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Exploring, Exploiting and Nurturing the Strong Link between Green Chemistry Education (GCE) and Education for Sustainable Development (ESD)

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Abstract

Green chemistry was born in the early 1990s as a bold and concrete commitment by the chemistry community to design safer chemical products and processes for a more sustainable world. It is often considered as an unorthodox yet smarter application of chemistry which protects human health and the environment in an economically viable and sustainable way. It is also the new inevitable paradigm for chemistry to meet the challenges of sustainable development.

The emergence of green chemistry entailed sharing this new philosophy and methodology of doing chemistry with other chemists and students aspiring for a chemistry-related career. Education was immediately identified as the most effective medium to propagate the green chemistry message to students and society at large.

Science educators realised the overlap between the fundamental green chemistry principles and the overarching concept of sustainable development, and viewed this as an opportunity to infuse sustainability issues in chemistry and science education.

This paper investigates such an intersection between green chemistry education and education for sustainable development, and attempts to identify potential ways and means of implementing some significant aspects of sustainability in pre-university curricula.

This study looks into both the educators' and students' perspectives of such an educational endeavour, taking into account the logistics such as resources, training and any potential barriers in teaching these basic principles of sustainable science, as well as the impact on learning such as motivation to study chemistry, moral and ethical thinking skills, environmental awareness and an understanding of the role of science in society.

Keywords: *green chemistry, green and sustainable chemistry, green chemistry education, education for sustainable development, sustainability science*

Background

The concepts of 'sustainability', 'sustainable development', 'green chemistry' and 'sustainable chemistry' were virtually born at the same time, possibly emerging from the same 'cradle' in an ingenious move by a number of well-meaning pioneers, including scientists, environmentalists and policy-makers, to preserve and safeguard life on earth for present and future generations.

It is a known fact that science, and chemistry in particular, influence virtually all aspects of our life on earth. Hence, science and chemistry educational curricula must reflect more profoundly the growing importance of sustainable development and support a stronger relationship between human civilization and the environment. After all, the ultimate goal for science curricula is not simply to highlight the importance of scientific disciplines in everyday life but also to foster the interrelationship between humans and human habitats. Such a strong emphasis to the importance of a concerted effort to defend the common good and preserve the world heritage will hopefully motivate the students of today to learn and gain the basic skills, values and competences which empower them to shape society in a positive sustainable way (Rauch 2015) while avoiding the past mistakes committed by our forefathers and the leaders of yesterday.

It is generally accepted that the term 'sustainability' and related concepts, gained prominence in the 1980s, and is associated with the Brundtland Report referred to as 'Our Common Future' which was adopted by most of the countries of the world in 1987 (Brundtland 1987). This marked perhaps the first significant effort of humanity to react to the environmental problems resulting from the booming chemical industry (fuelled by the huge success of chemical technology), well documented by Rachel Carson in her highly influential novel 'Silent Spring' way back in 1962. This publication brought several environmental issues to the forefront and created an unprecedented public awareness on pollution and environmental protection. This work catalysed environmental activism and launched the global environmental movement in the late 19th century in a bold effort to stop environmental degradation and protect natural resources (Carson 1962).

The concept of 'sustainable development' sought to combine the salient environmental concerns brought about by the industrial revolution (epitomised by large scale pollution and environmental disasters), with social and economic development (Council on Foreign Relations 2020).

Strictly speaking, the concept of *sustainability* had been used and referred to, in different contexts and using different connotations, since ancient times. It is claimed that it originated in Germany and appeared in a handbook of forestry in 1713 (World Energy 2014). The term used, which at that time was referred to as 'sustained yield', was meant to imply 'never harvesting more than the forest can regenerate'.

However, with time, a number of global changes such as the explosion in world population - estimated as 7.98 billion in year 2022 (Worldometers 2022) and projected to increase by 25% to reach a staggering 9.9 billion by the year 2050 - (U.S. Census Bureau 2016, Kaneda et al. 2020), increased consumption of food, the industrial revolution and the inevitable alarming rate of depletion of natural resources, all contributed to raise the public awareness to manage the environment in a more sustainable way in order to our current and future standard of living. All this paved the way to the adoption of the new term 'sustainable development' (Du Pisani 2006).

The concept of *sustainable development* was coined in the early 1970s and was introduced as a compromise between the notions of 'development' (a qualitative change synonymous with exploitation of resources) and 'conservation' (a quantitative change referring to protection of resources), and a solution to problems related with economic growth and industrialisation (Paxton 1993, Viederman 1993). It was one of the main themes discussed in the U.N. Conference on Human Development in Stockholm, in 1972.

The new concept or rather paradigm of sustainable development was further developed and popularised during international fora such as the World Conservation Strategy (1980), the U.N. World Commission on Environment & Development, UNWCED (1987), and the U.N. Conference on Environment & Development in Rio de Janeiro (1992), the latter known as the Rio Earth Summit. The most commonly agreed definition of Sustainable Development is that included in the previously cited Brundtland Report which actually placed environmental issues in the limelight, right in the centre of the global political agenda.

> "Sustainable Development is the (social) development which meets the needs of the present (generations) without compromising the ability of future generations to meet their own needs." (WCED 1987)

So, the mission of such a new important standard was to guarantee a better quality of life for everyone, both now and for generations to come. The objective of sustainable development was described in other terms, as an attempt "to use resources no faster than they regenerate themselves and release pollutants to no greater extent than natural resources can assimilate them" (Merkel 1998).

This grand idea which was originally criticised by many because of its ambiguity (Robinson 2004) was eventually embraced by the majority of governments, NGOs and society at large, as a point of departure and a point of continuous reference to secure a safer planet today and tomorrow (Muñoz Ortiz 2006).

The Global Goals of Sustainable Development

The Sustainable Development Goals (SDGs) emerged in 2012 at the U.N. Conference on Sustainable Development in Rio de Janeiro, Brazil, i.e. during the Rio+20 Earth Summit. The main objective was to draw up a set of goals in order to meet the environmental, political and economic challenges facing the entire world. The SDGs were meant to supersede the set of eight international Millennium Development Goals (MDGs) which had started a global effort in the year 2000 to tackle the shame and embarrassment of poverty within a 15-year timeframe (Fukuda-Parr 2004, WHO 2005).

The new set of international goals were adopted by all 193 U.N member states (representing practically all countries of the world) in 2015, to serve another 15-year timespan. The 17 global goals for year 2030, which are broad and interdependent, are now considered as a blueprint to achieve a better and more sustainable future. They provide guidelines and no less than 169 specific targets which describe in detail how to measure and achieve these goals. They form part of the resolution of the U.N. General Assembly, known as the '2030 Agenda' for sustainable development (DESA 2016).

The following are the Global Goals for Sustainable Development for year 2030.

Figure 1: The 17 Sustainable Development Goals of the United Nations

SOURCE: https://ied.eu/blog/sustainable-development-goals-and-the-2030-agenda-how-ied-supports-sdgs/)

In a nutshell, the SDGs represent a unique collaboration between many stakeholders (representing the international business community, NGOs, policy makers and civil society) to end poverty, protect the planet and ensure that all people enjoy peace and prosperity (Axon, James 2018).

Crucial role of green chemistry in sustainable development

The concept of green chemistry may be regarded as the response of chemists and the chemical industry to the challenge of sustainable development. It presents a novel way of thinking about the practice of chemistry. In fact, green chemistry was launched in the early 1990s and its origin is arguably linked to the U.S. anti-pollution legislation.

Green chemistry involves a combination of tools, techniques and technologies guided by a set of 12 scientific-based principles that help chemists look for alternative or renewable raw materials, design new chemical products and processes that are environmentally benign and efficient (that is, greener and more sustainable). These 12 principles of green chemistry introduced key concepts such as 'atom economy' and 'life-cycle-analysis' (LCA) which are based on sustainability and support some of the SDGs in their approach.

Figure 2: The 12 Principles of Green Chemistry

SOURCE: Harrison, E., Smith, H., & Dekker, I. (2021)

The universally accepted definition of **Green Chemistry** is that originally proposed by Paul V. Anastas and John Warner (widely regarded as the true founders and architects of contemporary green chemistry).

> "Green chemistry is the utilisation of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products."
>
> (Anastas, Warner 1998)

Some authors argue that GC must not be regarded as a sub-discipline of chemistry (Kirchhoff 2014, Ravichandran 2011) but as a new approach of doing chemistry aimed primarily at protecting human health and the environment, in an economically viable and sustainable way. It also marks a significant shift from a culture of regulations and banning of chemicals to one based on designing safer (less toxic, less hazardous) products with minimum waste (Sanderson 2011). It is also widely regarded as a unique contribution by science, through chemistry, towards sustainability. In fact, GC was precisely born to facilitate the achievement of many global challenges through the smart work of chemists who are committed to design and implement greener and more sustainable products and chemical processes.

Green chemistry is also frequently referred to with the alternative term **Sustainable Chemistry** (SC), and sometimes 'Chemistry for a Sustainable Development'. This is defined by the Office for Economic Cooperation & Development, OECD, as:

> "a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services."
>
> (van Roon et al. 2001, Carra 1999)

It has been suggested that SC refers to chemistry that address sustainability problems such as those addressed in the SDGs.

The use of these two separate terms, i.e. GC and SC and their respective definitions, has been the subject of a long debate (Hutzinger 1999, Poliakoff et al. 2018) with some authors still highlighting important differences between the two terms (Hill et al. 2013). It is argued that 'green chemistry' focuses mostly on concepts related to reducing waste, energy and risk to human and environmental health, without necessarily targeting long-term sustainability. Others claim that the broader term 'sustainable chemistry', which has been introduced more recently, puts more emphasis on industrial application and implementation, with innovations in chemistry targeting sustainability goals (for example, reducing greenhouse gas emissions, alleviating hunger and improving the quality of life). However, it is generally accepted that SC cannot be conducted in the absence of GC (Hogue 2019).

Although it is true that there is no general consensus among the scientific community on the use of these two terms because they may represent different purposes and interests of different chemists, it is equally true that they have now been endorsed universally and they are now being used interchangeably (Mandery 2013, Tundo 2008, Tundo 2012). Furthermore, many sources are today applying the merged term 'Green & Sustainable Chemistry' (GSC) and less commonly 'Green Chemistry for Sustainable Development'. After all, such terms are closely interrelated since the overall vision of GC is 'holistically aligned with environmental sustainability' (Hill et al. 2013).

Having said that, judging from the vast number of research articles, publications and other resources produced to date, the term 'Green Chemistry' is by far the one which is overwhelmingly preferred worldwide, as it is more user-friendly and embraces research, the use of sustainable technology and education (Linthorst 2010). It is also argued that, after all, 'genuine sustainable chemistry…. cannot be conducted in the absence of green chemistry' (Anastas, Zimmerman 2018).

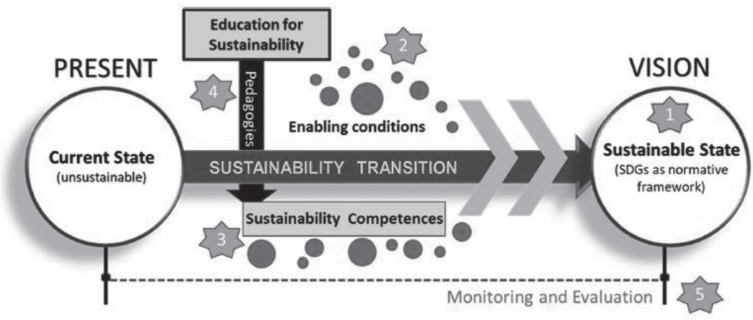
Transforming environmental education (EE) into education for sustainable development (ESD)

Literature suggests that Education for Sustainable Development (ESD) is very much related and overlaps with an earlier U.N. paradigm known as Environmental Education (EE), which knows its origin in the U.N. Conference on Human Environment in Stockholm in 1972 (McKeown, Hopkins 2005, Wesselink, Wals 2011). While it is true that both terms are defined in a different way and have a different perspective on how to educate citizens about environmental issues, there is a lot of common ground. In fact, EE and ESD share similar goals, are both multidisciplinary and both invoke behavioural change for environmental stewardship. Some sources suggest that though being distinct, EE has progressively evolved into ESD (Ärlemalm-Hagsér, Sandberg 2011).

Education for Sustainable Development was launched during the landmark Rio Earth Summit in 1992, as a response to educate citizens, particularly young generations still attending formal education, to address the mammoth task established and embodied by the concept of sustainable development. It became increasingly evident that education was to take centre stage on the achievement of the SDGs launched in year 2015. Over the last 2 decades, ESD has grown from an idea into real global movement (Hopkins 2012).

ESD is described as a lifelong learning process and provides quality education to learners of all ages and from all walks of life. It is the tool required to achieve sustainable development and aims to empower citizens with the right skills, knowledge, values and attitudes to take informed decisions and act responsibly and sustainably throughout their lives. ESD is cited specifically in SDG4 dealing with quality education, but is regarded as a 'key enabler' of the rest of the SDGs. UNESCO is the agency responsible for this global framework, overseeing the management, coordination and implementation of ESD (UNESCO 2021a).

Figure 3: A conceptual framework summarising the role of education to promote sustainable development



SOURCE: Kioupi, Voulvoulis 2019

According to UNESCO:

> "**Education for Sustainable Development** means including key SD issues in teaching and learning, e.g. climate change, disaster risk reduction, biodiversity, poverty reduction and sustainable consumption. It also requires participatory teaching and learning methods that motivate and empower learners to change their behaviour and take action for SD. ESD consequently promotes competences like critical thinking, imagining future scenarios and making decisions in a collaborative way."
>
> (UNESCO 2012a)

Such a detailed definition suggests that ESD involves 2 important features: content and pedagogy (Boeve-de Pauw et al. 2015). Literature shows that ESD is expanding in both aspects and is becoming progressively recognised and embraced worldwide (Hopkins 2012).

The interdependency of the SDGs and the complexity of the concepts of sustainability and sustainable development make it hard to relate the global goals to educational learning outcomes (Kioupi, Voulvoulis 2019). However, a number of strategies and pedagogies have been developed over the years to include more ESD in various curricula of different subjects and at different levels of education all over the world. UNESCO itself designed what it described as the 'ESD for 2030 Roadmap' outlining actions in five priority action areas, indicating amongst others, a clear policy, learning environments and building capacities of educators (UNESCO 2020). It even produced a set of educational resources in the form of a user-friendly manual, called the 'ESD Tookit', to help leaders and educators in their quest to promote ESD in communities and educational institutions (McKeown et al. 2002).

It is often believed that educators serve as models for their students (Cheung 2020) and are very influential in society. In fact, it has been estimated that teachers, on average, leave an impact lasting at least a 100 years, considering their influence during their career and later through the students they would have taught. This is why it is crucial to train educators to teach ESD is a systematic way (Aksela 2016, Kioupi, Voulvoulis, 2019).

The true success of ESD ultimately relies on the educators' commitment to sustainability and their competency and confidence in teaching its basic theory and content. Literature indicates that although educators tend to be interested in investigating and integrating concepts of SD in their curricula, they might experience a number of limitations. These include a lack of knowledge about the topic, training and collaboration among their colleagues, misconceptions, lack of financial and educational resources, overloaded curricula, non-environmental attitudes, lack of research and development, and lack of support and involvement of the school/ college administration (Kanapathy et al. 2019).

It must also be noted that the U.N. recognised the importance of ESD so much so that it declared the period 2005-2014 as 'The Decade of Education for Sustainable Development' (DESD). The objective was to integrate the principles, values and priorities of SD into all aspects of education including learning. It meant to catalyse changes in behaviour to create a more sustainable future by promoting the three dimensions of sustainable development (i.e. environmental integrity, economic viability and social equity).

So the ultimate task of the DESD was to 'reorient education towards sustainability' in the hope of changing attitudes and creating a sustainability mindset. After collecting and analysing data, the UNESCO (which was entrusted with the DESD project) came up with a Global Action Programme (GAP) on ESD in a bid to accelerate, scale up and intensify the change to an education that is more relevant to the world of today (UNESCO 2021b).

The road to green chemistry education

Teaching of chemistry plays a central role in the teaching of sustainable development by providing a number of opportunities to connect the subject with issues of sustainability. This can be done through the use of laboratory experiments, lectures and classroom discussions.

However, teaching the main chemistry theories and facts will not necessarily enable students to deal scientifically with the challenges of SD (Ware 2001). Some authors suggest that chemistry education should take a deeper role in ESD. They believe that ESD should be integrated in the chemistry and science curricula in a multi-dimensional approach, starting from compulsory school science education (Burmeister et al. 2012). This can be done, for example, by introducing the periodic table of elements, at an earlier stage of education, to teach about the composition and effects of greenhouse gases and measures required to minimise their emissions (Kanapathy et al. 2017). Chemistry can also address other challenges of environmental sustainability such as alternative or renewable sources of energy, healthcare, nutrition and quality control. Chemistry can also teach about producing novel materials and products, sustainable energy supplies, composition and properties of medicine and fertilisers (Burmeister et al. 2013).

Integrating ESD in chemistry education provides a golden chance of introducing a number of concepts, skills and practices related to sustainability which students can then relate to real life situations, making the subject more relevant to their daily lives (Juntunen, Aksela 2014).

Evidence suggests that including stronger connections between human sustainability and the chemistry curriculum leads to a win-win situation as it brings a number of benefits to the students, the academic discipline itself and the planet in general (Middlecamp 2019).

It follows that chemistry educators have to make sure that besides engaging all students in learning the subject content, they also have to motivate them to learn how chemistry has the potential to meet today's global challenges.

The emergence of GC in the 1990s was followed by the growing need of its exponents to share their new philosophy and methodology of doing chemistry with fellow chemists and students aspiring for a chemistry-related career. In fact, as in the case of SD, education was soon recognised as the ideal medium through which the GC message could be diffused among students, professionals and even society at large (Wardenchi et al. 2005).

Teaching of GC was found to be an effective way of highlighting the importance of chemistry for SD (Burmeister, Eilks 2012). In fact, teaching of green and sustainable chemistry (GCE or GSCE) usually involves a discussion of sustainable development as this allows learners and educators to address in an ethical way the various environmental issues faced by local and international communities (Haack, Hutchison 2016, Pavez et al. 2018). A growing body of literature suggests that this has, in fact, become an urgent matter when one considers that ESD is making slow progress and is still virtually absent in many science and chemistry curricula in many countries (e.g. Vilches, Gil-Perez 2013, Karpudewan et al. 2011, Boeve-de Pauw et al. 2015, Juntunen, Aksela 2014). Hence there is still a significant potential and a strong desire to infuse GSCE in mainstream education (Zuin et al. 2021). Evidence suggests that teaching a more sustainable chemistry entails GC practices (Burmeister et al. 2012) as GC has always been known to be 'the chemistry of sustainability' (Beach et al. 2009).

GCE (or GSCE) has two main objectives:

- to cultivate and enhance scientific literacy in sustainability;
- to develop and propagate corresponding skills among current and future generations.

(Anastas, Warner 1998). Teaching GC promotes a number of scientific principles aimed to safeguard the environment and prevent or reduce environmental pollution. Hence when 'teaching of GC' is integrated with ESD, one instils in students a greater sense of environmental awareness, positive attitudes towards environmental issues and a motivation to behave more sustainably (Chen et al. 2020). Exponents of GC recognise that knowledge of GC alone, no matter how crucial, extensive and effective, will not create a sustainable civilisation (Anastas, Zimmerman 2018). People's behaviour can only change through sustainability education as this aims to prepare future generations of responsible citizens and to start and foster a mainstream culture based on the principles of SD.

Literature shows also that the teaching and learning of GC for SD can adopt learning models that connect real-life situations with wider human concerns involving the environmental, economic and social aspects of SD.

GCE has a history of about 30 years, during which there have been many attempts and approaches to integrate concepts and practices of GSC into the chemistry curriculum (Haack, Hutchison 2016, Bastin, Dicks 2019). Examples include:

- programmes designed specifically to integrate completely the 12 GC principles across the chemistry curriculum (Cann 2001; Timmer et al. 2018);
- separate, stand-alone GC elective courses (University of Toledo 2021);
- GC laboratory programmes (Doxsee & Hutchison, 2003; Timmer et al, 2018; University of Minnesota 2021);
- GC initiatives outside the traditional classroom setting (Waked et al. 2019; Zuin, Eilks 2019);
- using controversial socio-scientific issues from sustainability challenges related to chemistry (Zuin, Eilks 2019);
- integrating chemistry learning with ESD-driven development of educational policies (Zuin, Eilks 2019).

The concepts of GC can alternatively be taught in training course and research activity, along with other disciplines. This requires the collaboration between life scientists and social scientists in an effort to develop new sustainable solutions. Such an interdisciplinary approach warrants the integration of GC curricula with both science-related disciplines (e.g. biology, ecology, artificial intelligence) and non-science-related ones (e.g. psychology, philosophy, business and ethics). Such programmes have a strong potential to educate and increase motivation in advanced students towards a greater sustainability (Chen et al. 2020).

Despite all these and similar efforts and initiatives, it is considered that the principles of GSC have not yet sufficiently integrated in the standard undergraduate chemistry curriculum.

The idea of blending chemistry and SD in pre-university curricula is also gaining support as educators are increasingly become aware and recognising the importance of incorporating the concepts of GC in different levels of education and different settings including high schools, colleges and other institutions (Haack et al. 2005, Anastas, Beach 2009, Eilks, Rauch 2012, Mandler et al. 2012, Jegstad, Sinnes 2015, Aubrecht et al. 2015, Karpudewan et al. 2015, Fenech Caruana 2015, Linkwitz et al. 2021).   Other literature confirms that education and society at large would be significantly improved if students were exposed to the philosophy and practice of GSC at an earlier stage (Wardenchi et al. 2005, Braun et al. 2006, Savitskaya et al. 2012).

A number of theoretical frameworks have been proposed on the most effective ways to include GC and ESD concepts in chemistry education, particularly at secondary and post-secondary levels (Burmeister et al. 2012, Fenech Caruana 2018, Linkwitz, Eilks 2019, Ballard, Mooning 2021, Linkwitz et al. 2021).

Burmeister et al. (2012) devised a combination of strategies involving application GC in the school laboratory, subject content, classroom discussions and school development policies based on ESD.

A Norwegian study (Jegstad, Sinnes 2015) developed this model further and combined the principles of GC and SD in the chemistry curriculum by referring to five inter-related aspects of ESD, namely,

- chemical content knowledge (tackling topics such as biofuels and life-cycle analysis);
- chemistry in context (by making the subject more relevant through individual, societal and vocational experiences);
- exploiting the uniqueness of teaching or learning chemistry (e.g. macro, micro and symbolic dimensions of the subject);
- applying sustainable practices in chemistry;
- ESD competences such as systems thinking, problems solving, creativity, critical thinking, action competence, communication and collaboration.

On the other hand, a Finnish project (Aksela 2016) developed a strategy on how to train chemistry teachers in ESD based on a number of areas such as:

- teaching of chemistry in context (e.g. climate change);
- the four dimensions of sustainable development (society, environment, culture and economy);
- pedagogical content knowledge (required for microcomputer-based laboratory teaching);
- exploiting modern technology in teaching.

There is a growing consent that GC should feature more prominently in chemistry education across all sectors. Clearly, there is a number of potential benefits associated with the introduction of GC even at lower levels of education. These include:

- relating traditional chemistry concepts to the real world context;
- connecting chemistry with other school subjects and aspects of students' lives;
- attracting bright students to the chemistry-related professions;
- students to become more scientifically literate and better citizens (Braun et al. 2006, Goes et al. 2013, Anastas, Beach 2009, Bradley 2002).

Students experiencing GSCE also develop a critical mind by gaining higher-order thinking skills (e.g. analysis, evaluation, synthesis) which enable them to react to the complex sustainability issues in line with the principles of SD (Chen et al. 2020).

Overcoming barriers to green and sustainable chemistry education

As in the case with ESD, the initiatives taken so far to disseminate GSCE across the science and particularly the chemistry curricula, were not yet sufficiently coordinated. Hence, despite registering remarkable progress, this ambitious educational project is still considered, as 'a work in progress' (MacKellar et al. 2020, Linkwitz et al. 2021).

In fact, although the process of integrating the content and theory of GC was partly successful in many institutions across the globe it still encounters a number of persistent obstacles along the way, making it harder for educators and policy makers to make further inroads at a faster pace. Some of these obstacles have been identified to be:

- lack of knowledge about GC among staff / educators;
- a crowded chemistry curriculum with so much fundamental theories regarded as essential;
- a limited number of pedagogical material currently available, including greener laboratory experiments;
- few educators and decision-makers were experienced enough or in a position to update and green the curriculum accordingly;
- a sense of scepticism or inertia by a number of established educators and scientists to adopt the GC approach (i.e. professional and institutional resistance);
- prioritising on research and publications at the expense of creating and budgeting for the necessary resources required to affect such an educational reform (Clark et al. 2012, Kopnina 2012, Haack, Hutchison 2016, Zuin 2019, Zuin et al. 2021).

This is not a complete list and literature reveals further possible complications such as the language barrier (which may limit access to international literature), lack of financial, social and economic support and other issues related to definitions and GC metrics used by different academics and decision makers (Matus et al. 2012).

All these barriers tend to reduce awareness among potential educational stakeholders and need to be addressed continuously in order to allow GSCE to flourish and boost the propagation of the broader and parallel concepts of SD.

One effective way to overcome most of the above-cited barriers is to produce and continuously promote updated and relevant educational material and make it immediately accessible to educators. Although the first published educational resources were mostly addressed to an undergraduate and postgraduate audience, the situation is progressively changing and it now includes an increasing number of books and online material that have been adapted to reach other levels of education and the community at large.

Current open educational resources about GSC, that are available to educators and students alike, include a number of textbooks, laboratory manuals, short publications, research and education networks, webinars, graded laboratory activities, educational videos and even initiatives intended for young schoolchildren.

There are other methods through which students and teachers can get more involved in green and sustainable chemistry. These include participation of students in outreach activities organised by the various GSC institutions and centres proliferating in various parts of the world, voluntary participation of teachers in workshops, training courses and summer schools organised periodically by various accredited organisations and universities (Fenech Caruana 2015, Green Chemistry Institute 2021a, Royal Society of Chemistry 2021).

Infusing sustainability in education

More than ever, the world needs quality education to promote the essence of sustainable development. Science, and chemistry in particular, play a critical role in disseminating the concepts of sustainability and help solving the global challenges through various ways including research, innovations and education.

Literature strongly points out that the most effective way to implement concepts of SD in education is by embracing and integrating the principles of GSC in newly designed curricula and to adapt them to different levels of education, starting from the years of compulsory science education up to university. This has to be complemented by the continuous professional development of educators, providing them with the appropriate tools (updated textbooks and other resources) and pedagogies to be able to motivate their students accordingly.

All this is becoming urgent and a global joint effort is required to create and promote a strategy and possibly a road map to mainstream GSC concepts and practices into the science or chemistry curricula and as part of a broader, cross-curricular, multidisciplinary ESD. This has already been launched recently, at university level, through the action spearheaded by the Green Chemistry Institute of the American Chemical Society in an initiative denominated as the 'Green and Sustainable Chemistry Education Road Map'. Such a strategic masterplan has a clear vision which describes a number of green and sustainable core competences and promotes a number of initiatives required to achieve the same vision of training and inspiring chemists to overcome the global challenges of sustainability (MacKellar et al. 2020, Green Chemistry Institute 2021).

What needs to be done, from now on, is to construct an adapted version of such a roadmap which enables pre-university students and educators to adopt a systematic strategy to ensure the optimisation of teaching and learning of the basic tenets of sustainability. This has to include a number of features such as:

- designing new programmes for GSCE including appropriate concepts, clear objectives, pedagogies and methods of assessment;
- promoting and propagating best practices through the integration of GSCE in chemistry and other curricula in the right educational settings;
- investing in training more educators on GSCE and ESD across all levels of education;
- exploiting the various GC and SC networks to promote GSCE worldwide (including developing countries);

- prioritising GSC in all efforts to re-shape education in the context of more sustainable economies and societies (collaborating with international programmes such as UNESCO ESD initiatives);
- involving stakeholders such as the private section, academia and civil society in designing new and effective strategies in GSCE;
- enhancing mainstream GSCE in professional training, possibly involving also public-private partnerships.

(Zuin, Eilks 2019, Zuin et al. 2021)

In other words, future educators need to be well-versed in this growing area of education, and also be well-equipped with an effective pedagogy that enables them to transfer the core principles of sustainability to their target audiences. This may be done in many ways exploiting all possible educational resources, platforms and fora.

Although this may appear to be a tall order, such recommendations stand a good chance of providing new opportunities to achieve further progress in a holistic education that reflects the relentless population explosion and its impact on life including a greater demand for resources and changing scenarios (changing climate, changing planet and a changing society).

Conclusion

In the light of all this and the continuous evolution of socio-educational priorities, educators are therefore urged to prepare students on how to optimize their intellectual potential - rather than celebrate an 'artificial intelligence', and develop into smarter citizens - rather than wizards of 'smarter' devices, by empowering them to practise the art and science of 'green and sustainable chemistry', and by teaching them the tricks of the trade of sustainability… and also how to propagate such principles and apply them in everyday life. Let's lead our next generation to the forefront of a radical educational reform aiming to allow this 'pale blue dot' (Sagan et al. 2017) to shine brighter and evolve into a 'greener' and more habitable planet for its future inhabitants.

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