability [54][55]. Problem solving, an essential skill that fits with interdisciplinary curriculum, is also necessary for GCE [53]. When discussing theoretical and practical principles concerning the challenges of sustainable development and sustainability education, interdisciplinary thinking [56],, design thinking [40], systems thinking [12][57][58] and eco-reflexive thinking [59][60] are considered essential for green chemistry teaching (GCT). In addition, with the help of positive psychology, motivational skills can be developed [28][61] to change students' thinking towards a more positive, sustainable direction [62].

Understanding how to teach issues in an interdisciplinary curriculum is one of the key factors of interdisciplinary learning. Due to the nature of unsustainability problems, interdisciplinary learning on this topic often requires collaboration. Interdisciplinary green chemistry learning can be developed by exploring how cognitive, social, and emotional factors interact with each other to promote an understanding of issues and problems. Interdisciplinary learning often also requires group experiences whereby key elements of the development of thinking skills include reflection on the problems, the comparison of information from different disciplines, the promotion of the leverage effect of integration, and the willingness to critically evaluate [63]. Students' tasks are to construct their sustainability knowledge and understanding of the human world; to learn decision making based on ethical, social, environmental and economic issues; and to learn to act and behave in accordance with sustainable development thinking. In this case, in addition to sustainability theories, positive psychology can offer different lenses to understand the relationship between social values and well-being.

3. Conclusions

Integrating GCE with natural sciences, psychology and philosophy can promote GCT and GCL. First, the integration of GCE with ecology can deepen students' understanding of the relationships between the natural environment and human beings. Second, the integration of GCE with psychology can support students' understanding of the synthesis and integration of intangible links between nature and human well-being and motivate students to study green chemistry and the dimensions of SD. Third, the integration of GCE with philosophy can support reflections on an interdisciplinary holistic view of the intertwined complex problems and thus develop a holistic conception of how things relate to each other.

In addition to integrating GCE with other disciplines, systems thinking approaches and high levels of thinking skills, such as synthesis (creativity) and evaluation, need to be raised, e.g., to support the green process design and the LCA studies of green chemistry students. The development of ICT education skills and deepening the digital expertise of students and teachers in GCE are also important because achieving learning objectives requires collaboration with actors outside the university, such as researchers and representatives of different professional groups.

Most importantly, fostering students' environmental awareness through the integration of green chemistry studies with sustainability development and sustainability issues is crucial since the protection of the environment and the reduction of environmental pollution are the core goals of green chemistry. To achieve this aim, prosocial behavior changes in students resulting from teaching personal and social responsibility (TPSR) for students may play a key role due to the importance of TPSR as one of the best models for promoting responsibility, values, and life skills [64].

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