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Green Chemistry for Postgraduates

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ABSTRACT (Química verde para posgraduados)
The multidisciplinary nature of Green Chemistry is recognised worldwide as a route to the development of chemical products and processes with lower environmental impact. Green chemistry and sustainability have had a profound effect on the way industry wish to be perceived. To promote uptake of green and sustainable methodologies amongst the chemical and chemical-using industries requires the exemplification of green chemistry in education and training material to influence and inspire the next generation of scientists. Herein, we examine important aspect of successful graduate green chemistry courses and how the skills gained from such studies can open doors to careers in a wide cross section of chemistry related industries.

KEYWORDS: Green Chemistry, graduate, multidisciplinary, career, transferrable skills, courses

Resumen (Química Verde para posgraduados)
La naturaleza multidisciplinaria de la Química Verde ha quedado reconocida mundialmente como una ruta para el desarrollo de productos y procesos químicos con un menor impacto ambiental. La Química Verde y la sostenibilidad han tenido un profundo efecto en la forma como la industria desea ser percibida. Promover la apropiación de metodologías verdes y sostenibles entre la industria química y la consumidora de productos químicos requiere la introducción de la Química Verde a la educación y a los materiales de entrenamiento, para que ello influye e inspire a la siguiente generación de científicos. Aquí examinamos algunos aspectos importantes de los cursos de Química Verde exitosos para graduados y cómo las habilidades ganadas en esos cursos pueden abrir la puerta a empleos profesionales en una amplia gama de industrias relacionadas con la química.

Palabras clave: Química Verde, graduado, multidisciplinaria, carrera, habilidades transferibles, cursos

Increasing demand for chemicals worldwide, depleting resources, stricter legislation and the rising cost of waste disposal is placing increasing pressure on the chemical and related industries (Tucker, 2010). For any organisation to survive in the current climate, the issue of sustainability must be fundamental to the way it operates. The products of the chemical industry are ubiquitous in modern society and have greatly improved the quality of our lives; however manufacturing these products in both an environmentally compatible and economically viable way is of critical importance (Clark, 1999). Solutions will only be found through collaboration between a multidisciplinary community of chemists, biologists, engineers, economists and legislators. Hence the need for graduates with the requisite skills, knowledge and experience is growing.

Green Chemistry has undoubtedly been one of the most noteworthy advancements in the chemical sciences of late and is recognised worldwide to describe the development of more sustainable chemical products and processes (Anastas and Warner, 1998). Green chemistry and sustainability have had a profound effect on the way companies wish to be perceived and now more industries are putting the issue of sustainability as a key facet of their longer term strategies (Jenck, Agterberg and Droescher, 2004). The multidisciplinary nature of green chemistry is one of the keys to its success. The combination of chemistry, chemical engineering and biology are a powerful tool for meeting the challenges for developing cleaner processes. The emergence of Green Chemistry Centres in rapidly developing countries is also highly valuable as they have a wealth of natural resources and waste that could be exploited to produce valuable chemicals, materials and fuels. To realise this potential will require people with sustainability training.

To promote uptake of green and sustainable methodologies amongst the chemical and chemical-using industries requires the exemplification of green chemistry in education and training material to influence and inspire the next generation of scientists (Hjeresen, et al., 2000). From an industry perspective being 'green' is not enough on its own, and consideration of the sustainability including economics and viability of new developments is as important, if not more, than an enhanced environmental profile (Clark, 2006). Therefore green chemistry education itself may not be enough; chemists must also possess transferrable skills, have knowledge of the commercialisation of science and have the ability to work effectively with people from a range of disciplines and communicate science to a wider audience.

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Box 1

The GCCE and the CIEC (Chemical Industry Education Centre) at York were jointly awarded the 2012 ACS-CEI Award for Incorporating Sustainability into Chemical Education. This encompasses the CIEC and GCCE's work in this field ranging from primary right through to postgraduate level and outreach for the general public. Particularly highlighted were the CIEC's extensive programme of science CPD (professional development) and interactive websites and the GCCE's development of undergraduate practicals in green chemistry, the MSc course in Green Chemistry and Sustainable Industrial Technology and outreach activities.

A number of green chemistry courses are available around the world, for example Masters courses in Zaragoza (Spain) (Máster en Química Sostenible, 2012), Patras (Greece) (MSc degree in Green Chemistry, 2012), Imperial College London (MRes in Green Chemistry, 2012), and Sofia (Bulgaria) (Química Verde, 2012), Green Chemistry Doctoral Programmes are running at Bath (UK) (Centre for Sustainable Chemical Technologies, 2012), and Massachusetts (USA) (Center for Green Chemistry, 2012). In 2001, Professor James Clark and colleagues in the Green Chemistry Centre of Excellence (GCCE) at the University of York (UK) established the Masters degree course originally called Clean Chemical Technology and now known as Green Chemistry and Sustainable Industrial Technology (Masters Course in Green Chemistry, 2012). The course was first of its kind in Europe, is the only green chemistry course to have RSC accreditation and was recently commended as part of an ACS-CEI award for Incorporating Sustainability in Chemical Education (see Box 1).

The GCCE at the University of York (UK) is a world leading research centre which aims to promote the development and implementation of green and sustainable chemistry and related technologies into new products and processes (Green Chemistry Centre of Excellence, 2012). Originally established in 1999 as the Clean Technology Centre (CTC), the centre was awarded the status of Green Chemistry Centre of Excellence in 2005, and over the past 13 years a significant number of PhDs and Master students have graduated from the Centre. Hence this puts us in an ideal position to share in this paper our experiences of training graduates to enable them to make an immediate positive impact with future employers in sustainability terms.

What should a graduate experience to become a well-rounded, highly employable green chemist?

Postgraduate and graduate training in green chemistry should, in our opinion, ideally consist of a blend of taught material and research, in the areas of the principles of green chemistry, its application and commercialisation as well as opportunities to develop transferable skills. As mentioned previously, Green Chemistry is a multidisciplinary subject; to date most postgraduate Green Chemistry courses have been strongly chemistry linked, although some, such as York, have broadened syllabuses to accommodate law, the environment and business. The course at York does not just attract chemistry students, but those from a range of related academic backgrounds (see Box 2). The latest venture at UCBerkeley is remarkably multidisciplinary with interested academics from departments as diverse as Chemistry and History (The Berkeley Center for Green Chemistry, 2012). At graduate level, seminar courses and lecture courses in green chemistry are offered. The graduate activity will increase through support from the integrative graduate education and research traineeship "IGERT" program which will incentivise students to take green chemistry courses as well as offering opportunities to spend time in overseas green chemistry laboratories. Multidisciplinarity is key to the future of green chemistry – the next generation of graduates will need to work across several traditional boundaries.

The foundations of any Green Chemistry course are without doubt provided by the 12 principles of green chemistry, which are as relevant today as when they were conceived by Anastas and Warner in 1998 (Anastas, 1998). Students should become familiar with the fundamental philosophy and tools of green chemistry, which should incorporate understanding of the use of green chemistry metrics in order to calculate environmental impact of chemical processes; the control of environmental impact; as well as raised awareness of the legislative, financial and social factors connected with reducing environmental impact.

It is also important that teaching material incorporates up-to-date industrial case studies which demonstrate green chemistry in application and the direct relevance of the course content. To achieve this at York, the course is run in-collaboration with a wide range of companies and organisations that manufacture or use chemicals or are involved in chemicals management and policy, who are directly involved in the course delivery through lectures and workshops.

Box 2

Students admitted on to the course have degrees in a variety of different subjects including:

- Chemistry (and related courses)
- Pharmacology
- Environmental Biology
- Environmental Chemistry
- Pharmaceutical Science
- Chemical Engineering
- Pharmaceutical Engineering
- Material Science
- Analytical Science
- Biochemical Engineering
- Chemical Physics
- Macromolecular materials and engineering

Research Projects

Original research should be central to any postgraduate course on green chemistry. The aim of Green Chemistry graduate research projects should wherever possible be to solve current and real industrial problems and to put the theory into practice, applying green chemistry principles to process and product design. Real-life scenarios prepare graduates for the type of challenges they will face in industry, and provide a greater understanding of the interests, priorities and constraints of a business. Working in collaboration with industry can also often lead to direct opportunities for employment, as has been the case for a number of our previous graduates at York (see Box 3 for a description of previous York research project topics).

Box 3

Projects are offered by organisations and companies from a wide range of sectors including chemical manufacturing, pharmaceutical, engineering, aerospace, retail, food, home and personal care, oil and polymers. Previous project titles include:

- From food waste to bio-fuels and beyond
- Utilisation of waste fatty acids for developing hydrophobic surfaces
- New environmental legislation and its effects on the chemical industry
- Supercritical extraction and fractionation of renewable feedstocks
- Catalysis for the formation of amide bonds
- Green oxidation of alcohols in water
- Biocatalytic routes to esters in supercritical carbon dioxide
- Starbons® as adsorbents for water purification
- Generation of high energy chars from biomass utilising microwaves
- From ash to bio-boards
- Adhesion promoters for water based links
- Development of PVC replacements

Transferable Skills

Public engagement is essential to influence and inspire the next generation of green chemists. Engaging the public in discussion on critical issues and challenges that affect sustainable production and consumption can raise awareness of the role green chemistry can play in improving the quality of our everyday lives.

The University of Oregon has developed a highly comprehensive database of experiments and activities. The GEMs (Greener Education Materials for Chemists) database covers a range of educational levels (from primary school through to university and the general public) and contains laboratory exercises, lecture materials, course syllabi and multimedia content that demonstrate important green chemistry concepts (University of Oregon, 2012). Dr. Peter Licence at the University of Nottingham (UK) is also very active in raising awareness of green issues and with colleagues at Nottingham has developed videos about the periodic table that help to increase the general appeal of chemistry to a younger generation (Peter Licence, 2012; The Periodic Table of Videos, 2012). In recent years the MSc course at York has successfully incorporated Public Awareness of green chemistry. Students receive training in public engagement from York staff and external experts, work in teams to develop an idea for a green chemistry outreach activity and participate in the GCCE programme of outreach events throughout the year. This encompasses the development of educational material, running events, and hosting exhibitions and workshops for young children and the general public at National Science Centres, shopping centres and annual Festivals of Science. Through this programme of activities the students not only develop valuable transferable skills, but also contribute to the dissemination of green chemistry knowledge to a wider audience, in particular raising awareness of the role of green chemistry in improving the sustainability of products we enjoy as part of our everyday lives.

Commercialisation of Science

Growing concerns over the impact of chemicals on the environment are resulting in increasing pressures on industry to design and use greener chemicals. Many everyday-products contain a mixture of chemicals which increases the difficulty of developing genuinely greener and more sustainable products. Understanding the real world use of chemical products e.g. pharmaceuticals, personal care products and plastics, and their interaction with the environment, is critical in order to appreciate the potential for and the complexities of the design of commercial greener products. Organisations that capitalise on emerging technologies and processes, can turn perceived threats such as increasingly demanding environmental legislation and depleting resources into new business opportunities. The course at York aims to demonstrate the business case for the application of green chemistry and give its graduates an insight into the processes of collaboration with industry, technology transfer and intellectual property protection.

Careers in Green Chemistry

The application of green chemistry principles to business has the potential to give companies a competitive edge over their rivals, and therefore recruitment of graduates trained in these principles is an attractive prospect for many employers. A wide range of career paths are open to those with green chemistry training, not only in 'traditional' chemistry roles, such as research and development, but also in positions in government and policy, environmental and legal services, consultancy, NGO's, education, and industry.

To provide a snapshot of the types of careers we have interviewed four different graduates of the GCCE, who are either employed in or working towards employment in four

different fields: government, industry, academia and non-governmental organisations, to discover how green chemistry has influenced their career choices and what impact it has on their current role.

A CAREER IN GOVERNMENT AS A SCIENTIST

Name: Fabien Deswarte
Nationality: French
Position: International Science & Innovation programme manager
Sector of business: Government

Q1. Please describe your current role
I work for the UK Government's Science & Innovation Network (SIN) jointly funded by the UK Research, Innovation and Business Ministry BIS and the UK Foreign Ministry FCO. As part of my role, I am in charge of developing and managing a programme of international Science & Innovation activities aimed at fostering R&D collaborations between the UK and the rest of the world in all areas of science including chemistry. My responsibilities also include preparing reports and briefings on recent science and innovation policies and initiatives as well as technological developments in France and providing advice and support on science and innovation issues to the UK Government.

Q2. Briefly describe your academic background/educational qualifications
I obtained my PhD from the University of York in 2006 and graduated from the National Chemical Engineering School of Toulouse, France in 2002. I also have a Master in Science of Agro-resources from the same engineering school in Toulouse.

Q3. Why did you choose to do green chemistry?
I have always been attracted by the idea of doing a job, which would make a difference to the Environment. While studying chemistry, I understood quite quickly that all chemistries were sadly not green chemistry and became fascinated by the work of green chemists including Prof James Clark. Our crude oil reserves are finite so it is clear that we need to develop new chemical products derived from renewable resources including waste. The processes we use also need to be energy-efficient and environmentally-friendly.

Q4. How important do you think green chemistry education will be for the future?
I think green chemistry education will be crucial. I expect the demand for green chemists to grow significantly over the next few years as countries, and in particular industry, continue to invest significantly in sustainable technologies as a source of new jobs and new markets and as means of tackling climate change and protecting our environment. The future is bright for green chemists!

Q5. What advice would you give chemistry students interested in a career in government?
I would recommend that, whatever the career path they are envisaging, they need to make the most of their study and exchange ideas with their peers and experts in the field. Learned societies such as the Royal Society of Chemistry (RSC) in the UK run networking events for students, which are always very useful and a good source of new ideas.

A CAREER IN INDUSTRY

Name: David Cantrell
Nationality: British
Position: Head of Development
Sector of business: Industry

Q1. Please describe your current role
Head of Development Lonza Wood Protection Europe: managing the product development for a formulator of industrially applied wood protection products. The products include both wood preservatives and fire retardants. Managing and directing the activities of a team of 5 people; investigating new technologies; managing patents.

Q2. Briefly describe your academic background/educational qualifications
My most current scientific qualification is an MRes in Green Chemistry from the University of York. Prior to that I had been out of the scientific arena for a number of years. My previous scientific training was in theoretical solid state physics: a PhD and three years post doctoral experience.

Q3. Why did you choose to do green chemistry?
I chose to study Green Chemistry as a route back in to science as the issues of environmental impact and sustainability are very important factors for the future of industrial development. The course at York was very stimulating and provided a good training in this area. The study of Green Chemistry provides a new way of thinking about and approaching development.

Q4. Has this decision influenced your career path? If so, how?
My first post on finishing the course was a direct result of the qualification: I was employed as an environmental scientist by Arch Timber Protection (now Lonza). This post picked up areas of study in Green Chemistry: the legislative training and the understanding of product life-cycle, notably waste issues.

Q5. How important do you think green chemistry education will be for the future?
Green Chemistry education is very important for the future of industrial development: the areas of resource sustainability and environmental impact over product life-cycles will never go away.

Q6. What advice would you give chemistry students interested in a career in industry?
Remember that whilst Green Chemistry may be an interesting and stimulating subject to study, industry will require a motivation to adopt insights and benefits. Be prepared to account for the business benefit of Green Chemistry approaches. Get a good grounding in the legislative and regulatory background that sets the context for industry: this sets the constraints within which development takes place.

Studying towards a Career in academia

Name: Cinthia Mena Duran
Nationality: Mexican
Position: PhD student
Sector of business: Academia

Q1. Please describe your current role
Currently I am a third year PhD student at the Department of Chemistry in the University of York and also I am a Preparing Future Academics student.

Q2. Briefly describe your academic background/educational qualifications
I have a degree in Industrial Chemistry, which I got in the Universidad Autónoma de Yucatán. I also did a Master in Sciences in Physical Chemistry, which I finished in 2009 at Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional – Mérida. Also, I worked as a teacher in General Chemistry during 2009-2010.

Q3. Why did you choose to do green chemistry?
I always have been interested in doing "something very positive that can change the world". Since I was little, I have been thinking that "We need to save the world", and I discovered that Green Chemistry provides this opportunity, because you can find the way to save energy, reduce waste and toxicity in chemistry reactions and propose alternative materials which are environmentally friendly like bio-based materials.

Q4. Has this decision influenced your career path? If so, how?
I got my Master degree working with antimony compounds, it was so interesting to work in Fundamental chemistry like crystallography and X-ray diffraction, however I wanted to do "research" that can be applied now to "solve" some current problems. For this reason I decided to apply for a PhD in Chemistry, specifically in Green Chemistry. Now I am working in catalysis, using a material based on starch and also I am using microwave irradiation to do reactions, reducing time of reactions.

Q5. How important do you think green chemistry education will be for the future?
I consider that Green Chemistry is going to be very important for the future, because students not only need to learn chemistry, I think that it is important to take in account the development that Green Chemistry has got to design the NEW programmes, we need to extrapolate what have been found in Green Chemistry research to the study rooms.

Q6. What advice would you give chemistry students interested in a career in academia?
I think that for people working in Academia and doing Green Chemistry, it is important to keep developing Green Chemistry in study programmes, subjects and teaching labs. I think that it is time to teach/learn Green Chemistry, make it part essential of the studies plan in University. I have seen that "Green Chemistry" is an alternative for some projects; I think that we can combine different researches and adding "a bit of Green" to them.

A career in a Non-Government Organisation for scientists

Name: Helen Gray
Nationality: British
Position: Assistant Publishing Editor
Sector of business: Non-Government Organisation

Q1. Please describe your current role
I am a publishing editor for a learned society for their physical chemistry journals, which was most closely aligned with the subject of my master's thesis.

Q2. Briefly describe your academic background/educational qualifications
I started by doing an undergraduate degree in chemistry at Imperial College (London) and I knew I wanted to do further research in an area that interested me and that it why I decided to study at the University of York in Green Chemistry. This course was very innovative and what I liked about the course was the significant interaction with industry that was missing in my previous studies. After my master's degree in green chemistry I decided I wanted to move away from conducting research myself but, I wanted to stay in the loop about current research which is why I moved into publishing.

Q3. Why did you choose to do green chemistry?
I have been interested in environmental chemistry for some time and when I heard about green chemistry during my studies, I realised that humanity generates significant quantities of waste. I thought that conducting research into adding value to wastes would be both interesting and worthwhile.

Q4. Has this decision influenced your career path? If so, how?
I think so, certainly in my current role my degree helps me stand out in a team as we don't have many specialised Green or Environmental chemists. Compared to other areas of chemistry green chemistry is still in its infancy and as such it is vital to a publisher to develop new areas of science. So yes, it has influenced my career so far.

Q5. How important do you think green chemistry education will be for the future?
I think it is a vital area of chemistry, you can see in the news that there is a real drive for companies to reduce their environmental impact in many ways. The chemical industry has a big effect on our lives, so I feel that green chemistry is important for the future of our industry.

Q6. What advice would you give chemistry students interested in a career in academia?
I would suggest being really interested in what you are doing, as working in an NGO may not pay as well as other sectors of industry but, it allows you to work with and support both industry and academia which can be very rewarding to know your job is appreciated by the wider scientific community.

Conclusion

Green Chemistry has very wide application and relevance. As such it needs to be incorporated into many postgraduate programmes which are science and technology based reflecting importance in areas as diverse as government, legislation, manufacturing, retail and research. Green Chemistry is not a separate discipline, but rather a mindset which requires chemists to think critically about their reactions and to take into consideration other parameters, e.g. the by-products of the reaction and not just the desired products; to think about, for example, the choice of solvent and also to consider the renewability of the resource and the toxicity of the product.The experiences of students of taking postgraduate courses in the area have demonstrated that having a background in green chemistry can be a real benefit in opening doors to employers and new career paths in a wide range of chemical related sectors.

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