Integrating Green Chemistry and socio-sustainability in Higher Education:

successful experiences contributing to transform our world

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More than ever, Green Chemistry can be considered a powerful tool to modify unsustainable practices in Chemistry, Engineering and correlated areas all over the world. It is well-known that the contextualized insertion of the Green Chemistry principles into the curricula in higher education institutions (HEI) can contribute to a better professional education, modifying and engaging students to learn conceptual contents associated to procedural and attitudinal subjects.

In order to promote Chemistry Education and Education for Socio-sustainable Development in Latin America and Africa, the project 2013-041-3-300 coordinated by Prof. Zuin (Brazil) and Prof. Mammino (South Africa) involving researchers, lecturers, professors, students and related HEI representatives from 14 different countries has been developed to study, adapt and create new contents for HEI. The project webpage available in Portuguese, Spanish and English can be seen on **http://greenchemed.iupac.ufscar.br/**

At Federal University of São Carlos, São Paulo, Brazil, for instance, a number of teaching experiments and related didactic initiatives have been conducted in the undergraduate and post-graduate levels since 2013, considering topics of ultimate importance locally, mostly associated to sustainable agriculture, agro-resilience, green chemistry and socio-environmental technologies, especially for the bio-rational control

of plagues. As an example, multifactorial mechanisms to repel, control or eliminate *Aedes aegypti* have been studied, since they are the main type of mosquito that spread Zika, dengue, chikungunya, and other viruses. Such scientific approaches have been transformed and adapted to make them suitable to be used as learning objects at UFSCar [1-3].

As a consequence of multiple actions at the Chemistry Department, another collective initiative was the elaboration and implementation of a new curriculum for teaching education at UFSCar at the beginning of 2017, emphasising the Green Chemistry principles in several theoretical and practical subjects, including one dedicated exclusively to Green Chemistry and Sustainability projects.

At University of Venda, South Africa, the Chemical/science education at the tertiary level is a type of educational research fully integrated within tertiary-level science teaching. It aims at continuous enhancement of the quality of the teaching activity through the investigation of students' difficulties, through general-character reflections on contents and approaches, and through active participation in international meetings and debates. Particular attention is given to crucial issues like the language-related difficulties encountered by science students studying through a second-language, or the exploration of approaches to suitably and effectively incorporate education for sustainable development into the course activities, and to the educational aspects of advanced chemistry courses, because of the comparative scarcity of studies concerning the teaching of advanced chemistry material.

The total picture - from raw materials through beneficiation to research, including management aspects - is presented. Therefore our courses provide a firm foundation in chemical ideas, processes, and applications and the context of Chemistry in society. Experimental and field work form an integral part of all courses and self-initiated research is encouraged at postgraduate level.

Apart from the current courses, several main meetings and workshops have been organised by the coordinators, as are the case of:

- Green Chemistry Education Session on the 4th, 5th and 6th International IUPAC Conference on Green Chemistry (2012-2016) [4-5]*:*
http://www.ufscar.br/icgc4/, *http://www.saci.co.za/greenchem2014/index.html and http://www.greeniupac2016.eu/*

- Green Chemistry Session on the Brazilian Chemical Society Annual meeting, Brazil (2013-2016):
http://www.sbq.org.br/36ra/workshops.php#hiddenDiv6,
http://www.sbq.org.br/37ra/coordenadas-qve.php and
http://www.sbq.org.br/37ra/workshops.php,
http://www.sbq.org.br/38ra/programacao-completa/conferencias-convidadas and
http://www.sbq.org.br/38ra/programacao-completa/sessoes-coordenadas

- 2nd African Conference on Research in Chemical Education:
https://sites.google.com/site/acrice2015/

In this context, divulging material about the project have been prepared and disseminated by magazine articles, hypertexts, scientific papers and a didactic book, the last one organised by Prof. Zuin and Prof. Mammino and published by the Royal Society of Chemistry in 2015 (Worldwide Trends in Green Chemistry Education, http://pubs.rsc.org/en/content/ebook/978-1-84973-949-8#!divbookcontent)

Another book focusing on the topic will be published by the UFSCar publishing soon, also integrating many members of the project. It is important to emphasise that we aim at mobilising efforts to achieve the United Nations 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals. These objectives are discussed together with industries and governmental/non-governmental organisations as well as schools.

Some members are actively participating, as can be seen below:

The Pontificia Universidad Católica del Perú

Currently, in our country, the state is implementing a policy to support the development of science and technology. Among other strategies, it is providing financial support to graduate schools, specifically the master's programmes showing the best conditions for the formation of new researchers. Our master's program is one of the winners of this subsidy program, so the conditions to promote the research in Green Chemistry are quite favourable.

Thus, we focus particularly on the following objectives of the project:

- Proposing general modules for up to date university Green Chemistry curricula for chemistry courses.
- Development of Green Chemistry contents for the theoretical and experimental components of such courses.
- Contributing to establish Green Chemistry as a component of training of professionals and to promote the public understanding of Green Chemistry principles.
- Developed activities: in 2013, a new curriculum for the Master's program in Chemistry was implemented. In this new curriculum a Green Chemistry course was included as one of the elective courses. In this course, the fundamental concepts of green chemistry are presented and the application of its principles is discussed by mean of the review and critical analysis of the research reported in the relevant scientific literature.

After completing the course the student will be able to:

- Apply the fundamental principles of green chemistry in the critical analysis of chemical processes reported in research.
- Analyze, from a green approach, the design, selection of materials and reaction conditions in chemical synthesis processes.
- Analyze, from a green approach, analytical methodology, sample treatment and analysis techniques.
- Develop a green proposal for traditional applications in the field of organic synthesis and / or analytical.

The Universidad Nacional de La Plata, Argentina; Universidad Pedagógica y Tecnológica de Colombia, Universidad del Cauca, Colombia;

- A number of short courses on green chemistry for the undergraduate level as well as outreach activities (school, communities).

The Brazilian Green Chemistry school, Brazil

The Brazilian Green Chemistry School is based at the School of Chemistry of the Federal University of Rio de Janeiro (UFRJ) which offers undergraduate courses in chemical engineering, industrial chemistry, food engineering and bioprocess engineering and a graduate program in Technology of Chemical and Biochemical Processes. The Green Chemistry School has resource to a staff made up of professors from UFRJ and other universities, as well as researchers from technology centers and companies. It conducts surveys on the state of the art on bio-based chemicals from raw materials abundant in Brazil, organises courses, workshops and meetings on green chemistry and related topics and develops materials, experiments and demonstrations for students at a high school level that can also be used for outreach activities.

The Faculty of Sciences and Technology, Portugal

This four- year doctoral programme was born in the largest Centre of Excellence / Laboratório Associado para a Química Verde (LAQV) at REQUIMTE and is now hosted by three Portuguese Universities, NOVA Lisbon, Porto and Aveiro, since 2014. During the first year of the course the students attend mandatory and optional courses offered by the three Universities. During the 2nd, 3rd and 4th years, the students develop projects covering different fields of Sustainable Chemistry, taken in a very wide view of the research agenda of the SusChem platform (the European Technology Platform for Sustainable Chemistry).

FCT-NOVA is highly committed to the dissemination of Green Chemistry to the general public hosting different activities for high school students. The students have the opportunity to do research together with Master and PhD students in projects focused on the development of sustainable processes for the production of novel products for different applications. The training period starts with a lecture introducing the

Principles of Green Chemistry and Sustainable Engineering. Special effort is made to give practical examples of applicability of concepts to the real world. On-going research activities are fostering the transfer to the industry of a new philosophy before chemical reactions and processes. The methodology includes the co-supervision of Master and PhD students developing collaborative projects with national companies.

The Green Chemistry Centre of Excellence, University of York, UK

In addition to the successful Masters course in Green Chemistry & Sustainable Industrial Technology that has been running at the University of York for the past 15+ years, green chemistry will now be incorporated in the undergraduate chemistry curriculum at York, both in taught and practical material.

Greener Reagents and Sustainable Processes (GRASP) project has been running for the past 2 years with the aim of addressing the use of hazardous/unsustainable chemicals in teaching labs, and providing chemistry undergraduates with the requisite skills and knowledge to prepare them for future careers in the chemical industry.

The GCCE recently launched the RenewChem initiative, which incorporates graduate training as one of its core activities. The training will be specifically aimed at equipping future employees of the chemical industry with the requisite skills and knowledge to make an immediate impact on the transition to green manufacturing and circular economy within the chemical industries.

A bespoke e-learning platform has been developed with the aim of promoting the uptake of green and sustainable methodologies, with a particular focus on the synthesis of pharmaceuticals. The CHEM21* online learning platform comprises a range of free, shareable and interactive educational and training materials that have been created in collaboration with industry.

Also via the CHEM21* project the GCCE, in collaboration with other CHEM21 academic and industry partners, have also organised a series of face-to-face training workshops

aimed at graduates, PhDs and postdocs covering topics such as metrics, route selection, safety, biocatalysis to name but a few.

We continue to engage Masters-level students and provide them with hands-on experience of organising and delivering public engagement activities to a wide range of audiences, from primary school children through to members of the general public. Many of the experiments and exhibitions have focus on obtaining chemicals from food waste as a way of introducing green chemistry principles in a way that is directly relevant to a non-technical audience. The GCCE also continues to engage with our international partners to share knowledge and examples of best practice, in particular through the G2C2 network.

References

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