Highlighting the Green Face of Chemistry to Sixth-Form Students

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Abstract: Green chemistry is based on radical ideas, overlapping with the principles of sustainability, which propose a modern version of chemistry that is less toxic, less hazardous, highly efficient and non-polluting. Introduced in universities in the early 1990s, it was later adapted to lower levels of education. There is little research on the impact of green chemistry on students learning chemistry at post-16. This project investigated the reaction of Maltese sixth-form students to its possible introduction in the A-level programme of studies. It involved the design and implementation of a classroom and laboratory intervention to introduce basic ideas of green chemistry at this level of education. Data gathered from the participants and from a control group were later analysed both qualitatively and quantitatively.

Results show that green chemistry raised the students' environmental awareness and their motivation in the subject. Students realized that it could close the gap between a traditional curriculum and one emphasizing the effect of chemistry on society. Participants strongly supported the inclusion of green chemistry in future A-level chemistry curricula as it opened their minds to think more critically and evaluate better the sustainability of chemical products and chemical processes, and their impact on their lives.

Keywords: chemistry for the environment, environmental chemistry, green chemistry, green chemistry education, sustainable chemistry, sustainable education

When one analyses the recent versions of the local A-level chemistry syllabus, one notices that environmental topics, usually introduced at ordinary level, are conspicuously absent. It is quite surprising (if not disappointing) to note how young

students who are usually so interested and sensitive to environmental issues are not given the chance to delve into more detail on some of the aspects of environmental chemistry at post-secondary level despite possessing sufficient background knowledge of the subject.

Whilst one may argue that the revised syllabus does include some isolated references to environmental chemistry, local science educators might not have sufficiently realized the developments and growing importance of another aspect of environmentally related chemistry in research and in academic circles. This is not the same type of environmental chemistry which is significantly lacking prominence in our A-level programme. In fact it is referred to by the curious name of 'green chemistry'.

Evolution of green chemistry

Green chemistry is a relatively new area of chemistry that aims to prevent pollution at the molecular level by designing safer non-toxic/non-hazardous chemicals and chemical processes. It is also known as 'sustainable chemistry' as it protects human health and the environment and is also economically viable.

This new aspect of science is based on a set of scientific guidelines known as 'The Twelve Principles of Green Chemistry' which were launched by Anastas and Warner in 1998. These principles serve as a framework for chemists to evaluate the 'greenness' or sustainability of chemical products and reactions and are regarded as the rules of the game for the adoption of green chemistry by the chemical industry.[1] In other words, it is a more sophisticated way of doing chemistry, aiming at preventing pollution and health problems at the chemical design stage.

Green chemistry started as a research programme in the USA in the early 1990s as a reaction by chemists to address environmental problems created in the twentieth century by the chemical industry, but also to counteract the mounting legislation to control pollution. With time, it metamorphosized into a scientific movement involving people from the chemical industry, universities, laboratories, and other scientific

1 Paul T. Anastas and John C. Warner, *Principles of Green Chemistry* (New York, 1998); M. Lancaster, *Green Chemistry: An Introductory Text* (Cambridge, 2002).

organizations. It did not take long for green chemistry to proliferate in different countries across the world with activities being organized by a growing number of green chemistry centres and networks, largely operating from universities and colleges. Green chemistry was also shortly adopted by various international organizations while research started being published in a number of journals, some of which being entirely dedicated to this new area of science.[2] Research in green chemistry was crowned on more than one occasion with the prestigious Nobel Prize in Chemistry.[3]

Green chemistry in education

The parallel evolution of the concepts of green chemistry and sustainable development earned the attention of educational fora and institutions, and educators started promoting them in various levels of education. Green chemistry started being taught in universities in the 1990s but was later adapted for younger audiences and introduced in the curriculum of secondary and post-secondary schools. Literature suggests that teaching green chemistry to young students enables them to relate better basic chemistry concepts to their everyday lives and may even attract bright students to chemistry careers. However, other sources indicate that several potential obstacles could hinder the introduction of green chemistry in schools. These include an already overburdened curriculum, resistance from teachers, lack of adequate educational resources, and different forms of scepticism.[4]

While green chemistry does not feature as yet in any science curriculum in Malta until post-secondary level, it has already appeared in A-level (or equivalent) exam specifications in various countries, such

2 Ibid.; W. Wardencki, J. Curyło, and J. Namieśnik, 'Green Chemistry – Current and Future Issues', *Polish Journal of Environmental Studies*, Vol. 14, No. 4 (2005); Paul Anastas, 'Twenty Years of Green Chemistry', *Chemical & Engineering News*, Vol. 89, No. 26 (2011), 62–5.

3 Nobelprize.org., 'The Nobel Prize in Chemistry 2001 – William S. Knowles, Ryoji Noyori & K. Barry Sharpless', available at http://nobelprize.org/nobel_prizes/chemistry/laureates/2001/ (accessed 20 February 2014); id., 'The Nobel Prize in Chemistry 2005 – Yves Chauvin, Robert H. Grubbs & Richard R. Schrock', available at http://nobelprize.org/nobel_prizes/chemistry/laureates/2005/ (accessed 20 February 2014).

4 M. Lancaster, 'Green Chemistry', *Education in Chemistry*, March 2000; Paul T. Anastas and Evan S. Beach. 'Changing the Course of Chemistry', *Green Chemistry Education*, ACS Symposium Series 1011, (Washington DC, 2009).

as the UK.[5] This means that green chemistry is now gaining recognition as an important area of chemistry education even at post-secondary level, by being presented with core chemistry concepts which students are expected to understand and learn how to apply before pursuing higher education.

In this project, the present author tried to investigate how a group of first-year A-level chemistry students would respond when they experience learning green chemistry through theory and practical sessions.

Research design and methodology

The research study involved the design, implementation, and evaluation of a green chemistry intervention for 17–18 year old students attending a Maltese sixth-form college. The intervention took the form of a programme of events consisting of a set of classroom seminars on various aspects of green chemistry, practical work, and other activities such as student presentations and a slogan competition. It was aimed to introduce basic concepts of green chemistry by identifying a number of areas of interest related to established A-level topics. The intervention package was designed to allow students acquire a good background of green chemistry over a period of one academic year.

The pilot intervention was carried out during academic year 2008–09 and data were collected from a single cohort of students before and after

5 AQA Examination Board, 'AS & A Level Chemistry Specifications (for first teaching in 2015), available at http://filestore.aqa.org.uk/resources/chemistry/specifications/AQA-7404-7405-SP-2015.PDF (accessed 1 August 2017); CCEA (Northern Ireland).'GCE Specification in Chemistry', available at http://www.rewardinglearning.org.uk/microsites/chemistry/revised_gce/specification/index.asp (accessed 1 August 2017); Edexcel Limited, 'AS and A Level Chemistry from 2015', available at https://qualifications.pearson.com/content/dam/pdf/A%20Level/Chemistry/2015/support/T794_A_Level_Chemistry_spec_subject_guide_new.pdf (accessed 1 August 2017); International Baccalaureate, Diploma Programme – Chemistry Guide (First Assessment 2016)', available at http://www.ibchem.com/root_pdf/Chemistry_guide_2016.pdf (accessed 1 August 2017); OCR Examination Board. 'AS/A Level GCE Chemistry 'A' Specification', available at http://www.ocr.org.uk/Images/81089-specification.pdf (accessed 1 August 2017); WJEC-CBAC (Wales) Examination Board.'GCE AS/A Level in Chemistry – Specification', available at http://www.wjec.co.uk/qualifications/science/as-a-level/chemistry-as-a-level-2015/wjec-gce-chemistry-spec-from-2015.pdf?language_id=1 (accessed 1 August 2017).

the intervention. A preliminary analysis of the data generated from the pilot study led to some modifications and fine tuning of the intervention package and of the research tools required for the main study. The main intervention was carried out on a similar group of students (GC group) during the following academic year, i.e. 2009–10, with data being collected from the same class and from another class within the same cohort which was not involved in the main intervention, thereby acting as a control (non-GC group). The total number of participants in the study was 67, representing 30.3% of the first-year students then studying chemistry at the Maltese sixth-form college.

Data were collected during the main study using a number of research instruments such as questionnaires (included in a chemistry survey), students' activity worksheets and presentations, research journal, laboratory practical reports, and particularly from focus group discussions which were all transcribed and translated prior to analysis. The types of questions addressed to students (both in the survey and focus groups sessions) ranged from their perceptions and difficulties of chemistry taught at school, the impact of chemistry on society, current careers and opportunities in chemistry, ideas on green chemistry forming part of the college chemistry curriculum, views of green and sustainable chemistry, views on learning green chemistry, and potential barriers to learning / studying green chemistry at this level. One part of the survey tested the students' abilities to understand the main concepts of green chemistry by asking them to discuss specific situations (sometimes involving relevant calculations) by applying some of the fundamental principles adopted by this new approach of doing chemistry. Students forming part of the GC group were also involved in setting up an exhibition of a number of posters created by them for their research presentations.

All data gathered before, during, and after the intervention were then processed and analysed with the help of computer-assisted qualitative analysis software, using a theoretical framework (for 'attitude' data) and an evaluation scheme (for 'understanding' data) developed as a result of literature reviewed for the same project. A strategy was also created to test the effectiveness of the intervention package and this was applied in conjunction with the theoretical framework to evaluate the intervention. Once the data analysis was completed, the main findings were known and a conclusion was drawn up.

Inferences and main findings

Students' Overall Positive Reaction

The study found that Maltese sixth-form students reacted very favourably to the introduction of green chemistry. Participants appeared to be particularly engaged with the ideas of green chemistry right from the very first seminar till the laboratory sessions which allowed them a close encounter with the practical side of the subject.

By the end of the intervention, the GC students adopted a more positive attitude towards chemistry as a science and even towards school chemistry. They also developed a higher degree of environmental awareness and a critical mind which enabled them to express themselves with confidence on several features of green chemistry. They also showed a significantly stronger positive attitude towards the applicability of green chemistry as could be confirmed through analysis of the chemistry survey. This higher sensitivity of the GC students towards the environment could also be confirmed in the way they reflected upon about the various environmental world problems and the way they perceived the impact of green chemistry on society during focus group discussions. GC students also showed higher-order thinking skills, both in the way they tackled certain questions of the chemistry survey as well in the way they argued on the future role of chemistry in the post-intervention focus groups.

The study also showed that participants were so convinced about the usefulness of green chemistry that they agreed almost unanimously that it should be incorporated in the A-level curriculum and future examinations. Indeed students realized that the current curriculum needed to be updated to reflect important contemporary developments in chemistry, such as the case of green chemistry. They also thought that one of the best ways of learning green chemistry was through the use of relevant practical work in the school laboratory.

Impact of green chemistry on students' attitudes

One of the main findings of this study was that green chemistry managed to change student attitudes towards societal chemistry. The survey showed, for example, that their initial negative attitude towards the social responsibility of chemistry with respect to the environment

became less pronounced amongst the GC respondents but more meaningful within the non-GC group over the same period of time.

The intervention also brought new ideas and considerations among students about the true value of chemistry in society. The green chemistry experience helped them contemplate the unique contribution of this new form of chemistry to human civilization. It is evident that students recognized, by the end of the intervention, that the advent of green chemistry gave a further boost to the positive impact of chemistry on society, particularly in the health and environmental sectors. Students acknowledged, for example, that green chemistry has the potential to make the difference in the quality of human life as it targets pollution prevention in an unprecedented way. Evidence shows that the same students who experienced the intervention understood that green chemistry represents a radical reaction by chemists all over the world to prevent scientists and other people from committing once again past mistakes which claimed thousands of human lives throughout the years and ended up in environmental nightmares in different parts of the world. Students realized also that green chemistry had the potential to correct the public perception that chemistry is a dirty scientific discipline which inevitably ends up generating toxins and pollution. Students clearly acknowledged that green chemistry had the credentials to be proactive, harmless, and a problem-solver.

In contrast, the control group had a less positive viewpoint on the consequences of chemical activity on the environment. Evidence shows that these students were still adamant by the end of the year that chemistry was responsible for environmental degradation. They felt sceptical about the aims and applicability of chemistry that claims to be ‘green’, arguing for example that this would be too expensive to be applied on a large scale and that chemistry can never be rendered truly eco-friendly for a number of considerations, such as the high energy consumption and the unavoidable amount of pollution by the chemical industry.

Students participating in the green chemistry intervention thought that green chemistry would bring about a number of fresh and radical ideas to the A-level curriculum rendering the subject more relevant, more practical, and more appealing. The study found that students perceived green chemistry to be so close to their everyday lives that

they felt it had the potential to bridge the perceived gap between the current curriculum full of fundamental facts and established theories of chemistry, and contemporary chemistry which focussed also on the impact of chemistry on society.

The study found that students liked green chemistry for a number of other reasons, such as the fact that it was less abstract, more down-to-earth, and more easy-going with respect to the other topics and areas of chemistry. The same students were confident that, apart from being 'environmentally friendly', green chemistry tended to be also 'student friendly' as it added flavour and spice to the subject by including modern and unorthodox, yet positive, ideas that made a lot of scientific sense apart from connecting immediately with the outside world. The general feeling among students who experienced the green chemistry intervention was that its inclusion would raise students' interest and motivation to learn and study chemistry. This explains why the same students recognized the urge of science educators to put a greener face to chemistry thought in schools and in other educational institutions.

There is abundant evidence showing that students were enthusiastic and felt stimulated doing practical work in green chemistry. The study found that the green chemistry experiments provided students with what they described as 'one of the most memorable experiences' they ever had in a school laboratory. Data shows that green chemistry practical sessions instilled very positive feelings among students, giving them a sense of pride and achievement for being able to put some of the green chemistry principles to practise, proving also that they were feasible and not just theoretical. Their green chemistry laboratory experience appeared to restore also the elements of enjoyment and excitement in the laboratory which students found to be somewhat lacking in other routine chemistry practical sessions. Students were so much satisfied with their close encounter in the lab with green chemistry that they strongly favoured the idea of including it in future A-level chemistry programmes. The same students were convinced that such practical sessions were more useful and more appealing than some other analytical procedures which make use of standard techniques and conventional reagents.

Students' ability to understanding green chemistry concepts

This research investigation showed clearly that all students who were exposed to green chemistry were able to master the key ideas which characterize this newly emerging area of science. Students found no particular difficulties in grasping the basic concepts of green chemistry so much so that they were even able to apply them in the laboratory, carry out some individual research work, and then make a short presentation, as well as discussing in class some related concepts and their applicability.

The GC participants had the chance to prove their understanding of green chemistry throughout the entire intervention and particularly in the post-intervention survey. They were able to deal confidently with questions related to different aspects of green chemistry including waste minimization, atom economy, toxicity and safety of reagents and solvents, energy efficiency, renewable resources, chemical derivatives, catalysts, biodegradability, and preventive measures to avoid chemical accidents. The analysis of the students' responses in the survey showed clearly that the GC students were more prepared than their non-GC counterparts to tackle the questions, not only by recalling facts but also by applying the new green chemistry logic which they had just acquired throughout the intervention.

Evidence shows that, rather than learning new green chemistry 'rules' by heart, GC participants were better trained to evaluate the opportunities provided by green chemistry. Analysis of the pre-test responses shows that both groups of students could relate, at the beginning of the year, to environmental chemistry topics such as atmospheric pollution, the ozone layer, sources of energy, toxicity of chemicals, and safety considerations. However, their responses given at that point in time lacked any reference to 'sustainability', which is the over-arching leitmotif of the principles of green chemistry. In contrast, the answers provided by the GC participants towards the end of the year were more focussed and better articulated and showed a higher level of understanding of the essence of green chemistry and sustainable development.

The students' ability to grasp the basics of green chemistry was mostly evident during the learning activities, laboratory experience, and poster presentations. Further evidence was their ability to discuss

with confidence, using appropriate terminology, the different aspects of green chemistry during the seminars and focus group sessions upon completion of the intervention.

Besides learning about new facts and theories on how to make chemistry less toxic and more sustainable, students participating in the green chemistry intervention also developed a higher sensitivity towards the environment and a sharper mind which enabled them to think more critically on the environmental impact of chemistry and on how chemistry can be rendered safer and more sustainable. This is consistent with other studies showing that students who are exposed to green chemistry will improve their critical thinking and communication skills which are required in order to understand better the contexts of sustainable development.[6] It is also congruent with other sources of literature, suggesting that understanding green chemistry helps students address better environmental issues as they feel they can contribute to solving problems in a familiar context.[7]

Impact on future careers

The study found that sixth-form students studying A-level chemistry intended to use the background of the subject to follow a science-related career, particularly medicine or health sciences. Very few students showed interest in the pure sciences. The survey showed that the GC participants had a stronger inclination than other students to choose a scientific career and also a stronger ambition for a chemistry-related job. Participants realized that students wishing to pursue further studies in chemistry or those aspiring for a chemistry-related profession would soon be requiring a good background of green chemistry.

The students also thought that research in green chemistry was an important investment for a healthier future civilization while a few of them declared that, if they were to specialize in chemistry, they would seriously consider the area of green chemistry. This indicates that the intervention instilled a positive effect on students' behavioural attitudes towards studying chemistry.

6 Anne E. Marteel-Parrish, 'Toward the Greening of our Minds: A New Special Topics Course', *Journal of Chemical Education*, Vol. 84, No. 2 (2007), 245.

7 Irvin J. Levy, Julie A. Haack, James E. Hutchison, *et al.*, 'Going Green: Lecture Assignments and Lab Experiences for the College Curriculum' *Journal of Chemical Education*, Vol. 82, No. 7 (2005), 974–78

Implications of this investigation for policy and practice

This study showed that, by being both 'environmentally friendly' as well as 'student friendly', green chemistry has the potential to serve as a much-needed new point of engagement for adolescent science students in the learning of chemistry. Young students studying science subjects at A-level are usually well-informed and rather keen on environmental topics and that explains why green chemistry was so well received by the participants. One important finding was that the same sixth-form students strongly believed that the chemistry curriculum would be enhanced by including environmental and green chemistry topics as these would make the subject more relevant to their everyday life, making it also more appealing.

This work suggests it would be timely for local education authorities to revise their policy in science education to reflect better the human achievements in science, including progress made towards sustainability on Earth. Green chemistry, which has now been around for more than 20 years, is right at the heart of sustainability and hence there is a strong case for it being promoted and taught at all levels of education. The findings point to the need for green chemistry to be given high priority by local educational policy makers when contemplating future changes in school curricula and public examination syllabi.

Students suggested that the best way to learn green chemistry was to infuse its concepts into the regular chemistry programme. Such student voices echo similar ideas from other sources suggesting that one of the most effective way of introducing green chemistry at high school/sixth-form level was by integrating it in different parts of the curriculum.[8] The project found that green chemistry would also be taught effectively through the use of laboratory experiments.

The study also indicated that the introduction of green chemistry in the A-level chemistry curriculum brings about a radical change in the way students start looking at chemistry as it empowers them with a new frame of mind that allows them to judge better the sustainability of chemical products and chemical reactions.

8 Christopher Kitchens *et al*. 'Completing our Education. Green Chemistry in the Curriculum', *Journal of Chemistry Education*, Vol. 83, No. 8 (2006), 11–26; K. Parent, Mary M. Kirchhoff, and S. Godby, *Going Green: Integrating Green Chemistry into the Curriculum* (Washington, DC, 2004).

Conclusion

The analysis of data from this research investigation found that students reacted positively and enthusiastically to the introduction of green chemistry as this raised significantly their interest in the subject. Green chemistry allowed them to view chemistry in a more intelligent way, allowing them to think more critically on the possible impact of chemical products and chemical changes on human health and the environment. The green chemistry intervention also helped in improving students' motivation to further their studies in chemistry and to choose a chemistry-related career.

Above all, this study shows that the introduction of green chemistry in the A-level curriculum is welcome by students as it includes those aspects of science that are valued by them in real-life situations and in different contexts. Evidence shows that green chemistry has the potential to engage students with the subject as it gives a more positive picture of chemistry, adds relevance, deals with contemporary environmental issues, and proposes a new chemistry at the centre of sustainability.

The author hopes that this project served as a modest educational contribution to the goals of the decade 2005–14, declared by the United Nations as the 'decade of education for sustainable development'.[9]

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9 UNESCO, 'UN Decade of Education for Sustainable Development 2005–2014', available at http://unesdoc.unesco.org/images/0014/001416/141629e.pdf (accessed 1 August 2017).