A inserção da Química Verde nos programas de pós-graduação em Química do Brasil: tendências e perspectivas

The inclusion of green chemistry in postgraduate programmes in Chemistry in Brazil: trends and perspectives

La inserción de la Química Verde en los programas de posgrado en Química en Brasil: tendencias y perspectivas

Vânia Gomes Zuin, PhD in Sciences and Education from University of São Paulo (USP), professor at the Federal University of São Carlos (UFSCAR) and Brazilian coordinator of the Project Sustainable Education and Environmental Development (SEED) in Latin America. Address: Rodovia Washington Luís (SP-310), km 235. ZIP Code: 13565-905 – São Carlos, SP. Telephone number: (16) 3351-8096. E-mail address: vaniaz@ufscar.br.

Resumo

Este artigo tem como meta investigar as formas pelas quais os princípios da Química Verde têm sido inseridos nos programas brasileiros de pós-graduação em Química. Parte da premissa de que, diante dos atuais desafios que tocam à produção de conhecimentos e formação de recursos humanos voltados à sustentabilidade socioambiental, faz-se necessário refletir sobre os temas, as propostas, as potencialidades e os limites relacionados à Química Verde que ocorrem nos cursos ofertados por mais de 40 programas de pós-graduação em Química do País. Observa-se que a quase totalidade desses programas apresenta disciplinas, grupos, linhas e projetos de pesquisa para o desenvolvimento, a análise e a formação que permitem repensar as formas de geração de materiais e processos verdes no contexto acadêmico brasileiro contemporâneo.

Palavras-chave: Química Verde. Pós-Graduação em Química. Ciência, Tecnologia e Inovação (CT&I). Sustentabilidade.

Abstract

This article aims at investigating ways in which the principles of Green Chemistry are included in Brazilian postgraduate programmes in Chemistry. It assumes that, in the face of today's challenges concerning the production of knowledge and the formation of human resources focused on social and environmental sustainability, it has become necessary to reflect on topics, proposals, potentialities and limits related to Green Chemistry, which occurs in the courses offered in over 40 postgraduate programmes in Chemistry in the country. It is possible to observe that almost all of such topics include disciplines, groups, research lines and projects for development, analysis and formation which permit the rethinking of ways of creating green materials and processes in the contemporary Brazilian academic context.

Keywords: Green Chemistry. Postgraduate Programs in Chemistry. Science, Technology and Innovation (ScT&I).Sustainability.

Resumen

Este artículo tiene como objetivo investigar las formas mediante las cuales los principios de la Química Verde se están insertando em los programas brasileños de posgrado en Química. Se supone que, dados los retos actuales que afectan la producción de conocimientos y la formación de recursos humanos centrados en la sostenibilidad socioambiental, es necesario reflexionar sobre los temas, lãs propuestas, las potencialidades y los límites relacionados a la Química Verde que ocurren en los cursos ofrecidos por más de 40 programas de posgrado en Química de Brasil. Se observa que casi la totalidad de estos programas presenta asignaturas, grupos, líneas y proyectos de investigación para el desenvolvimiento, análisis y la formación que permitan repensar las formas de generación de materiales y procesos ecológicos dentro del contexto académico brasileño contemporáneo.

Palabras clave: Química Verde. Posgrado en Química. Ciencia, Tecnología e Innovación (CT&I). Sostenibilidad.

Introduction

Nowadays, the construction of paths toward sustainability is admittedly permeated with obstacles, often due to existing risks, with emphasis on environmental risks.

Socio-sustainable development models can be understood as processes whose most important restrictions are the exploitation of natural resources, scientific and technological orientation, and institutional landmarks, with an emphasis on "qualitative aspects, notably those related to equity, the use of resources – in particular of energy resources – and the generation of residues and contaminants" (JACOBI, 2003, p. 195; JACOBI; GUNTHER; GIATTI, 2012).

In this sense, chemistry significantly changed our lives during the 20th century, be it due to medicines, materials for clothing, food, housing, fuels for different equipment, or to a myriad of other products regarded as essential. However, even today the production process – and its externalities – is also seen as an enterprise that may give rise to risks, given the environmental disasters that have occurred around the world, such as in Seveso (Italy, 1976), Bhopal (India, 1984) and Toulouse (France, 2001), among others (LACANSTER, 2010).

Given contemporary demands across the planet, especially those related to environmental issues, it is necessary to reflect on the most suitable ways to produce scientific and technological knowledge that reduce or eliminate the generation of waste and toxic effluents. In this context, we may observe the movement known as Sustainable Chemistry, benign by design, or Green Chemistry, started with greater emphasis in the late twentieth century, mainly in the United States, England and Italy. This movement can be defined as "the application of a number of principles that reduce or eliminate the use or generation of hazardous substances including design and manufacture" (ANASTAS; WARNER, 1998, p. 11) and aims at reducing the risk by means of, ideally, eliminating the danger associated with toxic chemical substances, instead of the restriction related to exposure to them. To put it another way: instead of using the historical approach of controlling the concentrations or emissions

of a particular substance, Green Chemistry seeks to modify the intrinsic nature of substances, which will then be unable to cause pollution, making it unnecessary to remedy environmental impacts often observed nowadays (CORREA; ZUIN, 2009; CORREA et al., 2013).

The 12 principles proposed by Anastas and Warner (1998), which delineate the actions of Green Chemistry are: 1) prevention (one must prevent, rather than treat, waste generation); 2) atom economy (synthetic methods must be designed so as to maximize the incorporation of all materials used in the final product); 3) reactions with lower toxicity compounds (methods that use or generate substances with little or no toxicity must be planned); 4) development of safer chemicals (one should reduce or eliminate the toxicity without compromising effectiveness); 5) decrease in the use of solvents and auxiliaries (every step for the manufacture and use of chemicals should be reviewed); 6) energy efficiency (energy requirements should be minimized in chemical transformations); 7) use of renewable substances (renewable raw materials must be used to the detriment of non-renewable resources); 8) avoidance of the formation of derivatives (the use of blockers, protection or deprotection reagents, and temporary modifiers must be avoided in chemical and physical processes); 9) catalysis (catalytic reagents as selective as possible should be used in chemical transformations); 10) development of degradable substances (products that fulfil their function and do not persist in the environment, degrading into harmless materials, must be designed); 11) real-time analysis for the prevention of pollution (analytical methodologies should be established to prevent the formation of toxic substances in a chemical process); and 12) safe chemistry for the prevention of accidents (the use of substances that minimize the potential for leaks, fires, explosions, etc. must be planned).

The Green Chemistry movement has been growing in the past years, involving the main world Chemistry societies, such as the International Union of Pure and Applied Chemistry (IUPAC), which seeks to establish guidelines and goals aimed at the development of Green Chemistry in the world (HÖFER, 2009; JESSOP, 2011). In Brazil, Green Chemistry has been reaching greater projection mainly in the industrial sector, but also in universities and Government agencies. Since the mid-2000s, many

[1] http://www.inpi.gov.br.

educational and research institutions, professional associations and companies in the area of Chemistry and Engineering have promoted events to disseminate Green Chemistry. In 2004, the book "Green Chemistry in Latin-America" was published as a result of a project supported by IUPAC (TUNDO; ROSSI, 2004).

In 2007, the Brazilian Network of Green Chemistry was created. It aimed to act institutionally in order to promote scientific and technological innovations forcompanies, supported by the scientific community and government agencies, which included the establishment of the Brazilian School of Green Chemistry. In 2009 and 2010 many books were published aimed at Green Chemistry emphasizing the themes, studies and experiences found in Brazil, such as the work "Green Chemistry: fundamentals and applications", which received the 52th Bronze Jabuti award in the category "Exact Sciences, Technology and Computer Science", from Câmara Brasileira do Livro (CORREA; ZUIN, 2009), and the book "Green Chemistry in Brasil: 2010-2030", edited by the Center for Strategic Studies and Management in Science, Technology and Innovation (CGEE), which presented the following priority themes: biorefineries, through thermo-chemical and biochemical routes; alcohol-chemistry; oleo-chemistry; sucrochemistry; photochemistry; CO_2 conversion; bioproducts, bioprocesses and biofuels; alternative energy, including other cross-cutting key areas such as catalysis, modelling and process scheduling (CGEE, 2010).

In 2012, Brazil hosted the United Nations Conference on Sustainable Development(Rio+20), which triggered the preparation of the document "The Future We Want", which defends Sustainable Development to eradicate poverty at all levels, among other propositions. As part of the programming of Rio+20, CGEE promoted nine panels, one of which discussed Green Chemistry and the challenges for Sustainable Development.

Similar aspects related to the increase in the number of studies that seek renewable energy sources and clean processes in the area of Chemistry were also discussed in the book "Contribution of the Brazilian Postgraduate Studies to Sustainable Development: Capes at Rio+20",

published by the Coordination for the Improvement of Higher Education Personnel (Capes),whose main objective was to present the advances in the Brazilian Postgraduate studies at Rio+20 (BRASIL, 2012).

Also in 2012, as one of the results of the project Sustainable Education and Environmental Development (SEED) in Latin America supported by IUPAC, the 4th International IUPAC Conference on Green Chemistry (4th ICGC) was held in Foz do Iguaçu, Brazil, under the auspices of IUPAC and the Brazilian Chemistry Society (SBQ). The Conference was attended by more than 600 participants from more than 45 countries, representatives of the academic, industrial, governmental and non-governmental sectors, who discussed recent advances and future prospects in the field of Green Chemistry, both in Brazil and abroad. The 4thICGC program included mini-courses, plenary talks, technical and business lectures, oral presentations, posters, and roundtables.

In order to deepen the discussions in the roundtables of the 4th ICGC, some guideline questions were sent to its members, in the case of the panel entitled Perspectives on Green Chemistry: the role of the Brazilian research funding agencies, formed by representatives of the main agencies which fund scientific and technological research and training of researchers from Brazil (such as Capes; the National Council for Scientific and Technological Development, CNPq; and the Research Support Foundation of the State of Rio de Janeiro, Faperj). In order to verify the reach of Green Chemistry in the context of the Chemistry Postgraduation in Brazil, the guiding questions of discussions at the 4th ICGC were expanded and forwarded to all coordinators of professional Masters, MSc and PhD Courses in the area of Chemistry in Brazil. Thus, the answers presented and debated at the 4th ICGC provide the purpose of this article: understanding the nature and the ways by which Green Chemistry is included in Chemistry Postgraduate programmes in Brazil, and a glimpse of the main challenges, potentials and limits of this green movement in the current Brazilian academic context.

Outline of survey and data analysis

Today, the area of Chemistry has 61 postgraduate programmes recommended by Capes, totalling 96 courses: 57 academic Master's

courses; 37 doctoral courses; and two professional masters' courses, present in practically all Brazilian States (BRASIL, 2012). The older programmes are consolidated and support several other courses, especially in the Midwest and North regions in the country. One of the main challenges of the area is to further consolidate courses in these areas. It can also be noted that the "accredited professors in the area work in all sub-areas of chemistry with strong interaction with related fields (medical fields, physics, agronomy, biology, biotechnology, biochemistry, materials, engineering, teaching, etc.). Such multi- and interdisciplinarity is evidenced by the diversity and quality of scientific production" (BRASIL, 2012, p. 106).

In addition to the significant number of articles published (over 10 thousand, mostly in international journals), the "technological advancement in the area can be measured by the number of patents deposited – 272 during the triennium 2007-2009 – corresponding to an increase of 55% over the previous triennium. Although most masters and doctors trained in the area of chemistry are "absorbed by the academy, about 20-25%" have been incorporated by both public and private non-academic sectors. The area is consolidated internationally, and it is one of the fastest growing areas in terms of quotes/articles in Brazil" (BRASIL, 2012, p. 106).

Many topics of research in the area of Chemistry relate to the principles of Green Chemistry: the development of new materials; use of plant products; biofuels (biodiesel and ethanol); hydrogen production; fuel cells; and additives and antioxidants for biofuels. Such increase in the past five years can be explained on the basis of the demands and incentives in the search for renewable and green processes. Faperj has launched Edict No. 27/2012 (Support to the Scientific and Technological Research in Green Chemistry – 2012), which aimed at encouraging the development and innovation of environmentallyfriendly products and chemical processes. The guidelines of Edict No. 27/2012 were based on the book "Green Chemistry in Brazil: 2010-2030" (CGEE, 2010), and the projects approved focused mainly on organic synthesis, followed by biomass and biocatalysis (CORREA et al., 2013).

Other leading actions, not necessarily named Green Chemistry, were also developed by other research funding agencies together with companies. The program of the São Paulo Research Foundation (Fapesp) aimed at Bioenergy (BIOEN) also aims at stimulating and coordinating research and development activities using academic and industrial laboratories to promote the advancement of knowledge and its application in bioenergy-related production areas in Brazil.

Other agencies, in addition to encouraging research in science, technology and innovation in that direction, have sought to understand how Green Chemistry develops in Brazil.

Thus, due to the 4th ICGC, the questions raised by its Scientific Committee that aimed at mapping the ways in which Green Chemistry is included in several institutions, in Brazil and in the world, were forwarded to their respective representatives.

Therefore, coordinators of postgraduate programmes in Chemistry in Brazil received questions sent by the area of Chemistry of Capes, under the coordination of Prof. Dr. Luiz Carlos Dias, whose main results were presented at the roundtable entitled "Perspectives on Green Chemistry: the role of Brazilian research funding agencies", of the 4th ICGC. The questions are listed below, and the analysis of the answers is discussed in this article.

1. Is the theme Green Chemistry in any way included in your programme and institution?
2. What are the benefits of and difficulties in its implementation? (How do you evaluate its implementation?)
3. Are there proposals to insert Undergraduate or Postgraduate disciplines, seminars, workshops, symposia?
4. Are there proposals to hire professors with research lines in Green Chemistry?
5. What are the future prospects or concrete plans of your institution, in order to promote the inclusion of the Green Chemistry theme?
6. Please make comments that you may deem pertinent, not covered by the questions above.

Of the 61 coordinators of postgraduate programmes in Chemistry, 45 answered the questionnaire. By means of the content analysis, responses were studied, considering the written information as a starting point to identify the content (FRANCO, 2007). The categories established are related to the main idea of the questions, namely: the institutionalization of Green Chemistry; potential and limitations of Green Chemistry; and prospects for the establishment and the permanence of Green Chemistry.

The *status quo* of Green Chemistry in Brazilian Chemistry postgraduate programmes

The concept of Sustainable Development has been inserted in Postgraduate programs. Created in 1980, such a concept was present in Agenda 21, a document adopted by more than 170 countries that attended the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, the Rio 92. The main assumptions that make up this concept are the following:

> [...] long-term perspective, support of the capacity of ecosystems, inter-generational responsibility, precautionary principle, community and participatory welfare, ideas of cooperation, conservation and fairness, as well as the notion that sustainability involves various dimensions, ensuring at least an interrelation of the ecological, economic and social dimensions (BRASIL, 2012, p.11-12).

Such assumptions, which structure the foundations of the concept of Sustainable Development, have determined the engenderment of several scientific-epistemological thoughts that defend an anti-predatory attitude towards natural resources. Among such thoughts we should highlight the Green Chemistry philosophy, in the area of Chemistry, Engineering and related fields. By analysing the responses of the coordinators of more than 73 postgraduate programmes in Chemistry in the country, one can observe how the theme Green Chemistry racks up more and more space both in the disciplines and *ethos* of such programmes.

In answer to the questions "Is the theme Green Chemistry in any way included in your program and institution?," 95% of the respondents ensured that the theme Green Chemistry is organically linked to the disciplines of their respective programmes, which confirms the institutionalization of this movement:

> The same theme is addressed in the discipline "Air, Water and Soil Chemistry" offered at the Postgraduate Programme (PPGQ5).

> At the PPGQ we have an optional discipline: "Green and Sustainable Chemistry". Furthermore, our research group [...] works by aiming at the development of methodologies and the use of renewable resources in synthesis. Consequently, students are allowed to apply the principles of Green Chemistry during Postgraduate courses by means of Scientific Initiation programmes (PPGQ2).

> Graduation: Bachelor of Environmental Chemistry (evening). Postgraduate: Discipline "Green Chemistry", Research Lines "Environmental Chemistry" and "Green Chemistry" with at least a dozen professors involved. Winter Course: Green Chemistry with the participation of around 50 students from all over the country (PPGQ8).

It is interesting to note how lecturers, professors and researchers of Postgraduate programs in Chemistry have emphasized the presence of Green Chemistry in their disciplines, research and courses, be it directly or indirectly. The massive presence of the assumptions of Green Chemistry need to be understood in the context of the concern about the environmental consequences of the disposal of chemical waste, for example, which often affects life as a whole permanently. To the second question posed to coordinators/researchers, "What are the benefits and difficulties to its implementation?", the answers showed that many consider its potential obvious, but the education programmes which enable the proper treatment of issues related to Green Chemistry are currently one of the main constraints for its insertion in institutions:

> The main benefits aremultidisciplinarity, a large perspective of technological innovation, attractiveness to the private sector and development agencies, the great visibility of projects carried out in their scope, and the complementarity of efforts for the development of projects that can really make a difference for the future of humanity (PPGQ11).

> Green Chemistry-related topics are current and raise great interest from students. Knowledge in the area contributes to a broader formation and to the development of research projects aligned with the concern with the environment and sustainability. The difficulties are more related to the availability of professors who work in the core themes of Green Chemistry to offer courses focused on this theme. In general, the theme Green Chemistry is diluted in the disciplines taught in our PPG (PPGQ16).
>
> [Benefits include] Decreasing the amount of waste generated in undergraduate laboratories and, for some years, eliminating the use of hazardous chemicals and pollutants such as lead salts and sulfochromic solution; selective garbage collection; appropriate final destination via companies specializing in the treatment of chemical waste.
>
> Difficulties: financial limitations to give due destination to household waste and waste from laboratories; inadequate training of technicians responsible for laboratories; community awareness regarding the importance of the subject; final destination of some materials collected selectively, such as reagents glasses (PPGQ20).
>
> As (...) there are no professors with specific training in Green Chemistry, it would be important to provide them with a thematic update, which could promote a change in attitude and, consequently, in the training of academics (PPGQ15).

In general, all respondents agreed that the main benefits brought by the insertion of Green Chemistry into their programmes are related to the dissemination of a formative concern, that is, encouraging the renewed process of awareness of the importance of reflecting upon the scientific enterprise and the destination of chemical residues, in such a way to develop resistance to an instrumentalized and immediate perspective (ZUIN, 2011). It refers, therefore, to encouraging a mindset that considers crucial the history of the generation and disposal of waste, as it is known that considering such a history also means dealing with the history of human relationships and production.

The emphasis assigned to such a mindset and training show the difficulty in finding professionals whose research is directly and explicitly related to Green Chemistry, which represents a reinforcement of the need for the principles of Green Chemistry to be present in the respective

curricular structures sinceundergraduate courses. The few respondents who detailed the ways in which the implementation of the principles of Green Chemistry are evaluated considered the demand or interest in the proposed activities by the academic community one of the best evaluation criteria.

The following answers must be detailed as regards the question about the institution's future perspectives or concrete plans to promote the inclusion of the Green Chemistry theme, which means identifying prospects for the establishment and permanence of this movement:

> The teaching staff of the Department of Chemistry develops studies by practicing Green Chemistry, both in undergraduate and research laboratories. The main goal is to keep the planning so new members in the Department, both students and teaching staff, practice the principles of Green Chemistry. In this sense, seminars and courses will be scheduled to be taught regularly at the Programme (PPGQ25).
>
> In 2012 the university created a group called Sustainable (federal university), as well as a committee to discuss and improve issues related to Green Chemistry. The department of Chemistry has one representative in this committee (PPGQ20).
>
> There are research groups working at different fronts of the envelope "Green Chemistry". The public exams to fill vacant teaching positions aim to hire researchers in various fields that the [Institute] considers strategic, many of which address the theme Green Chemistry (PPGQ25).
>
> The future will include the topic through courses, workshops and lectures aimed not only at students but also at teachers (PPGQ25).

Many of the postgraduate programmes that participated in this study noted that the presence of Green Chemistry in their disciplines is already an undisputed reality. It is a fact that both the vast majority of respondents encouragethe future hiring of teaching staff and the continuing concern that students also become interested in the discussion of its assumptions.

The additional comments submitted by respondents allowed us to understand other dimensions involved in the object of this article. For

example, which individual actions of the teaching staff who participate in other institutions or postgaduate programmes have enabled the creation of programmes in which the research on Green Chemistry is a specific locus:

> A group of teachers (...) is organizing a Brazilian School of Green Chemistry (EBQV). (...). We have created a Brazilian Network of Green Chemistry, which has as one of its purposes offering specific courses for students and professionals in Chemistry. The professional master's (...) in Petrochemical and Biofuels Engineering, of which I am a permanent faculty member, isimplementing an emphasis on Green Chemistry. I think there are no formal actions [at the institute], but there are people here involved in multi-institutional actions (PPGQ43).

The questions, which have been forwarded to all coordinators of postgraduate programmes in Chemistry in Brazil, and whose first intention was to subsidize the discussions in the roundtables of the 4th ICGC, promoted reflection on the integration of principles of Green Chemistry into their present and future activities, be it in research, teaching, extension or management. In a sense, the questions also contributed to induce a deeper understanding about the motivations, themes and practices in the studies aimed at the development of materials and scientific and technological procedures that impact the environment to a lesser degree in the field of Chemistry:

> In this sense, the proposals direct us towards requiring from the management a physical structure, and even graduation and Postgraduate courses that prepare students, technicians and teaching staff to act on the environmental issue. At the same time, the questionnaire has prompted us to broaden our actions regarding Green Chemistry at the PPGQ (PPGQ13).

There were reports about the difficulty in defining the meaning of Green Chemistry, which was handled by requesting the whole teaching staff to think about the questions posed:

> This experience has made it clear that the issue is indeed very comprehensive. It is a cross-cutting issue and many of our teaching staff are interested in it, perhaps even as a result of their lines of research and its implications. It is important that many of the initiatives of our

> teaching staff concerning this topic are not visible under this label "Green Chemistry". It is true that actions are spontaneous and motivated by the perception and awareness and interest of the faculty. The theme is relevant and a matter of "Chemistry education," but it requires awareness of the whole community. In our opinion, this is an important and fruitful area. However, it requires carefulness that we do not usually have, especially when we are pressed for results (PPGQ35).

Respondents evidenced, not only in this statement, that there is a demand for an educational and formative cultural character thatmust be present in all academic institutions. The inclusion of Green Chemistry needs to move beyond labels, since current and future demands require a constant critical review of the objectives, principles and implications that guide the generation of results, products and processes that have to be green.

Final remarks

Green Chemistry has become more present in postgraduate programmes in Chemistry in Brazil. Be it directly or indirectly, its premises gain academic ground in such a way that it spreads an ethos in which the need that socio-sustainability be not only a protocol label of some actions, but rather organically assimilated and materialized by Chemistry lecturers, professors and researchers in our country. The discussion about green products and processes becomes not only urgent but also decisive, at a time when both waste and human beings seem to be disposable, insofar as they are no longer deemed as productive. If the curse of unstoppable progress is unstoppable regression (ADORNO; HORKHEIMER, 1986), it does not mean that this is the inexorable destiny of human beings and the environment, because current regression is human construction and, as such, is liable to being modified.

The analysis of the responses of coordinators/researchers of Postgraduate Programs in Chemistry reveals that the main concern is the educational and cultural dimension of teaching staff and students. Following this line of reasoning, one should emphasize that several of the respondents stated that in future hiring of teaching staff and laboratory technicians, the principles of Green Chemistry must be taken into consideration as relevant items in the curricula of both.

Such a concern is definitely not a matter of chance, because the awareness that natural resources cannot be predatorily used also reflects on the assessment that human beings who use them must give them a new meaning, and that they also need to stop having predatory relationships. The basic assumptions of Green Chemistry, to the extent that they question forms of regression, confirm the veracity and the central importance of such a premise.

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