# Greening the Chemistry Curriculum in Maltese Educational Institutions

**The reaction of pre-university students**

**to the introduction of green chemistry: a case study from Malta**

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## Abstract

Green chemistry is based on a set of radical ideas that overlap with the principles of sustainability and propose a modern version of chemistry that is less toxic, less hazardous, highly efficient and non-polluting. Literature suggests that green chemistry started being taught in universities but was later adapted to lower levels of education. It appears that little research has been done on the impact of green chemistry on students studying chemistry at post-sixteen.

This research project is a case study investigating the reaction of a group of Maltese sixth form students to the introduction of green chemistry. It involved the design and implementation of an intervention package to introduce some basic ideas of green chemistry in the classroom and school laboratory. Data were gathered from the participants before and after the intervention through the use of questionnaires, focus groups, research diary and other documents. Similar data were also collected from a second group of students from the same cohort which did not experience the same intervention. A conceptual framework was developed to analyse the attitudinal data while an evaluation scheme was used to analyse the knowledge and understanding data. The effectiveness of the intervention package was assessed using one of the models of educational evaluation.

Results of the analysis show that green chemistry raised the students' environmental awareness and their interest in the subject, and may influence also their motivation to follow a chemistry-related career. Students were particularly interested in the practical side of green chemistry. With green chemistry students also developed a more positive perspective of chemistry. They thought that green chemistry had the potential to close the gap between a traditional curriculum and one that emphasized the impact of chemistry on society. Students strongly supported the inclusion of green chemistry in future A-level chemistry curricula.

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**Author's Declaration**

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University.

All sources are acknowledged as References.

# Chapter 1

# INTRODUCTION

## 1.1 Preamble

Concepts are not usually born overnight and out of nowhere. They originate from a complex interaction in the mind involving the life experience of a person, knowledge gained from formal, informal and non-formal education and future aspirations. A new concept is likely to undergo a period of gestation before it finally takes a definite shape. If the idea is then challenging enough to its creator, it may evolve with time and develop into an ambitious project.

This is the way the author believes his research project was conceived. It all started while the author was reading his Master's degree in environmental health studies at the University of Malta and in the same time teaching chemistry full-time to post-16 students attending a foundation course at the pre-vocational college (health care) before qualifying for one of the courses provided by the Institute of Health Care (now the Faculty of Health Sciences) of the University of Malta. The author was always particularly intrigued by the environmental component of chemistry so much so that upon his graduation, he accepted to lecture some modules related to environmental chemistry and environmental health to undergraduate health care students. In the meantime he was also appointed by the University of Malta to sit on the board of examiners in Environmental Science (a subject usually chosen by non-science sixth form students as part of their Matriculation Certificate required to be admitted to university).

When he moved on to fill up a full-time post as a lecturer of chemistry in one of the sixth form institutions in Malta (from now on referred to as ‘the Maltese sixth form college’), he soon noticed that there was a vacuum in the A-level chemistry programme with regards to environmental topics already introduced at the secondary level of education. At that time the author was both surprised as well as disappointed to discover how young students who are usually so interested and sensitive to environmental issues, were not given the chance to delve into more detail on some of the aspects of environmental chemistry at A-level despite having stronger foundations of the subject. He found it equally strange that some of these environmental issues, conspicuously absent in the A-level Chemistry curriculum, then featured more prominently in another examination, namely the intermediate level (equivalent to the English AS level, but with material covered in two years) Environmental Science. It must be noted that there are no O-level or A-level examinations in Environmental Science in Malta and students opting for this subject at the sixth form stage, may have little or no previous chemistry background and are usually regarded as non-science students.

Whilst pondering on the fact that the current local A-level chemistry curriculum does not relate much to environmental matters, i.e. it makes little reference to the chemistry ‘of’ the environment, the author realised that another aspect of environmentally related chemistry was making news particularly in research and in academic circles. It was not the same type of environmental chemistry which the same author had in mind and which he was so keen about. In fact it was referred to by the curious name of ‘green chemistry’. The author soon discovered that it was all about a new way of doing chemistry that does not create the problems identified through environmental chemistry. He realised that this ‘new’ chemistry is more of a problem solver than a problem finder, that it inspires an environmentally conscious and ethical behaviour, and that it addresses important issues such as toxicity of chemicals and environmental pollution, in an unorthodox but also an intelligent and creative way. The author realised also that green chemistry was neither a public relations exercise, nor ‘a pipe dream’ of some environmentalists. In actual fact he discovered that it was an evolving scientific field full of new ideas and revolutionary progress. In other words, the author realised that green chemistry involved such a fundamental change in approach of doing chemistry that it truly represented ‘the future of chemistry’ (American Chemical Society, 2014a).

This was the moment which sparked off the author’s interest in learning more about green or sustainable chemistry with the possibility of teaching some of its basic concepts to others. Furthermore, the more he read on the subject, the more he discovered how relevant this emerging field of science was to his concern and the more he thought of the possibility of adapting it to fit in a chemistry curriculum for post-16 students especially when one considers its slow but successful progress it was making in university courses. The author was particularly interested to know how students, as part of a young generation that is becoming increasingly sensitive to pollution problems and issues of environmental sustainability, would react when they start discovering about this latest and most radical form of applied chemistry.

## 1.2 What is Green Chemistry?

Green chemistry, which is also known as 'sustainable chemistry', especially in European countries where the term 'green' is strongly associated with politics, involves the application of a set of scientific principles which enable chemists (and chemical engineers) to create safe, energy efficient and non-toxic chemical products and processes, without harming human health and the environment (Anastas & Warner, 1998; Lancaster, 2000; Wardenchi, Curylo & Namiesnik, 2005). In other words, it is a more sophisticated way of doing chemistry, aiming at preventing pollution and health problems at the chemical design stage (Taylor, 2010). Hence it is more of a 'chemistry FOR the environment', i.e. a more environmentally friendly chemistry than a 'chemistry OF the environment', i.e. chemistry that explains nature and the impact of man on the nature.

Green chemistry can neither be viewed as a new branch of chemistry nor as another term for environmental chemistry. It is a new philosophy and a fundamental methodology in the production, use and disposal of chemicals that includes all aspects of safety and sustainability.

## 1.3 Why including Green Chemistry in the Chemistry A-level Curriculum?

Green chemistry is today considered as one of the key scientific solutions to the problems associated with environmental degradation. It is essential that future scientists are sufficiently equipped with the knowledge of contemporary chemistry which supports sustainable development but also safeguards human health. This can be achieved by providing green chemistry education to all future chemists and chemistry-related professionals starting from a young age. It is becoming increasingly important that the school chemistry curriculum allows space for the introduction of the fundamental principles and some aspects of green chemistry, especially for post-16 students who already possess a good background of the subject. This offers a golden opportunity for students to learn that chemistry is evolving in such a way that it is becoming more environmentally friendly by focussing on the development of harmless and non-polluting chemicals and chemical processes. Teenage students are particularly sensitive to environmental issues and so, adding the basics of green chemistry may also serve to boost their interest and motivation to learn chemistry at pre-university level and beyond.

## 1.4 Background to the Research Investigation

Malta had been a British colony for more than 150 years (between 1800 and 1964). This explains why there is still a strong influence of British traditions in different aspects of Maltese life including education. In fact, Malta's educational system (comprising administration, primary, secondary and tertiary sectors, and examinations) has been based for about two centuries on the British model (Sultana, 1997; Zammit Ciantar, 1993; Zammit Mangion, 1992).

The Maltese mainstream education system is divided into five main stages: three years of pre-school education (age 3 to 5) with voluntary attendance, six years of compulsory primary education (age 5 to 11), five years of compulsory lower secondary education (age 11 to 16) divided into a two year orientation cycle (middle school) and a three year specialisation cycle, two years of non-compulsory upper secondary education (age 16 to 18) and tertiary education (18 years on) mainly provided by the University of Malta.

Further education in Malta (post-16) is divided into two strands, the academic strand which leads students to the entry requirements of the University of Malta and the vocational strand which channels students to alternative courses at higher education provided by institutions such as the Malta College of Arts, Science & Technology (MCAST) and the Institute of Tourism Studies (ITS).

Teaching of science was introduced in Maltese schools towards the late nineteenth century but secondary science education was only made compulsory in 1970. Secondary schools in Malta today provide for the teaching of integrated science in the first two years (i.e. Forms I and II) while students are compelled to choose one science subject in Form III (year 9) and may opt to study a second and even a third science till Form V (year 11). All secondary students can therefore sit for at least one science subject at SEC – Secondary Education Certificate – level (equivalent to O-level) by the end of Form V but the local examination board does not provide, for the time being, the option to sit for an examination in integrated science.

Chemistry is the least studied subject in Maltese state secondary schools with only 8% of students choosing it at Form III in year 2011, as compared to 18.3% opting for biology and 100% studying physics (this being still a compulsory science subject). The situation is different in non-state schools with a higher number of students studying chemistry – 32% in independent schools and 42% in Church schools in the same year 2011 (Debono, 2011), even though it is still the least chosen subject of the three sciences.

Statistics published by the local Matsec Examination Board over the period 2005-2013 confirm that chemistry is the least popular subject at secondary level with the SEC level (O-level) examination attempted only by an average of 12% of all registered candidates in one session, compared with 22% for biology and 56% of physics (the latter still being a compulsory subject in state schools).

The sixth form colleges / schools form the main part of the academic strand of the post-secondary or further education in Malta, which prepares students for tertiary education. Maltese students can choose to further their education at post-16 level in one of eight institutions – three public ones (including one in Gozo), two run by the Church and another three private sixth forms (National Commission for Higher Education, 2009a). All post-16 students who qualify for any one of these institutions will then follow a two-year programme of studies preparing them for the Matriculation Certificate Examinations set by the local examination agency – the Matsec Examination Board, or equivalent overseas qualifications recognised by the Malta Qualifications Council, such as the GCE A-level and the International Baccalaureate Diploma. The local Matriculation Certificate, which is the main entry requirement to the University of Malta, is awarded to students passing two subjects at an advanced matriculation (AM) level and four subjects at an intermediate matriculation (IM) level which must include the compulsory subject of Systems of Knowledge.

Local Matsec examinations statistics confirm that chemistry is the least popular subject even at the AM level (or A-level) as compared to the other sciences, although the differences are not as sharp as in the SEC level (or O-level). In fact the number of students attempting AM level chemistry over a period of 7 years (2005-2013) amounted to 16% of all A-level candidates compared to 22% biology and 18% physics. Participation in A-level chemistry fluctuated over the same period, but increased over the last three years (Matsec Examination Board, 2006a-2014b).

Although this shows there is less interest by students in chemistry than in other subjects, the rate of progression from the SEC (O-level) to the AM (A-level) stage is highest in chemistry. In fact if one were to compare the number of Maltese students sitting for SEC-level in one year with the number of students sitting for AM-level in the same subject in two years' time, one would notice that there are more chemistry students sitting for both exams (SEC and AM) than the other sciences. The progression rate (calculated as percentage of A-level candidates over O-level candidates in the respective age cohort) over the period 2005-2013 was 45.0% in chemistry, 35.1% in biology and 10.9% in physics. This means that the chance of SEC level students to choose the same science subject at A-level is highest in chemistry.

The situation is different in other countries such as the UK where chemistry is more popular than physics but less popular than biology. Studies show that interest in chemistry (and in other sciences) in the UK as reflected in the number of A-level entries, declined for a number of years but then started to recover over the last years. For example, the percentage of A-level chemistry students out of the 17-year-old UK population decreased from 6.4% to 5.3% between 1996 and 2007 (Hampden-Thompson, Lubben & Bennett, 2011) but now stands at around 6.0 % (Joint Council for Qualifications, 2015). Similar declines were registered in other countries such as Australia which, for example, is still experiencing a downward trend in high school participation in sciences, with chemistry suffering a drop from 23% in 1992 to 18% in 2012 (Fullarton, Walker, Ainley & Hillman, 2003; Kennedy, Lyons & Quinn, 2014).

## 1.5 Context of the Study

### 1.5.1 Local and Foreign Examination Syllabi

Green chemistry does not feature as yet in any science curriculum in Malta until post-secondary level. In fact the only direct references to environmental chemistry topics, the closest to green chemistry, are found in the examination syllabi of SEC-level chemistry, SEC-level environmental studies and IM-level (intermediate) environmental science.

The SEC-level chemistry examination syllabus has a whole section dedicated to 'Chemistry, Society and Natural Environment' with specific reference to the impact of the chemical industry on the environment. The intermediate (IM) and advanced (AM) level chemistry syllabi have no such sections related to environmental issues but there are some references in the AM chemistry syllabus to 'green' topics such as the role of catalytic converter as a pollution control measure and the chemistry of biodegradable plastics. However, to date, there is no more direct or indirect reference to any aspects of green chemistry, except for the most recent added reference to 'fuel cells' under the topic of electrochemistry (Matsec Examination Board, 2015).

The SEC-level environmental studies examination syllabus treats some of the most common environmental issues and refers to aspects of sustainable development and renewable sources of energy amongst other topics. The foundations of environmental chemistry are certainly more concentrated in the IM-level environmental science examination syllabus. Such examination syllabus does not relate directly with green chemistry but refers to aspects of pollution prevention and hence touches on some of the principles of green chemistry through topics such as the use of alternative fuels, catalytic converters, energy efficiency, recycling of waste and exploitation of renewable sources of energy (Matsec Examination Board, 2014c-2014g).

Given the long-standing tradition of Maltese education to emulate the British educational system, Maltese students used to sit for GCE O-level and A-level examinations set by UK examination boards, before the establishment of the local Matsec examination board in 1991. Today there are still Maltese students who sit for these examinations offered by the UK boards as alternative or additional qualifications to the local Matsec examination set up. Hence it is important if not imperative to compare Maltese examinations with examinations offered by the main UK examination boards as far as green chemistry is concerned.

All UK A-level examination specifications refer to a number of environmental issues but only three of them refer specifically to green chemistry. Edexcel GCE A-level specifications cite green chemistry prominently among the aspects of contemporary chemistry that students are expected to understand and be able to explain. In this examination, students should know, for example, how a chemical process can be made greener or more sustainable by applying green chemistry concepts (Edexcel Ltd, 2014). Another examination specification which dedicates a whole section to green chemistry is the OCR A-level Chemistry 'A'. In this OCR examination students are expected to be able to appreciate the growing national and international concern to protect the environment and promote 'green chemistry'. Green chemistry is however less conspicuous in the other OCR specification for GCE Chemistry 'B' (Salters approach) with reference being limited to sustainability issues in the chemical industry (OCR Examination Board, 2013b). The third UK examination specification which refers directly to green chemistry concepts is the

WJEC (Wales) A-level Chemistry. Although the Welsh A-level chemistry specification does not allow a prominent section to green chemistry it still provides a framework to encourage educators and students to explore and address certain aspects of green chemistry (WJEC-CBAC Examination Board, 2009).

The AQA A-level chemistry specification does not refer to green chemistry but requires students to understand the green chemistry principle of atom economy and a few other environmental issues (AQA Examination Board, 2014). The SQA (Scotland) Chemistry Higher and Chemistry Advanced Higher examinations specifications are structured on traditional core chemistry topics making some reference to topical environmental issues. Although it does not refer directly to green chemistry it expects students to be able to understand the positive impact of chemistry on everyday life referring amongst other to green chemistry concepts such as atom economy, the use of alternative fuels, hydrogen economy, biodegradable plastics and the use of enzymes by the chemical industry (SQA Examination Board 2002a, 2002b). The other UK examination board, CCEA (Northern Ireland) features some environmental issues in its A-level chemistry specification but topics related to green chemistry are not yet evident in the most recent version of this examination specification (CCEA Examination Board, 2008).

Two other examinations of interest to some Maltese students particularly those attending independent schools are the CIE Cambridge International A-level chemistry and the International Baccalaureate (IB) Standard Level and Higher Level Chemistry. Both exams give prominence to environmental chemistry but none of them refer specifically to the principles of green or sustainable chemistry. However the CIE Cambridge International examination syllabus refers to a number of key concepts in applied chemistry such as the use of what is described as ‘novel chemistry’ to allow monitoring and solving of environmental problems, the design of new molecules, materials and methods of analysis and how chemistry can address problems related to pollution, health and resources. These may be regarded as indirect references to green chemistry (International Baccalaureate Organisation, 2009; Cambridge International Examinations, 2014).

All this points out that green chemistry does not yet feature in any of the Maltese chemistry or science curricula and examinations but is gaining prominence in other countries such as the UK where it is already featuring in A-level examination syllabi / specifications. This means that green chemistry is being recognised 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 being admitted to university. This is also a strong indication that the current trend in high schools / sixth forms institutions is to move one step further and complement the issues traditionally associated with environmental chemistry with more contemporary ones reflecting the efforts by chemists all over the world to render chemistry truly greener and more sustainable than older practices.

### 1.5.2 Availability of Educational Resources

One of the main problems teachers and students are likely to encounter when they are introduced to green chemistry at pre-university level is lack of educational resources to facilitate teaching and learning. Though such resources are becoming more abundant and readily available for undergraduates, graduates and researchers, they are more limited for students and educators at lower levels of education.

However, efforts are being made to improve the situation and in fact there are already some (very few indeed) textbooks, laboratory manuals and online resources targeted to post-16 chemistry students and their teachers. The resources currently available were reviewed in more detail in the literature review chapter (i.e. chapter 2).

## 1.6 Students participating in the Green Chemistry Intervention

The students participating in the green chemistry intervention which forms part of this research study attend the Maltese sixth form college. This is a post-secondary institution in Malta which prepares students for tertiary education by providing a course of studies leading to the Matriculation certificate as the main entry requirement to the University of Malta. Such programme requires students to study two subjects for the Advanced Matriculation (AM) level examination and four subjects for the Intermediate Matriculation (IM) level examination. One of the IM level subjects is Systems of Knowledge which was introduced in 1987 as a compulsory subject to encourage students to acquire communication skills and an interdisciplinary approach to learning (Giordimaina, 1999). Each IM level subject is considered to have a weighting of one third of the same subject at AM level and is treated accordingly in terms of curriculum, student time-table load and setting of examination papers.

All students attending the Maltese sixth form college are required to opt for a combination of languages, sciences and other humanities subjects approximately equivalent to the contents and standard of the former three A-level system (similar to that offered by UK sixth forms) which was phased out in Malta in 1994.

Almost all students participating in the research project opted for chemistry and biology as their AM-level subjects, with only two (out of a total of sixty seven, at the beginning of the year) choosing to study an alternative subject to biology at AM-level. Students came from different social backgrounds and had completed their secondary education in one of the many state, Church or independent schools in Malta.

## 1.7 Research Questions

In this project 'Greening the Chemistry Curriculum in Maltese Educational Institutions' the author tried to investigate how a group of chemistry students (**the GC group**) attending the first part of a two-year programme leading to A-level, would respond when they experience learning green chemistry through theory and practical sessions. The students' reactions were then compared to that of a similar group of students (**the non-GC group**) attending the same year who did not experience the same teaching intervention.

The main research question addressed in this study is:

***'How do Maltese sixth form students respond to the incorporation of green chemistry in the A-level chemistry curriculum?'***

The author tried also to address a number of supplementary questions:

- *'In what ways do students' attitudes change by including aspects of green chemistry in the core A-level curriculum?'*

- *'What understanding of green chemistry ideas is developed by students who do, or do not experience the green chemistry intervention?'*

- *'What are the effects of the green chemistry intervention on the students' views of studying chemistry beyond A-level?'*

It is hoped that this research into the possible integration of green chemistry concepts in the A-level curriculum would help in the redesigning of a programme for post-16 students of chemistry that would include more reference to contemporary issues related to a more sustainable environment and reflect better the way chemistry would be taught in the near future, across all levels of education.

## 1.8 Overview of Study

This 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. Students were also invited to take part in a chemistry survey divided in two parts, one concerning their attitudes towards chemistry at school and out of school, the other concerning the understanding of green chemistry concepts. The survey was carried out before and after the programme and was also administered to the other group (the non-GC group) of students who did not participate in the green chemistry intervention. Students from both the GC and non-GC groups were divided into a number of focus groups which discussed various aspects of their chemistry learning experience at school. The total number of participants in the study (GC and non-

GC groups) was sixty seven and this represented 30.3% of the first-year students studying chemistry at the Maltese sixth form college.

Data were collected from the chemistry survey, students' activity worksheets, research journal, laboratory practical reports and particularly from focus group discussions which were all transcribed and translated prior to analysis. Students forming part of the green chemistry group were also involved in the setting up of an exhibition of posters which they had created and which was held at the college chemistry department. All data collected were then processed and analysed with the help of ATLAS.ti 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 in this project.

## 1.9 Overview of Thesis

This section will outline the main points from each subsequent chapter of the thesis.

**Chapter 1** explains how this project was conceived and why green chemistry has been proposed to be included in the Maltese A-level curriculum. The chapter discusses the background of this research investigation, the context of the study and the type of students participating in this project. It also introduces the research questions which the author tries to address through his work.

**Chapter 2** presents a review of literature on green chemistry and green chemistry education. It refers to the aims, definition and terminology used in green chemistry and to the twelve key principles which characterise this new area of science. The chapter highlights the salient parts of the short history of green chemistry and describes how it started being taught first at university and then at lower levels of education, particularly in high schools and sixth form institutions. The chapter discusses problems encountered by educators in the integration of green chemistry in chemistry curricula. It finally discusses also some of the future challenges in green chemistry education.

**Chapter 3** deals with the second part of the literature review dedicated to students' attitudes to science and chemistry and to the understanding of chemistry and green chemistry ideas. The chapter refers to various definitions of attitudes and describes how attitudes of science are viewed by researchers through different viewpoints which all indicate that such attitudes are made up of a number of components. The chapter considers some of the main research findings on attitudes to science and explains those factors which affect the students' interest in science. Reference is also made to techniques used by researchers to measure the students' attitudes towards school science. The chapter discusses also some aspects of the students' attitudes to chemistry, the students' interest in green chemistry and the students' knowledge and understanding of chemistry and green chemistry.

**Chapter 4** deals with the research methodology employed in this study. It describes the choice of the research paradigm, the research strategy, the samples used, the research setting and the various research instruments used to gather data. It also describes the research model used to test the effectiveness of the green chemistry intervention package and the theoretical framework and other criteria used to analyse the data. Details are also given on the measures taken to guarantee the reliability and validity of the data collection tools and of the data analysis. The chapter concludes by referring to a number of limitations in research procedures and data collection.

**Chapter 5** focuses on the intended curriculum and describes the objectives, learning outcomes and planning stage of the green chemistry intervention package. It refers to the educational resources prepared for the pilot intervention, changes planned for the main intervention and the revised intervention package to be applied in the main study. The chapter then gives a short description of all package materials produced for the classroom and laboratory intervention.

**Chapter 6** explains how the intended curriculum was implemented in the classroom and laboratory during academic year 2009-2010. It describes in detail all the activities that took place during the intervention, ranging from classroom seminars to learning activities to students' poster presentations to the green chemistry laboratory experience. It concludes with a critical analysis of the implemented curriculum.

**Chapter 7** refers to the first part of the analysis of the attained curriculum. It covers the data gathered from the participants and linked to two of the ten dimensions of the theoretical framework. This section analysed the students' cognitive attitudes towards chemistry and green chemistry in society which were developed into a number of themes. The chapter concludes by outlining a number of convergent and divergent views of the two groups of participants on the value of chemistry and green chemistry, out of school.

**Chapter 8** consists of the second part of the analysis of the attained curriculum and treated the remaining eight dimensions of the theoretical framework used to analyse the students' attitudinal responses. These included the cognitive and affective dimensions of learning chemistry theory and practice, the cognitive and affective dimensions of learning green chemistry theory and practice, the behavioural dimension of studying chemistry and the behavioural dimension of studying green chemistry. The chapter then concludes by summarising the points of convergence and divergence between the two groups as a result of the analysis of the eight dimensions of the framework.

**Chapter 9** continues with the analysis of the attained curriculum, referring to the analysis of data collected from part B of the chemistry survey concerning the students' conceptual understanding of green chemistry. The chapter refers to the detailed analysis of the twenty four items included in the understanding questionnaire. It concludes by reporting the changes in students' understanding as a result of the green chemistry intervention.

**Chapter 10** summarises the main findings of the study, referring to the changes brought about by the intervention package. It then attempts to answer the research questions of the study, based on the research findings. In addition, the chapter discusses how this thesis contributes to knowledge. It then reflects on some limitations of the research methodology used, and also on limitations of the intervention package and research instruments. This chapter finally discusses the implication of this work for educational policy and practice.

# Chapter 2

# LITERATURE REVIEW (GREEN CHEMISTRY)

## 2.1 Introduction

There is no doubt that chemistry has profoundly changed our lives during the twentieth century. Thanks to the research and development in chemistry and in its different branches, we can enjoy an improved quality of life as we can now be served by a multitude of chemical products that certainly have an overall positive impact on our health and well-being. In fact, there is no single aspect of human life in which chemistry does not play an important role (Domenech, 2005). Besides this, chemistry has the potential to address other future challenges, of an ever growing world population, in a number of areas such as the use of alternative sources of energy, energy efficiency, healthcare, nutrition and quality control in industry (van Dam-Mieras, 2007).

In spite of the benefits brought about by science, and chemistry in particular, to our lives, chemists are still frequently depicted as the 'bad guys' (Allen, 2004; La Merill, Parent & Kirchhoff, 2003), while the chemical industry is still viewed by many as 'causing more harm than good' (Lancaster, 2002). Prof James Clark, President of the UK Green Chemistry Network reports that the European Chemical Industry Council (CEFIC) survey in 1994 showed that 60% of the general public had an unfavourable view of the chemical industry in America. On the other hand, a survey of the public attitudes towards chemistry and chemists commissioned by the American Chemical Society and conducted in year 2000 found out that about one third (34%) of respondents had an unfavourable opinion of chemical companies, citing environmental impact of chemicals, harm to human health and bad publicity received by the same industry as the main reasons for this (National Science Board, 2002). One could also add other reasons such as negative feedback from the widely publicised past environmental disasters and ineffective methods used to communicate chemistry to the general public (Lerman, 2003). In fact it appears that today chemistry tends to hit the headlines only for the wrong reasons, such as the result of a disaster rather than an important invention or some other benefit to society (Allen, 2004; Clark, 1999).

Lancaster (2002) argues that the damage caused to human health and the environment by the chemical industry was not intentional but a consequence of a number of factors such as lack of knowledge especially on long term effects of chemicals polluting the environment.

Green chemistry has been purposely established in the early 1990s in order to design safer chemical products and processes for a more sustainable future. Rather than being viewed as a new branch of science, it is considered as a new philosophy or a new way of thinking that has the potential to contribute to sustainable development (Lancaster, 2001; Wardenchi et al, 2005). It has sometimes been also described as a *pro-active, innovative science* which aims at preventing pollution and minimising waste. In simple terms, it is a 'cleaner, cheaper, smarter chemistry' (National Environment Health Association, 1997) which proves that chemistry can in fact be done in a way that does not harm the human health or the environment. It is a multi-faceted discipline based on the premise that if a chemical process or a chemical product is 'benign', it presents no risk to human health and the environment (Hjeresen, Schutt & Boese, 2000). Taylor (2010) regards green chemistry as 'a revolutionary change in preventing pollution and health problems starting at the chemical design stage', whereas Collins (1995) describes it as an 'ethically and politically powerful idea'. It has been described as a combination of 'tools, techniques and technologies' that help chemists develop new products and processes that are more environmentally benign and efficient. Hence it involves revising old ways and means of doing chemistry to pave the way to a modern chemistry that is less toxic, less hazardous and non-polluting (Lancaster, 2001).

As can be seen in this chapter, the concepts of green chemistry can be promoted and taught at different levels of education and can serve as the ideal medium to portray a fresh, novel and positive image of chemistry in all classrooms and school laboratories, right from the secondary level.

This chapter outlines the definition, objectives and key principles of green chemistry. It also refers to the sustainable development context, the historical context and green chemistry education. A body of literature has been surveyed to follow all relevant developments closely related to the unfolding of this new phase in the teaching of chemistry, starting from university circles down to the first lessons and the first laboratory experience in chemistry at school.

## 2.2 Aims, Definition and Terminology

Green chemistry was launched as a science in the early 1990s and its introduction is associated with U.S. anti-pollution legislation and one of the programmes of the U.S. Environmental Protection Agency – U.S.E.P.A. (Lancaster, 2002).

Green chemistry has been defined in a number of ways but the definition which is most widely quoted in literature and the one which by now has been universally accepted is that proposed by Paul V. Anastas and John Warner who are widely regarded as the true founders and architects of green chemistry (Anastas & Warner, 1998).

> Green chemistry is the utilisation of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products (p. 11).

A number of authors stress the point that green chemistry must not be regarded as a separate field of chemistry (Kirchhoff, 2014; Ravichandran, 2011) but as a new approach of doing chemistry aimed primarily at protecting human health and the environment in an economically viable and sustainable way. Green chemistry marks an important shift from a culture of regulations and banning of chemicals to one based on designing safer products, a strategy described by Lisa Jackson of the USEPA as similar to the difference between 'treating disease and pursuing wellness' (Sanderson, 2011).

Green chemistry has also been described by a number of other alternative terms or phrases such as 'sustainable chemistry', 'benign-by-design chemistry', 'environmentally benign chemistry', 'clean chemistry', or simply 'chemistry for the environment'. Some of these terms were not well-defined and were debated among chemists (Centi & Perathoner, 2009; Eissen & Metzger, 2002). Although it is clear that the most popular term used since 1998 is that of 'green chemistry' there are still some quarters, particularly in Europe and in some international institutions such as the Organisation for the Economic Cooperation and Development (OECD, 1999) where the preferred term remains that of 'sustainable chemistry'

The use of these two terms, i.e. ‘green chemistry’ and ‘sustainable chemistry’, and their respective definitions have been the subject of a long debate (Hutzinger, 1999) and it appears that the issue of adopting one common term has not yet been fully resolved. In fact some authors still point out important differences between the two terms (Hill, Kumar & Verma, 2013).

Although it is true that there is no general consensus among the scientific community on the use of these two terms, because they may represent different purposes and interests of different chemists, it is equally true that both terms have now been universally accepted and they are now used interchangeably (Mandery, 2013; Tundo 2008; Tundo 2012). After all, the two terms are closely interrelated since the overall vision of green chemistry is ‘holistically aligned with environmental sustainability’ (Hill et al, 2013). Nevertheless, judging by the vast number of research articles, publications and other literature produced to date, the term ‘green chemistry’ is by far the one which is overwhelmingly preferred worldwide (Linthorst, 2010) embracing a number of different interests ranging from research work, the use of sustainable technology and education (Clark, 2006). Linthorst (2010) suggests that by being user-friendly the term ‘green chemistry’ has contributed significantly to the growth of green chemistry as a chemical philosophy and as an important area of modern chemistry.

## 2.3 The Twelve Principles of Green Chemistry

Green chemistry is governed by a set of rules known as ‘The Twelve Principles of Green Chemistry’ which were originally formulated and launched by Paul T. Anastas and John C.

Warner in their seminal book, 'Green Chemistry: Theory and Practice' (Anastas & Warner, 1998). This book has been described as the 'bible for sustainability' as it contained the so-called 'golden rules for achieving sustainability in the chemical industry' (Benjamin, 2013).

The principles of green chemistry shown in table 2.1 are intended to serve as guidelines for chemists to achieve sustainability while developing environmentally-benign products and processes. They are also considered as a set of widely accepted criteria which can be used to assess any claims of 'greenness' on a chemical product or process, or to compare the eco-friendliness of two similar processes (Tang, Bourne, Smith & Poliakoff, 2008). The twelve principles deal with all aspects of synthesis and processing including the use of renewable raw materials and solvents, atom economy, separations, energy requirements, waste minimisation, biodegradability and toxicity of chemicals. The main emphasis overarching the other principles is that of 'pollution prevention' which echoes the proverbial expression "prevention is better than cure". Apart from pollution prevention, the green chemistry principles also emphasize 'efficacy' and 'economics' as the other two main priorities to render chemistry truly sustainable (Pokrandt, 2010). One other important aspect stressed by the principles is the concept of 'design' which implies human intention having elements such as of 'novelty, planning and systematic conception' (Anastas & Eghbali, 2010).

**Table 2.1: The Twelve Principles of Green Chemistry**

| | |
|---|---|
| 1. | **Prevention**<br>It is better to prevent waste than to treat or clean up waste after it is formed. |
| 2. | **Atom Economy**<br>Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product. |
| 3. | **Less Hazardous Chemical Syntheses**<br>Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment. |
| 4. | **Designing Safer Chemicals**<br>Chemical products should be designed to preserve efficacy of function while reducing toxicity. |
| 5. | **Safer Solvents and Auxiliaries**<br>The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used. |
| 6. | **Increasing Energy Efficiency**<br>Energy requirements should be recognised for their environmental and economic impacts and should be minimised. If possible, synthetic methods should be conducted at ambient temperature and pressure. |
| 7. | **Using Renewable Resources**<br>A raw material or feedstock should be renewable rather than depleting wherever technically and economically practicable. |
| 8. | **Reducing Chemical Derivatives**<br>Unnecessary derivatisation (blocking group, protection / deprotection, temporary modification of physical / chemical processes) should be avoided whenever possible because such steps require additional reagents and can generate waste. |
| 9. | **Using Catalysts**<br>Catalytic reagents (as selective as possible) are superior to stoichiometric reagents. |
| 10. | **Designing for Degradation**<br>Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products. |
| 11. | **Real-time Analysis for Pollution Prevention**<br>Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances. |
| 12. | **Inherently Safer Chemistry for Accident Prevention**<br>Substances and the form of a substance used in a chemical process should be chosen so as to minimise the potential for chemical accidents, including releases, explosions, and fires. |

(Anastas & Warner, 1998, p. 30)

Authors such as Winterton (2003) argue that the twelve defining principles of green chemistry do not have equal weighting in terms of value and applicability. For example, according to the same Winterton, the principle dealing with the careful use of energy resources which suggests that chemical processes are carried out at ambient temperature and pressure, is more important than the principle of waste minimisation.

The 12 principles of green chemistry were subsequently complemented, in about five years' time, by another set of guidelines known as 'The 12 Principles of Green Engineering' (Anastas & Zimmerman, 2003). The idea was to apply green chemistry to the chemical processing industry in order to make it more sustainable from the design stage to the end product, by minimising its impact on the environment (Benjamin, 2013). The principles of green engineering cover a number of scientific and technological aspects that need to be considered to achieve sustainability. They represent the same underlying features of green chemistry, but taken from an engineering point of view (Sheldon, 2007). Estévez (2007) explains how these chemical engineering concepts can in fact 'multiply the positive effects of green chemistry'. The 24 principles of green chemistry and green engineering are collectively regarded by many as a 'scientific and ethical tool' which helps chemists and chemical engineers come up with intelligent decisions involving risk and sustainability (Anderson et al, 2004). The overall aim of green chemistry and green engineering has been described by the ACS Green Chemistry Institute as being that of encouraging 'the creativity and innovation of our scientists and engineers in designing and discovering the next generation of chemicals and materials so that the chemicals and materials provide increased performance and value while meeting all goals to protect and enhance human health and the environment' (ACS Green Chemistry Institute, 2011; Ruth, McGowan, Masciangioli, Wood-Black & Anastas, 2007).

## 2.4 Overlapping Aims of Green Chemistry and Sustainability

The concepts of ‘sustainability’ and ‘sustainable development’ have now been around for about three decades and different sources tend to define them in different ways depending on the context to which they are applied. However all definitions include common features such as ‘living within the limits’, ‘understanding the interrelationship between economy, society and the environment’ and an ‘equitable distribution of resources and opportunities’.

The term ‘sustainable development’ was introduced for the first time in 1987 by the UN World Commission on Environment and Development (UNWCED, 1987) in an effort to address the growing conflicts between economic and social development and the environment. The commission report ‘Our Common Future’, better known as the Brundtland Report, defined sustainable development as follows:

> “Sustainable development is the (social) development which meets the needs of the present (generations) without compromising the ability of future generations to meet their own needs”.
>
> (UNWCED, 1987)

The main objective of sustainable development is therefore ‘to use resources no faster than they regenerate themselves and release pollutants to no greater extent than natural resources can assimilate them’ (Merkel 1998). In the words of green chemistry founder Paul Anastas, sustainable development is ‘a way of preserving the things you cannot live without and preserving them forever’ (Anastas, 2003).

The idea of sustainable development which was originally criticised because of its ambiguity (Robinson, 2004) was eventually universally accepted by governments, NGOs and society at large, as a point of departure for planet earth to become a better place to live not only for us, but also for future generations (Muñoz Ortiz, 2006). The concepts of sustainability and green chemistry emerged and developed side by side for more than two decades sharing common goals and perspectives. In fact the idea of green chemistry which emphasizes principles such as minimisation of waste, energy and resources, is sometimes regarded as the response of the chemical industry, supported by academia, to the challenge of sustainable development.

Lancaster (2002) explains that the chemical industry has a moral obligation to continue providing benefits to society but this has to be done in an environmentally friendly way. This means that the adoption of green chemistry by the industry is inevitable considering the current unsustainable trends in exploitation of natural resources and the concurrent increase in global demands for chemical products, which are expected to exceed the world population in the near future (OECD, 2001).

The aims of green chemistry and sustainability are so much overlapping that their activities, methods and scientific foundations became ‘inextricably intertwined’ according to Anastas (2011), proving the crucial role of chemistry in realising the vision and desire of people to live on a sustainable planet. In fact, green chemistry is often viewed as the essence of sustainable development or the contribution of chemistry to sustainability (Kirchhoff, 2014). Putting it in Sheldon’s words, sustainability is the ultimate aim while green chemistry is the means to achieve it (Sheldon, 2007). That is precisely why it is frequently labelled as ‘chemistry for a sustainable development’ or simply ‘sustainable chemistry’.

## 2.5 Historical Background

Green chemistry is widely considered as a major development of chemistry and could also be viewed as the reaction by chemists to address the many problems created in the twentieth century by a fast growing chemical industry relying on the hugely successful modern technology. In her critical analysis of green chemistry as a scientific movement, Roberts (2005) explains how the idea of green chemistry originated from the merging of the environmental movement, particularly popular in the U.S. and represented by the publication of Carson's landmark book 'Silent Spring' in 1962 (Carson, 1962), and the growth and expansion of the chemical sciences and the chemical industries. In fact Carson was the first to raise environmental awareness about the unintended damage caused by pesticides which led to the introduction of environmental legislation in the US (Hogue, 2013). Roberts shows how the uneasy mixing of the two histories – environmentalism and chemical industries – brought to the forefront a number of issues such as the public perception of chemistry (Allen, 2004), the role of chemical accidents, the decreasing interest of students to enrol in chemistry programmes and the negative impact of the ever increasing regulations on the cost of business (Roberts, 2005).

Until the 1960s there were no environmentally-related regulations on the manufacture, use and disposal of chemical substances and pollution used to be controlled by reducing the concentration of the pollutants in a medium, a strategy described as 'dilution is the solution to pollution' (Anastas & Warner, 1998). The situation however changed drastically with the widely publicised environmental disasters and an ever growing public concern and knowledge on chronic toxicity, bioaccumulation, carcinogenicity and other health related issues on the use and exposure to chemicals. Different countries started reacting by adopting different approaches to safeguard human health and the environment from risks posed by the production, use and ultimate disposal of chemical substances. According to Cann (2001), by the year 1990 the U.S.A. alone had sanctioned no less than 130 environmental laws dealing with the treatment or capture of pollutants at source. By that time, the emphasis had shifted from a ‘dilution’ approach to ‘end-of-pipe’ control.

An important development which occurred in the U.S.A. in 1991 was the enactment of the Pollution Prevention Act of 1990 which established ‘pollution prevention’ at source as the best strategy to solve environmental problems. This new legislation represented a major shift in the environmental protection paradigm, from the ‘command and control’ approach (which included the ‘end-of-pipe’ or ‘cleaning up pollution’ solutions) to a ‘pollution prevention’ approach based on ‘waste minimisation’ (Carra, 1999).

In the meantime, another major driving force in the adoption of this new approach to deal with environmental degradation started to emerge. This was the sustainable development movement that originated in the 1980s following the publication and adoption of the Brundtland Report in 1987 (UNWCED, 1987). The report ‘Our Common Future’ emphasized the need to conserve raw materials and minimise waste in what is now referred to as the green chemistry principle of ‘atom economy’ (Newton, 2008; Trost, 1991). Consequently, the ‘command and control’ policy suddenly shifted on an international scale towards an approach of ‘pollution prevention’ (Linthorst, 2010).

The new pollution prevention legislation in the U.S. set the stage for the emergence of the green chemistry movement as the U.S. Environmental Protection Agency launched its first research initiative in 1991, focussing on pollution prevention in the synthesis of chemicals.

The programme was originally called ‘Alternative Synthetic Pathways for Pollution Prevention’ but was officially renamed in 1993 as the ‘Green Chemistry Program(me)’. The aim of the programme was to implement sustainable development in chemistry and chemical technology through the collaboration with a number of organisations representing academia, the industry, government agencies and NGOs (Lancaster 2002; Newton, 2008; OPPT, 2002; Pellerin, 2005; Wardenchi et al, 2005).

It is widely recognised that ‘green chemistry’ as a concept was introduced for the first time in the early 1990s by Paul V. Anastas, one two authors of the first handbook in green chemistry (Anastas & Warner, 1998). This new philosophy was originally referred to as ‘benign by design chemistry’ or simply ‘benign chemistry’ but then changed to ‘green chemistry’ (Linthorst, 2010), a shift regarded by Roberts (2005) as deliberate as it is difficult for a chemical process to be truly and completely environmentally benign.

The US green chemistry research programme served as a platform and catalyst for the major green chemistry events in the USA and beyond. These included symposia, conferences and the prestigious US Presidential Green Chemistry Challenge Award which was established in 1995 to recognise outstanding achievements in green chemistry (Fairley, 1998; National Environmental Health Association, 1997; Newton, 2008; OPPT, 2002; USEPA, 2010).

Another important milestone in the history of green chemistry was the launching of the Green Chemistry Institute (GCI) in 1997 to support collaboration between industry, universities, (US) national laboratories and other organisations in order to promote and advance green chemistry and green engineering. The GCI, which joined the American Chemical Society

(ACS) in 2001, is now regarded also as an international network of green chemistry experts and is represented in no less than 25 other countries, across all continents, through a number of international affiliate chapters.

Green chemistry activity started also proliferating in other parts of the world in the late 1990s with the setting up of various green chemistry centres, institutes and networks mostly based in prominent universities. A number of countries (such as Italy, UK, Japan, Canada and Australia) also launched their national awards in green chemistry, similar to the US Presidential Award in a bid to promote further research in green chemistry. Europe launched its own international award scheme known as the European Sustainable Chemistry Award in 2010 through the European Association for Chemical and Molecular Sciences (EuCheMS 2010a; EuCheMS 2010b).

One of the first and perhaps the most influential publications in green chemistry was the previously cited book 'Green Chemistry: Theory & Practice' published by Warner and Anastas in 1998. This book practically gave life to green chemistry by giving it a precise definition and by introducing the 'twelve principles' as the main framework for the application of green chemistry. Since then, the book has been translated to several languages and marked the 1990s as the decade when green chemistry was established as a legitimate scientific field (ACS, 2014b; Warner & Anastas, 1998).

Another important event for green chemistry was the launching in 1999 of the first international scientific journal dedicated to green or sustainable chemistry. This journal, named 'Green Chemistry', was published by the UK Green Chemistry Network which was founded in the previous year by the Royal Society of Chemistry. The journal 'Green

Chemistry' was later joined by several other peer reviewed international scientific journals also specialising in green chemistry.

Two international organisations which are quite active in green chemistry are the Organisation of Economic Cooperation & Development (OECD) which established its own 'Sustainable Chemistry' programme in 1998 and the International Union of Pure & Applied Chemists (IUPAC) which launched a biannual international conference on green chemistry in 2006. Green chemistry research activity earned the international limelight in the early 21$^{st}$ century with the awarding of the Nobel Prize in chemistry in 2001 and 2005 to a number of chemists for their research into areas largely associated with green chemistry (Nobelprize.org, 2001, 2005a, 2015b).

Green chemistry was also influential in updating legislation on the production, use and circulation of chemicals around the world. An example is the important legislation recently introduced by the E.U. and known as the REACH Directive (standing for Registration, Evaluation, Authorisation & Restriction of Chemicals) which entered into force in 2007 (European Commission's Directorate General for Enterprise & Industry, 2014). This European legislation has been described as a 'major shift towards green chemistry' (Morson, 2007) as it encourages the development and use of chemicals that are harmless to human health and the environment. James Clark, another leading figure in green chemistry, described REACH as 'the most important chemicals-related legislation in living memory'. He suggests that apart from protecting public health and the environment, this EU directive allows European producers of chemicals to claim a high level of 'green credentials' to those products evaluated for toxicity and environmental impact, giving them a competitive advantage over others in the world.

## 2.6 Scepticism & Other Obstacles to the Adoption of Green Chemistry

Although it is clear that green chemistry is making significant progress both in research and industry, it still has a long way to go to being accepted and practised by all stakeholders (i.e. industry, consumers, pressure groups, governments, educators and researchers) across the world.

Drawing from the RAND report (Lempert, Norling, Pernin, Resetar & Mahnouski, 2003), the Royal Society of Chemistry, RSC (2008) cites a number of significant barriers to the introduction and adoption of green chemistry. These include the lack of global harmonised regulations and environmental policy, strict authorisation procedures which make it harder to develop new products and processes, the extra cost incurred to introduce new technology (requiring an initial short-term investment), inadequate economics of the implementation of green chemistry, insufficient funding for research and development, lack of clear guidance on best practice in green chemistry, lack of universally accepted green chemistry metrics that allow comparison between different chemicals across their life cycle, a culture that looks at the product rather than a whole process and life cycle, as well as the low profile of green chemistry in schools and universities (Lempert et al, 2003; RSC, 2008).

One other obstacle seems to be the lack of complete trust in the outcome of research. In fact, it is sometimes argued that the public is not fully informed with the entire picture about the green chemistry practices being advanced. For example, according to Roberts (2005) little is known about the toxicity of certain ionic liquids which are now being proposed as green solvents.

There are certainly other more obvious obstacles to the adoption of green chemistry, one of them being the scepticism or negative attitudes by certain 'old guard' chemists. Sanderson (2011) quotes Eric Beckman, a chemical engineer at the University of Pittsburgh, Pennsylvania, who attributes such an attitude to the fact that chemists used to be trained rigorously in chemistry but insufficiently in important areas such as engineering, product design and life cycle analysis. The same author also mentions how according to Neil Winterton, a former critic but now a convinced green chemist, green chemistry was originally perceived as 'fuzzy and non-rigorous' meaning it might have appeared to be too vague and unchallenging in its early stages. Other sceptics feared also it was nothing more than a 'trendy new buzzword' used to tap some funds 'for projects of dubious environmental value' (Sanderson, 2011).

Roberts (2005) goes as far as calling green chemistry 'a fractured idea' viewing it to be half way between a scientific movement and a community of practitioners who practise 'some form of green chemistry' as part of their daily work as chemists. In her critical analysis of the green chemistry movement, Roberts argues that green chemistry has not yet accomplished what it aspired to do and will therefore have to face an inevitable uphill struggle unless something is done to revamp the discipline to reflect what it takes to be a true scientific movement.

Although scepticism to green chemistry diminished with time, it did not disappear completely. In fact, John Warner, widely considered as a leading figure in green chemistry, was reported as saying that 'a mention of green chemistry in a gathering of chemists can still provoke sighs and eye-rolling' (Sanderson, 2011) even though the situation has improved with time particularly with the ongoing research momentum and the exponential rise in number of publications on a broad range aspects related to the field.

## 2.7 Green Chemistry in Education

The emergence of green chemistry in the 1990s was followed by the growing need of the exponents in this field to share their new philosophy and methodology of doing chemistry with other chemists and students aspiring for a chemistry career. In fact education was soon recognised as the ideal medium through which the green chemistry message could be diffused among university students and even society at large (Wardenchi et al, 2005). Educators even started looking at ways and means of integrating the green chemistry concepts with those of sustainable development which were developed a few years earlier in the 1980s (UNWCED, 1987) and teach them in different levels of education. This is so because green chemistry shares the main ideals of sustainable development. In fact, the teaching of green chemistry usually involves the discussion of sustainable development as it allows students and teachers to address in an ethical way the various environmental issues faced by the local and international communities (Haack, Hutchison, Kirchhoff & Levy, 2005). This explains why green chemistry is also frequently referred to as 'sustainable chemistry'.

Teaching green chemistry is one way of showing the importance of chemistry for sustainable development (Burmeister & Eilks, 2012). Some suggest that this has become an urgent matter when one considers that education for sustainable development is still virtually absent in many post-secondary chemistry curricula all over the world (Vilches & Gil-Pérez, 2013).

It also projects chemistry into the future considering the emphasis laid on 'environmental sustainability' during the International Year of Chemistry 2011 (Hill et al, 2013).

### 2.7.1 **Teaching Green Chemistry at University**

There were several authors who wrote about the importance of implementation of green chemistry in university chemistry courses especially at the undergraduate level (Ridley, 2011). Some of them emphasized that more than desirable this is now inevitable (Braun et al, 2006). Studies show that when students attend courses in green chemistry, they would improve their critical thinking, problem solving and communicative skills which they need in order to understand better the local and global contexts of sustainable development (Parrish, 2007). Learning green chemistry was also found to help students address environmental issues as they feel empowered to solve problems in familiar settings (Haack et al, 2005).

Green chemistry started being taught to undergraduates in the USA in 1992, well before the launching of the principles of green chemistry by Anastas and Warner in 1998 (Collins, 1995). At that time, it was thought that the ideal place to teach green chemistry was the university research laboratories and classrooms as undergraduates and postgraduates would have a higher standard of chemistry than younger students at lower levels. It is also a known fact that most of the university students would already be aspiring for a chemistry related career during their studies. Furthermore it was thought that green chemistry was regarded to be so challenging that it had the potential to generate 'intellectual excitement' among university students (Ware, 2001b). Similar opinions were shared by other authors who felt that it was 'imperative to teach the values of green chemistry to tomorrow's chemists' (Busch, 2000) in order to guarantee that chemists are always at the very centre of a sustainable society (Clark, 2006). This is also consonant with the moral obligation of contemporary chemists to continue developing sustainable products and protect human health, as specified in the updated codes of conduct of the chemical professionals (ACS, 2012; Prado, 2003; RSC, 2012).

Although green chemistry is now being offered by a growing number of universities from all over the world, the situation is still below expectations considering that it is still a long way from being accepted and integrated into all university chemistry curricula (Clark, 2006). In a way this is not unusual in education where curriculum reform is frequently described to occur in an 'evolutionary' rather than a 'revolutionary' way, with new major concepts requiring sometimes a whole generation to become truly integrated in the relevant programme of studies (Kirchhoff, 2009).

Some countries are currently increasing their efforts in order to step up the uptake of green chemistry by academia. One example is the launching of the American initiative known as 'The Green Chemistry Commitment' which aims to pool the efforts and resources of various educational institutions involved in green chemistry education (Beyond Benign, 2014b; Ritter, 2012). Indications show that university students show a strong interest in sustainability and are very receptive if not enthusiastic on the inclusion of green chemistry in the chemistry curricula (Haack et al, 2013; Kovacs, 2013).

### 2.7.2 Green Chemistry for Pre-university Students

The idea of extending green chemistry education to pre-university students is now gaining support and in fact more people are today recognising the importance of incorporating green chemistry, in one way or another, in different levels of education (Anastas & Beach, 2009; Andraos & Dicks, 2012; Beyond Benign, 2014c; Burmeister & Eilks, 2012; Burmeister, Rauch & Eilks, 2012; Eilks & Rauch, 2012; Karpudewan, Ismael & Mohamed, 2012a; Mandler, Mamlok-Naaman, Blonder, Yayon & Hofstein, 2012; Matlack, 1999; Ryan & Tinnesand, 2002). According to Wardenchi et al (2005) the philosophy and practice of green chemistry can contribute to sustainable development and this is why they believe that it has to be introduced to students at all levels. Literature shows there is an increasing support to the idea that students should learn 'to view chemistry with a green tint' (Savitskaya, Kimlenka & Rytau, 2012). A number of undergraduates who experienced green chemistry for the first time at university believed that education would be significantly improved if green chemistry were to be integrated in the curriculum at an earlier stage (Braun et al, 2006)

Some authors such as Ware (2001a) are concerned that pre-university chemistry students may not have enough background to be able to understand and appreciate the full implications of the whole set of green chemistry principles. Yet they believe there is enough content to introduce some of the basic ideas of green chemistry to lay the foundations of green chemistry in chemistry courses at high school / sixth form level (Ware, 2001a; Beyond Benign, 2014c; Anderson et al, 2004; Goes et al, 2013). Other authors also cite a number of benefits associated with the introduction of green chemistry in the lower levels of education. These include the potential of green chemistry to empower young students to relate traditional chemistry concepts that are taught in class to the real world outside and possibly to a future career in chemistry too, given the choice students have to make at this age (Braun et al, 2006). Learning green chemistry allows also students to connect chemistry with other school subjects and aspects of their lives (Goes et al, 2013; Karpudewan et al, 2012b). Even the scientific community stands to benefit significantly with the introduction of green chemistry into the curriculum. In fact it has been argued that learning about green chemistry at a young age provides the ideal platform 'to attract the bright students to the chemistry profession' (Anastas & Beach, 2009).

Countries such as the USA, UK and Australia have already started promoting and teaching some basic concepts of green chemistry in secondary schools and sixth forms / high schools in order to show students what chemistry can do for a sustainable future. Such a move is consistent with the new trend of contemporary secondary and post-secondary science and chemistry curricula which recommend the teaching of basic ideas of sustainable development to prepare students to become better citizens and future experts of science (Bradley, 2002).

### 2.7.3 Greening the Sixth Form Chemistry Curriculum

By now there are various countries across the world (particularly in Europe and America) which have adopted concepts of green chemistry in the curricula of sixth form / high school chemistry. Such a widespread interest to include green chemistry in further education programmes is being complemented by an increase in number of relevant educational material and resources available for students and educators (Beyond Benign, 2014c, Chinese University of Hong Kong, 2004; Karpudewan et al, 2011a).

Parent, Kirchhoff & Godby (2004) suggest a number of concrete ideas on how green chemistry can be integrated in a typical A-level chemistry curriculum. These include the use of strategies such as emphasizing the presence of target products and by-products in a chemical process, calculating and comparing the atom economy (an important principle of green chemistry) with percentage yield (a classical quantitative chemical concept) in order to check the efficiency of a reaction, addressing issues concerning raw materials and energy requirements when discussing preparations, providing alternative reaction routes (making students aware of the several options available), introducing green chemistry concepts through laboratory experiments, and discussing how chemistry concepts are related to social, economic and environmental issues, i.e. the three dimensions of sustainability.

An example of how green chemistry can be infused in a high school chemistry curriculum was provided by the organisation Beyond Benign which published a detailed method of integrating 'greener' concepts with established subject matter. This consists of a curriculum mapping document prepared by a group of educators after surveying the materials published online or in print and suggesting suitable resources for each of the topic areas usually included in a typical introductory (first year) course in A-level chemistry. However more work needs to be done in this area to improve on existing teaching and learning resources that are already available but also on the professional development of chemistry teachers and the choice of teaching approach.

There were other initiatives to design green chemistry programmes specifically for high school / sixth form and even lower stages of education. These include courses created by various colleges and universities in different parts of the world, mostly involving outreach efforts carried out by university chemistry students (Anastas & Beach, 2009).

### 2.7.4 Educational Resources

The amount of literature on green chemistry that has been published since its emergence in the early 1990s is substantial and reflects the growing interest and volume of research carried out in this new area of modern science. Yet the number of educational resources particularly textbooks that have been developed to date which target post-16 students and their teachers are not so abundant. In fact most of the teaching resources that have been created to date are more addressed to undergraduate and postgraduate students than to pre-university students (Cann & Dickneider, 2004; Hjeresen at al, 2000; Ware, 2001a).

Two major contributors to the teaching and promotion of green chemistry in educational circles are the Green Chemistry Institute of the American Chemical Society – ACS GCI, and the Royal Society of Chemistry of the UK – RSC. The American Chemical Society, ACS, published two chemistry textbooks which have been described as 'non-traditional texts' through which it introduces various aspects and examples of green chemistry. One of the books 'Chemistry in Context' ($8^{th}$ edition) is mainly addressed to non-chemistry undergraduates (ACS, 2014e) while the second one 'Chemistry in the Community' known also as ChemCom ($6^{th}$ edition) is specifically designed for high school chemistry students (ACS, 2011). The latter covers traditional chemistry topics and relates them to societal issues and real-world scenarios, and represents one of the first efforts to introduce green chemistry in a chemistry textbook for pre-university students. Yet another ACS publication which addresses high school teachers and students is the booklet 'Introduction to Green Chemistry – Instructional Activities for Introductory Chemistry' (published in 2002) which includes activities, references and resource materials on green chemistry with instructional notes linking green chemistry concepts with traditional chemistry curriculum (Ryan & Tinnesand, 2002).

One of the earliest European publications involving teaching of green chemistry was the booklet produced by the Royal Society of Chemistry (RSC) which carries the title 'Green Chemistry' (Warren, 2001). This may be considered as one of the first resources outlining areas for teaching of green and environmental chemistry as well as sustainable development, specifically aimed for 11-19 year old students (i.e. secondary and post-secondary education).

There were also some efforts to produce educational resources featuring a number of green chemistry experiments and related laboratory activities. An example is the manual prepared by the Union University containing experiments designed for high school students (Union University, Tennessee, 2014). There are quite a few other laboratory handbooks in green chemistry but these are more adapted to the undergraduates and higher levels of education (Dicks, 2011; Doxsee & Hutchison, 2003; Kirchhoff & Ryan, 2002; Roesky & Kennepohl, 2009). Experiments in green chemistry are also being added to other material typically found in laboratory manuals designed for sixth form chemistry students (Chinese University of Hong Kong, 2004). There is also an increasing trend to publish green chemistry educational resources on the internet so that they would be immediately available to students and teachers all over the world. Table 2.3 lists a number of such online resources that apply to all those involved in the greening of a post-16 chemistry curriculum.

**Table 2.2: Online Resources on Green Chemistry for Pre-University Students**

| | Name of Online Resource | Description and Source |
|---|---|---|
| 1. | Beyond Benign | A website managed by the non-profit organisation 'Beyond Benign' which aims to revamp the teaching of chemistry so that students would connect in a better way with the world and be able to relate chemistry to human health and the environment. It includes various resources and programmes aimed for K-12 science, university and professional level. (Beyond Benign, 2014b) |
| 2. | Chemistry is All Around Network | This is a EU project forming part of the Lifelong Learning Programme which promotes the studying of chemistry at school. The portal provides a number of teaching resources and other online material which promotes teaching chemistry in a more innovative, attractive and interactive way. It was launched in 2012 and includes a website dedicated to green chemistry teaching resources (including original experiments) aimed for upper secondary schools. Though the main language is Greek, most of the material is translated to English. (Chemistry is All Around Network, 2014) |
| 3. | Green Chemistry Educational Network (GCEdNet) | This is a social network for educators, provided by the University of Oregon, USA, to support opportunities to research, develop, implement and disseminate green chemistry educational materials. (GCEdNet, 2014) |
| 4. | Green Chemistry Network (GCN) | Based at the University of York, UK, and originally funded by the Royal Society of Chemistry, the GCN provides a list of useful information on green chemistry issues, of possible use in different levels including A-level and GCSE level. (Green Chemistry Network, 2014) |
| 5. | Greener Education Materials for Chemists (GEMs) | This is an interactive collection (database) of green chemistry resources compiled by the department of chemistry of the University of Oregon, USA. It includes laboratory exercises, lecture materials, course syllabi and multimedia content illustrating the green chemistry concepts. The level of material varies as it targets different audiences including the general public, secondary schools, colleges and universities. (University of Oregon, 2014) |
| 6. | Greener Industry | A website produced by the Chemical Industry Education Centre and supported by a number of organisations including the Royal Society of Chemistry, with contents being very relevant to the A-level curriculum, illustrating a number of products and processes of the chemical industry that can be rendered sustainable through green chemistry. (Greener Industry, 2014) |
| 7. | Online Educational Resources for Green Chemistry & Engineering | A website provided by the American Chemical Society featuring several links to a number of resources developed by the Green Chemistry Institute and the Education Division of the ACS. Resources include various teaching tools and ideas, and a number of activities and experiments in green chemistry designed for high school students and other levels of education. (American Chemical Society, 2014c) |

There are other methods through which students and teachers can get more involved in green chemistry. These include participation of students in outreach activities organised by the green chemistry institutes and centres proliferating in various parts of the world, participation by teachers in workshops, training courses and summer schools organised periodically by organisations such as the American Chemical Society, the Italian interuniversity consortium INCA and the British Green Chemistry Centres in York and Nottingham. Such activities are aimed to train teachers in the use of green chemistry educational resources and how to conduct green chemistry experiments and demonstrations. They also help them integrate green chemistry principles into the current science and chemistry curricula (Anastas & Beach, 2009).

## 2.8 Potential Barriers to the Integration of Green Chemistry

Although some progress has been registered in the integration of green chemistry in the curricula of both pre-university and university courses, the situation is still considered far from being ideal (Braun et al, 2006; Cann, 2001; Clark, 1999; Kirchhoff, 2009). In fact, to date, green chemistry still does not form part of the standard chemistry curriculum in most colleges and schools (Matus, Anastas & Zimmerman, 2012). It is evident that there are a number of obstacles which need to be addressed for a broader implementation of green chemistry in education.

One of the problems which is frequently cited by educators is that there is no place for new material in a chemistry curriculum that is widely regarded as 'overcrowded' (Andraos & Dicks, 2012; Ware, 2001a). One of the arguments brought about by sceptics is that traditional material is more important than green chemistry concepts and that there is not enough time to cover the mainstream concepts and introduce new areas (Braun et al., 2006). The counterargument is that green chemistry need not be added over and above the existing material and examination syllabi as it may replace part of the content in an exercise updating the present coursework (Kirchhoff, 2009; University of Oregon, 2005).

Significant resistance may also arise from teachers and lecturers who may be reluctant to introduce green chemistry simply for the fact that they might not have been trained to do so, or because they aren't yet convinced of its importance (Ware, 2001a). However the presence of the increasingly available online resources and the various proposed methods to introduce green chemistry in schools can all help to overcome such teacher inertia. Klinghsirn & Spessard (2009) suggest that teachers may always seek the support of colleagues and administrators especially when one considers that aspects such as enhanced safety and reduced waste generation are generally desirable by all educators.

Another major obstacle that is also mentioned in literature is the lack of relevant curricular material. In fact it is true that chemistry textbooks which refer to green chemistry are particularly lacking, especially at the post-16 level. However there are several online publications suitable for university students and some alternative educational resources which and appeal also to a younger audience and even the general public (ACS, 2014d; Michigan Green Chemistry Clearinghouse, 2014).

Some educators also perceive green chemistry as being either too political or not enough scientific and hence not as challenging as the traditional chemical sciences. In fact it has sometimes been labelled by critics using terms such as 'soft' or 'hippy' chemistry (Amato, 1993; Andraos & Dicks, 2012). Other authors rebut such claims by explaining that all green chemistry innovations are scrutinised in a rigorous way before being accepted as green or sustainable. Furthermore, they argue that the principles of green chemistry are based on the same principles underlying traditional chemistry (Klingshirn & Spessard, 2009).

Sceptics sometimes argue that converting to a new methodology such as green chemistry is too expensive and is therefore not truly sustainable when one factors in the cost of research and the investment required until changes are scaled up for the industry. There is also the perception among some consumers that green products are more expensive and less effective too. However, other sources argue that when one considers all costs of a new chemical product or process (including the amounts of reagents and solvents required, safety measures and methods of disposal), green chemistry is usually found to be cost-effective (Matus et al, 2012; University of Oregon, 2005).

Another point made by some critics is that the development of new experiments to illustrate green chemistry principles or the 'greening up' of others is a very time-consuming process and this may discourage teachers from promoting a greener approach to the chemistry laboratory (Klingshirn & Spessard, 2009). This chapter has already highlighted the availability of a limited number of resources that are already available for educators willing to adopt green chemistry in their teaching laboratory practice. This may be considered as 'work in progress' as experiments are continuously being developed and published on the internet (Berkeley Centre for Green Chemistry, 2014; Beyond Benign, 2014a; Green Chemistry Education Network, 2014; Greener Education Materials for Chemists, 2014).

According to some sources, educators who are willing to implement green chemistry especially in the school laboratory, may also experience what has been termed as 'greenophobia', i.e. the fear that a newly designed experiment or exercise may not be valid unless it adheres to all the criteria of green chemistry. However, Klingshirn & Spessard (2009) explain that the term 'green' is only relative and any improvement in laboratory procedures / exercises, even though gradual, would still be considered to lead to greener methods.

Green chemistry has also been criticised for the fact that it does not train students how to handle dangerous chemicals as it aims to minimize chemical hazards in laboratories and industry. Critics argue that students may eventually find it harder to deal with such chemicals at their future place of work (Klingshirn & Spessard, 2009). This argument is opposed by suggestions that students at this level of education need not be exposed to any hazardous chemicals to learn basic chemistry concepts. In fact students would have more time to deal with such chemicals, if and only if, they have to do so later in life, when they may even be in a position to offer greener alternatives (University of Oregon, 2005; Klingshirn & Spessard, 2009).

Andraos and Dicks (2012) explain that a common misconception with students and sometimes even with researchers is that green chemistry is synonymous with environmental chemistry. Although both these areas of chemistry deal with environmental issues and are also complementary to each other, they certainly have different aims and emphasize different concepts. Hence it is important that students learn how to distinguish between the two separate areas of chemistry.

## 2.9 Future Challenges of Green Chemistry Education

The type of chemistry that is often presented to students in the classroom is sometimes described as 'brute-force' chemistry that requires harsh conditions (e.g. high temperatures and pressures) and harsh chemicals (e.g. concentrated acids or alkalis). In contrast, green chemistry works using milder reaction conditions carefully chosen in order to avoid toxic reagents and hazardous waste products (Kirchhoff, 2009). It is safer and non-toxic and certainly more sustainable than traditional chemistry that has been taught in the classroom till now.

Given that students are already being taught concepts of sustainable development as early as their secondary level of education, it appears logical that one of the next challenges of chemistry education is that of presenting also the principles of green chemistry to the same audience of students, as the real centre of sustainability. This may also have the added benefits of improving the image of chemistry and working against chemophobia and low enrolments in chemistry, particularly at the post-16 level.

The body of literature surveyed in this chapter points to the fact green chemistry can only make significant progress once it is diffused in all areas of chemistry in order to reach all chemists. This process can only be achieved by integrating the principles of green chemistry in all levels of education, starting from the lowest possible level, i.e. secondary education. This means that ideas of green chemistry need to form part of the training of all future chemists right from the very start (Eilks & Rauch, 2012).

According to Kirchhoff (2009), all chemistry practitioners should realise that green chemistry is not to be regarded as an area of specialisation but a strategy that is beneficial to all chemistry. Literature clearly suggests that chemistry students and future scientists would greatly benefit from the introduction of green chemistry in the chemistry curriculum (Braun et al, 2006) as these would adopt a different 'greener' attitude from others during their studies and beyond. Other literature suggests that chemistry educators must continue working to develop, use and share their educational materials on green chemistry related to their areas of specialisation, in order to facilitate the process of integration.

## 2.10 Chapter Summary

Green chemistry is a relatively new area of chemistry that aims to prevent pollution by focussing on the molecular level to design safer non-toxic and 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 science is based on a set of guidelines known as "The Twelve Principles of Green Chemistry", which were launched by Anastas and Warner only 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. The recent history of green chemistry shows that it was born 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. The inception of green chemistry represented a major shift in the environmental protection paradigm from a 'command and control' approach to a 'pollution prevention' approach based on the principle of waste minimisation.

Green chemistry started as a research programme in the USA but then metamorphosized into a scientific movement involving people from the chemical industry, universities, laboratories and other organisations and then green engineering. It did not take long for green chemistry to proliferate in different countries across the world with activities being organising by a growing number of green chemistry centres and networks, the majority operating from universities and colleges. Green chemistry was also shortly adopted by various international organisations while research started being published in a number of journals all dedicated to this new area of science. Research in green chemistry was even recognised on more than one occasion with the Nobel Prize in chemistry.

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 to younger audiences and introduced in the curriculum of secondary and post-secondary schools. Literature suggests also 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 different sources indicate that a number of potential difficulties may 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.

Considering that students in secondary schools are already familiar with the concepts of sustainable development, it appears to be logical to present green chemistry in schools as the real centre of sustainability. Such move would possibly help improve the public perception of chemistry and attract more students to study the subject. Integrating green chemistry in the school chemistry curriculum would also help the green chemistry message to reach a wider audience and prepare future chemists and scientists to face better the challenges of a future sustainable world.

# Chapter 3

# OTHER RELEVANT AREAS OF LITERATURE

## 3.1 Introduction

The learning of scientific theories and concepts by students attending post-compulsory education is largely influenced by their interest and attitudes towards science. This has been confirmed by a body of literature dealing with various aspects of students' attitudes towards science in general and chemistry in particular. Students' attitudes towards societal science / chemistry and towards school science / chemistry get shaped by various factors originating from the same students' life experience at home, with friends and through their interaction with other people at school and in society at large.

This chapter deals with other areas of literature relevant to this research project, focussing mainly on theories of attitudes and factors which determine students' attitudes to science and chemistry, with special reference to work carried out on post-16 students. It also describes the different methods adopted by researchers in the area of science education to measure students' attitudes, highlighting some of their strong points and limitations.

The chapter discusses the various dimensions of the students' attitudes to chemistry and then refers to problems associated with understanding of chemistry and green chemistry ideas.

## 3.2. Research on Students' Attitudes to Science

Research work on students' attitudes towards science has now been featuring prominently in studies carried out over the past 50 years with interest and activity reaching a peak in the 1970s but then declining with time due to a number of issues possibly related with the use of terminology, instruments to assess students' attitudes, the use of accessible information and overlap in findings from earlier contributions (Ramsden 1998). The interest for research in science-related attitudes was re-ignited towards the beginning of the new millennium, marking a widespread international concern for certain trends in science education (Hofstein & Mamlok-Naaman, 2011).

All research in this area of science education had been trying to address a number of concerns ranging from the lack of students' interest in school science, the decline in interest of young people to pursue further studies in science and choose scientific careers, widespread lack of scientific literacy among the general public and more specific issues such as under-representation of females and certain minorities in professions related to science / technology.

A number of major reviews of literature on attitudes towards science have been carried out over the years. These include reviews by Gardner (1975), Munby (1983), Nieswandt (2005a), Osborne et al (2003), Potvin & Hasni (2014), Schibeci (1984), Simon & Osborne (2010), and Toplis (2011) which draw on hundreds of studies on students' attitudes. Such reviews indicate that this area of science education was extensively researched even though it was not always clear what type of attitudes were under investigation, given the ambiguity, poor articulation and lack of understanding of the concept of ‘attitude towards science’ (Osborne, Simon & Collins, 2003; Simon & Osborne, 2010).

## 3.3 What are Attitudes?

The term ‘attitude’ has been defined in a number of ways, the following being one that represents most definitions: “An attitude is the tendency to think, feel or act positively or negatively towards objects in our environment” (Eagly & Chaiken, 1993).

In research work, the term ‘attitude’ is correlated to a number of other terms such as ‘interest’, ‘motivation’, ‘views’, ‘images’, ‘beliefs’, ‘values’ and ‘personality characteristics’ (Ramsden, 1998). However, the quality of evaluation referred to in the above definition is considered as essential in distinguishing the concept of ‘attitude’ from others such as ‘beliefs’ or ‘opinions’ which are linked to an external object such as the influence of another subject or science (Putti, 2011; Van Aalderen-Smeets, Walma van der Molen & Asma, 2012).

An attitude is sometimes also referred to as a ‘positive or negative feeling about something’ (Koballa & Crawley, 1985), as ‘likes and dislikes’ towards an object (Bern, 1970), as a ‘tendency to react in a positive or negative style with respect to a given attitude object’ (Oskamp & Schultz, 2005) or simply as ‘a way of looking at things’ (Muellerleile, 2005). On the other hand psychologists consider ‘attitude’ to be an internal state that influences behaviour. For most educational researchers, ‘attitudes’ are ‘a state of readiness or predisposition to respond in a certain manner when confronted with certain stimuli' (Oppenheim, 1992). An attitude may be positive, negative or neutral (Khan & Ali, 2012). Attitude is not considered as a single unitary concept but is multifaceted as it is made up of a number of dimensions and sub-components. For example, Munby (1983) specifies that the three main characteristics of an attitude are feeling, cognition and behaviour. The overall attitude towards an object is therefore the sum of the separate evaluations of these sub-components (Ajzen, 2001).

Attitudes have been viewed by social psychologists from three different angles – the 'tricomponent' viewpoint, the 'separate entities' viewpoint and the 'latent process' viewpoint (Oskamp & Schultz, 2005).

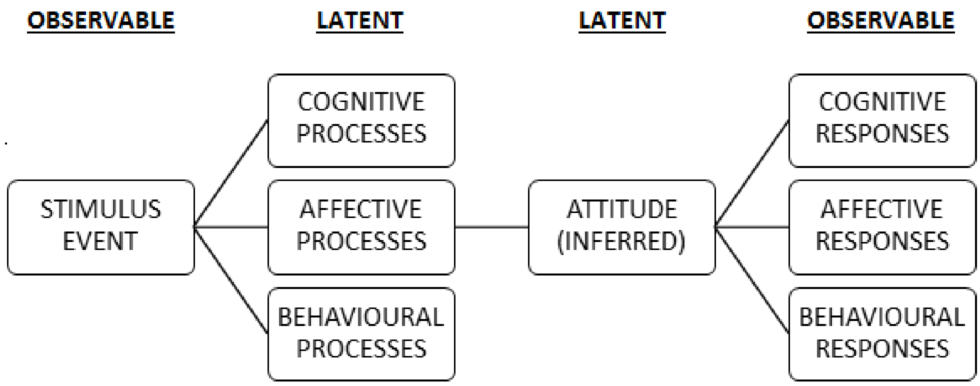
The **tricomponent viewpoint** represented by Krech, Crutchfield & Ballachey (1962) involves feelings and emotions towards the three distinct components or dimensions of attitude:

- the COGNITIVE component – which is a set of beliefs about attributes of the attitudes' object;
- the AFFECTIVE component – which includes positive and negative feelings about the object; and
- the BEHAVIOURAL component – which pertains to the way people act towards the object.

This viewpoint was popular in 1960s but was criticised for a number of weaknesses such as the fact that some people may tend to develop their attitudes on the basis of their feelings while others may choose to rely mostly on their beliefs. (Huskinson & Haddock, 2004).

The **separate entities viewpoint**, which was strongly advocated by Fishbein and Ajzen (1995) regards the above-cited components as being distinct separate entities. The term ‘attitude’ is solely reserved to the affective component while behaviour and cognition are considered as ‘determinants’ rather than components of attitude and are to be assessed separately. One of the drawbacks of this approach is the classification of evaluative beliefs (an intermediate category) which overlap significantly with affective responses (liking or disliking) and hence cannot be treated separately from attitudes (Oskamp & Schultz, 2005).

The **latent process viewpoint**, which is associated with DeFleur and Westie (1963) considers attitudes as a latent (or hidden / invisible) variable that can help explain certain observable stimulus events and behaviours. According to this perspective, the stimulus event (e.g. chemistry lessons) will trigger latent processes (which could be cognitive, affective or behavioural) within the individual, which result in the expression of an attitude summarising the information of these hidden processes (Eagly & Chaiken, 2005; Fabrigar, MacDonald & Wegener, 2005; Oskamp & Schultz, 2005). The following diagram summarises the latent process viewpoint showing the role of attitude as a hidden process in explaining the relationship between stimulus events and the individual’s responses.




(Oskamp & Schultz, 2005)

**Figure 3.1: the Latent Process Viewpoint of Attitudes**

This viewpoint of attitudes which formed the basis of the theoretical framework of analysis of attitude data in this study, has a number of advantages over the other two views. In fact, unlike the 'separate entities' viewpoint, this perspective does not equate attitude exclusively with the 'affective' or 'emotional' responses, thereby excluding completely the cognitive and behavioural dimensions of attitudes. Besides this, in contrast with the 'tricomponent viewpoint', the latent process point of view does not stress that the three components of attitudes must necessarily be congruent. An attitude may arise from one or a combination of processes, i.e. affective, cognitive and behavioural (Zanna & Rempel, 1988) and may generate one or more of the corresponding types of observable responses (Breckler, 1984).

## 3.4 Attitudes towards Science

According to Gardner (1975) students' attitudes to science consist of a 'learned predisposition to evaluate in certain ways, objects, people, actions, situations or propositions involved in the learning of science'. Koballa & Crawley (1985) are more generic in their definition which does not refer specifically to learning of science. They regard attitude towards science as to 'whether a person likes or dislikes science or has a positive or negative feeling about science'. In attitudes research, the word 'science' is an umbrella term used to encompass biology, physics and chemistry (Ramsden, 1998).

Gardner (1975) made an important distinction between the terms 'attitudes towards science' and 'scientific attitudes'. Attitudes towards science represent feelings, beliefs and values about attitude objects such as the enterprise of science, school science, the impact of science on society, scientists and chemistry lessons. In other words such attitudes describe how much a person likes or dislikes science (Nieswandt, 2005b). On the other hand, 'scientific attitudes' refer to qualities required by scientists such as open-mindedness or the ability of having an inquisitive mind which form the basis of scientific thinking (Gardner 1975).

This research study concerns the former type of attitudes, i.e. attitudes towards science (and not scientific attitudes) with specific reference to school chemistry as the main attitude object.

### 3.4.1 Multiple Components of Attitudes towards Science

Research in education has indicated that students' attitudes do not consist of a single unitary construct but are divided into a range of components which all contribute in some way towards a person's overall attitudes to science. In fact, a number of studies have included a list of components that were used to measure 'attitudes towards science'. These components include the perception of the science teacher, anxiety towards science, the value of science, self-esteem at science, enjoyment of science, attitudes of peers and friends towards science, attitudes of parents towards science, the nature of classroom environment, achievement in science and fear of failure on taking a science course (Osborne et al, 2003; Simon & Osborne, 2010).

### 3.4.2 Attitudes towards 'Science in Society' versus Attitudes towards 'School Science'

Research work by Breakwell & Beardsell (1992) on science attitudes and involvement in science activities of a number of 11-14 year olds in the UK found a significant demarcation between liking for science in society and liking for school science. Whereas 'societal science' is perceived by students in terms of medical and technological developments and their impact on society, school science is associated only with schools, science teachers, the science lessons, the classroom environment, school laboratories and practical work in science. Research shows that there is no correlation between the two types of attitudes to science and so it is suggested that science-in-school and science-out-of-school would be treated separately when students' attitudes are being analysed (Osborne et al, 2003).

### 3.4.3 Research Findings on Attitudes to Science

Over the years, considering all studies carried out on students' attitudes towards science, a number of general conclusions could be drawn regarding the students' experience of science in school and beyond. Studies and surveys show that students' attitudes towards science itself are generally positive, with students viewing it as useful and interesting (Jenkins & Nelson, 2005). This is confirmed by the ROSE study which found that young people hold very positive attitudes to science and technology viewing them as important means to make their lives healthier, easier and more comfortable (Sjøberg & Schreiner, 2010). But the same cannot be said on students' attitudes to school science.

In fact literature shows that school science is viewed by students as unattractive as it lacks topics of interest, does not allow students to be creative and does not connect with society. It also fails to relate with the progress of research work in science and is often perceived as fragmented in different isolated disciplines which prevents students from being provided with a coherent picture of science (Christidou, 2011; McSharry & Jones, 2002; Siegel & Ranney, 2003). In contrast, students tend to develop positive attitudes towards science-in-society as this is highly contextualised. It concerns complex, topical and controversial issues involving social aspects related to scientific knowledge. Christidou (2011) suggests that in order to make science curricula more appealing to students, science education needs to consider those aspects of science which are valued by students in everyday life and in different contexts such as health and environment.

Other studies show that interest in school science declines significantly during the period of compulsory education (Bennett & Hogarth, 2009; Christidou, 2011; Ramsden, 1998; Toplis, 2011) probably starting even as early as from the primary education (Pell & Jarvis, 2001) even though pupils / students may still hold highly favourable attitudes upon starting secondary school (Simon & Osborne, 2010). Research suggests that the attitudes which are mostly affected negatively are those towards learning of science at school, while attitudes towards practical work and towards the value of science remain more or less the same during compulsory education (Barmby, Kind & Jones, 2008). Contrary to earlier research evidence Sharpe (2012) found that even the attitudes to practical work in science decline as students progress through their secondary school education.

The ROSE project concluded that fifteen-year-old students found school science to be less interesting than other subjects (Sjøberg & Schreiner, 2010). Evidence shows also that it is the students' experience of school science that affects negatively their interest and motivation in the subject (Kahle & Lakes, 1983; Murphy & Whitlegg, 2006). The negative views are more associated with the physical sciences (i.e. physics and chemistry) rather than the biological sciences (Ramsden, 1998) and particularly concern non-science students (Holbrook & Rannikmäe, 2007; Roth & Lee, 2004).

Science as a school subject is also considered as difficult, not so relevant and therefore not useful to the lives of most people (McSharry & Jones, 2002; Osborne et al, 2003; Ramsden, 1998; Siegel & Ramney, 2003). This contradiction between the students' interest in science as a discipline and their disenchantment to school science featured prominently in research conducted by Ebenezer and Zoller (1993) and Lyons (2006). All these findings confirm the conclusion reached by Hendley, Stables & Stables (1996) that science appears to be a 'love-hate' subject that has a strong influence on the students' feelings, particularly at secondary level of education (Hendley et al, 1996; Osborne et al, 2003).

## 3.5 Exploring Students' Interest in Science

Research suggests that the main factor which influences the students' interest and decision to study science at high school level is their interest in the subject (Mamlok-Naaman, 2011). Furthermore it was also established that the students' interest to pursue further study in science gets largely crystallised by the age of thirteen or fourteen, i.e. half-way through their secondary education (Lindahl, 2007; Simon & Osborne, 2010). The small-scale study conducted by Lindahl on 12-16 year old Swedish students even found that it becomes progressively harder to engage older students to science. It is therefore imperative to look also into the factors that students find interesting and uninteresting in science in general and chemistry in particular, at such an important phase in their course of education.

### 3.5.1 What makes science / chemistry unappealing to students

One of the factors which has long been found to make school science unappealing is that students find it harder than other subjects with the main points of difficulty being the language used full of unfamiliar terms, complex concepts to understand, the mathematical aspect of physics and chemistry, as well as the need to memorise so many facts for exams (Collins, 2011; Osborne & Collins, 2001).

Another factor which students dislike in science is the rushed curriculum which they experience at school. Students feel that they are 'frog-marched across the scientific landscape' (Osborne & Collins, 2001) without being allowed to stop, reflect and assimilate concepts, discuss their own ideas and understandings and ask questions (Collins, 2011). The problem seems to be common to all sciences which are characterised by broad examination syllabi to be covered in a rather limited time, creating extra pressures in the classroom. The common feeling among students is that material is too crammed, allowing no room for reflection because of examination pressures. Porter and Parvin (2008) reported how according to OFSTED (2008) teaching of science in the UK was examination-oriented and was not creative and inspirational enough to engage and motivate students in the subject.

Students were found to be particularly disappointed for not being sufficiently involved such as not being allowed, mainly due to time restrictions, to raise questions and discuss their difficulties or any further points of interest they might have during the science lessons. In other words, students feel that they are deprived of having their own say in their own learning experience and express their creativity and imagination. Another factor which students disliked in science is repetition of material at different stages of the curriculum, with concepts becoming more complex with time. Such repetition is perceived by students as signs of lack of progression in the topics concerned and contributes to a growing disenchantment of science (Carter, Peloworth, Mant & Wilson, 2007; Osborne & Collins, 2001; Parkinson, Hendley, Tanner & Stable, 1998).

Research shows also that students find science to consist of a body of knowledge dominated by content emphasizing facts and rote learning.  Osborne and Collins (2001) suggest that a course dominated by content is likely to have a poor affective outcome as indicated by the cognitive-affective mismatch hypothesis of Millar and Tesser (1986). Adding more content to a science curriculum is viewed by Osborne and Collins (2001) as being counterproductive and may have a negative effect on contemporary science education.  In fact the general feeling today is that ‘less is actually more’ (Hofstein & Mamlok-Naaman, 2011).  Authors such as O’Neill and Polman (2004) suggested that if less content is covered in class, this would allow space for students to gain a deeper understanding of scientific theory and knowledge.

Osborne and Collins (2001) also argued that the school science curriculum is failing to give students a coherent picture of the subject by providing them with fragmented pieces of knowledge which are often dealt with separately under one of the three sciences, viewed by students as being so different from each other.  A study conducted by Tobias (1990) and based on a number of case studies of students being introduced to the three sciences, found that students often experienced an unappealing pedagogy which was described as ‘condescending and patronising’ which did not allow much space for discussion and which created a competitive atmosphere.  This is supported by Donnelly (2001) who found that science education was authoritarian, dogmatic and non-reflexive, allowing little space for students to act ‘as an autonomous intellectual agent’.  Other studies show that teachers do not usually provide extended explanations sometimes requested by students, a common excuse being that such queries would be treated in a better way at a later stage.

One of the main reasons for the decline in students' interest in school science was found to be its lack of relevance to their everyday life experience. In fact numerous studies show that students lose their interest and find science lessons to get less inspiring, boring and less relevant as they grow older. Students also experienced a mismatch between science-in-society and science-in-school (Barmby et al, 2008; Osborne, 2007; Porter & Parvin, 2008; Ramsden, 1998).

Chemistry was perceived by students to be the least relevant of the three sciences with certain aspects such as industrial processes regarded to be unimportant and outdated. Students were put off chemistry also for finding it hard to understand due to its abstract topics and mathematical skills required for certain topics. They also developed antipathy towards certain topics such as the periodic table, chemical equations, bonding and industrial chemistry (Cerini, Murray & Reiss, 2003; Osborne, 2007; Osborne & Collins, 2001).

Other possible factors which made science appear as an alienating subject include the fact that it often focussed on problem solving techniques, it also involved solving quantitative rather than qualitative questions, the type of pedagogy used, the examinations were not challenging and the competitive atmosphere which often dominated science lessons.

### 3.5.2 What makes science / chemistry appealing to students

Research studies identified also a number of aspects which engaged students' interest in science. These include some aspects taken separately from biology, chemistry and physics, as well as others such as practical work and the teaching approach.

There is enough evidence showing that students, especially girls, are more attracted towards biology than to the other sciences. Studies show that students were particularly interested in aspects of human biology which they considered as most relevant to themselves such as health and safety issues (Bybee & McCrae, 2011; Osborne & Collins, 2001).

With respect to chemistry, students were particularly interested in aspects that were concrete, observable and manipulable. These include mixing of chemical reagents, the smells and odours associated with chemical changes and other observations from practical work. They liked the idea of being given the chance to decide on their own what test to perform and which equipment to use (Wolf & Fraser, 2008). Students were found to be stimulated by the fact that experiments could expose them to hazards such as poisons and explosive materials, rendering laboratory experience even more memorable (Osborne & Collins, 2001; Collins, 2011).

Students were also found to be engaged more in science in those topics that had a personal relevance to their everyday lives, topics concerning contemporary issues or others that dealt with the existence of man. Other evidence suggests that the students' interest also depended on the type of teaching involved with the most effective teachers being the ones that maintained order in class, made lessons interesting by using different resources and activities, had a sense of humour and also built a good relationship with students involving them frequently in the lessons (Osborne & Collins, 2001). Students also prefer teachers who were less didactic, who allow them to have their say in class and who try to facilitate learning of science (Hampden-Thompson & Bennett, 2013; Lyons, 2006).

Other research suggests that students were very much interested in the practical side of science, emphasizing the element of fun and sense of ownership and autonomy which they feel each time they carry out practical work in the laboratory (Carter et al, 2007; Freedman, 1997; Parkinson et al, 1998). Researchers found that practicals help students understand and retain better the scientific concepts (Abrahams & Millar, 2008; Osborne, 2001; Toplis, 2011). Toplis (2012) also found that practical work in science allowed students to engage with and influence their own learning. This is consistent with the evidence from the Planet Science Survey (Cerini et al, 2003) and the work of Murray & Reiss (2005) which showed that practicals facilitated learning, resulted in a greater sense of enjoyment and provided deeper understanding for the students concerned. This is one of the reasons why the report "Vision for science and mathematics education" published by the The (UK) Royal Society (2014) emphasized the central role of practical work (and problem solving) in future science curricula. Salta and Tzougraki (2004) showed how students' interest declined when students were taught chemistry theoretically without any hands-on activities in the laboratory.

Abrahams and Millar (2008) question the role of practical work in science arguing that the fact that it raises students' interest need not imply that a higher degree of learning has taken place. They suggest that science involves an 'interplay between ideas and observations' which needs to be stimulated during each practical activity. Hence they recommended that practical lesson time ought to be appropriately divided between 'doing' and 'learning', to allow teachers to devote enough time to explain the link between concepts and observed phenomena by increasing the 'minds on' rather than the 'hands on' aspect of the laboratory experience.

## 3.6 Measurement of Attitudes towards School Science

Attitudes towards school science have been assessed using different methods developed over the years by a number of researchers in science education such as Bennett, Rolnick, Green & White (2001), Jenkins and Nelson (2005), and Pell and Jarvis (2001). One important point of reference is the 'Test of Science-Related Attitudes' (TOSRA) which was first developed in 1979 and then further amplified by Fraser (1981). Methods used to measure attitudes towards school science include subject preference studies, attitude scales, interest inventories, subject enrolment and qualitative methodologies.

Subject preference studies involve asking students to rank their liking of schools subjects and the students' attitude is inferred from relative popularity of subjects. The method is simple to use and results are easily presented and interpreted. One main disadvantage of this method is that it is based on a relative scale which may give false or inaccurate indications as the order applied by one student may not apply to another student having different attitudes to different school subjects. Another drawback is that it cannot be used to measure attitude change as this is too complex to be determined using such a 'blunt technique' (Osborne et al, 2003).

Attitudes are also measured using questionnaires designed to include Likert-scale items which consist of a number of opinion statements linked to favourable or unfavourable attitudes towards an object under study. Students indicate their own findings by choosing one of a number (usually five) options ranging from strong agreement to strong disagreement. The items on the Likert scale are typically drawn from answers generated by students during free conversations and discussions. These are then usually reduced to a set of usable and reliable items that would be first piloted and then further processed by statistical analysis. Such attitude scales are widely used in research work on attitudes (Simon & Osborne, 2010).

Another quantitative technique employed to gauge interest in science concerns data on enrolments to subjects. This method is ideal to follow trends in science subjects but is limited in the sense that it cannot be considered as the sole indicator of students' interest in science. It is a known fact that the choice or non-choice of science subjects at school results from a number of factors such as gender and perceived difficulties in the subject which do not necessarily depend on the students' attitudes to science.

One of the limitations of the quantitative measurement of attitudes is the assumption that attitudes are stable (Munby, 1983). Although it is true that attitudes, once formed, are hard to change, there is not enough evidence showing that attitudes do not change after being repeatedly measured by instruments such as questionnaires (Osborne et al, 2003; Simon & Osborne, 2010). Quantitative studies of attitudes were also frequently criticised because they provide only a partial understanding of the problem being investigated, by analysing only a few easily measurable quantitative dimensions.

The limitations of quantitative techniques in assessing attitudes have led researchers to explore students' attitudes qualitatively by using instruments such as small group interviews or focus groups. Literature suggests that although these methods have their own restrictions such as the problem of generalizability, they are superior to quantitative techniques as they provide valuable data not easily extracted quantitatively, which helps understand better the origin of attitudes to schools science (Osborne, 2010; Osborne &

Collins, 2001). Studies making use of qualitative techniques include those carried out by Ebenezer and Zoller (1993) and Woolnough (1994).

Both quantitative and qualitative methods have their own merits and demerits. Some critics argue that attitude instruments only measure limited aspects of the students' views without considering the context and any underlying influences (Potter & Wetherall, 1987). Other criticise the fact that there is no single common criterion in the various instruments that were developed with time (Osborne et al, 2003) and that such instruments cannot yet guarantee valid and reliable data on students' attitudes (Cheung, 2009).

The method used in this project to measure students' attitudes is a mixed approach based on the use of quantitative and qualitative methodologies. This was done to secure a better chance of discovering what actually goes on in the students' minds and hearts while learning chemistry at school and how their attitudes change, if any, upon introducing a curriculum intervention. The main instruments used to collect students' attitude data in this study therefore involved the use of both questionnaires (quantitative method) and focus groups (qualitative method).

## 3.7 Attitudes towards Chemistry

The fact that chemistry is the least studied science subject and is not so popular in Maltese schools at both secondary and post-secondary level does not make Malta an exception in this regard. In fact various sources suggest that physical sciences are among the least popular school subjects even in other countries (Bennett, 2008; Hendley et al, 1996; Holbrook, 2005; Whitfield, 1980).

Although students' attitudes toward science have been extensively studied there are only few studies on the students' attitudes towards chemistry (Cheung, 2009; Hofstein, 1986; Hofstein, Ben-Zvi & Samuel, 1976; Menis, 1983; Menis, 1989; Salta & Tzougraki, 2004). These studies indicate that one of the important factors affecting the choice of physical sciences for further studies deals with the students' interest and attitude towards science at the post-secondary level. Menis (1983) explained that such attitudes towards science and chemistry should be assessed on the basis of at least three distinct aspects, namely the students' attitudes towards the importance of chemistry and science (i.e. out-of-school science / chemistry), the students' attitudes towards chemistry and science in the school curriculum (i.e. in-school science / chemistry) and students' attitudes towards chemistry and science as a career.

### 3.7.1 The Importance of Science / Chemistry in Society

This chapter has already highlighted how the students' attitudes to science and technology are generally positive, with students viewing scientific progress as one of the most important achievements of mankind. The ROSE study found that this positive attitude is particularly pronounced in the less developed countries while Northern European and Japanese students show a greater amount of conflicting feelings and scepticism towards the importance and usefulness of science and technology. The same study showed that the same pattern was observed when students were asked about the impact of science on human life. In fact although students in most countries of the world thought that the benefits brought about by science, by far outweighed any harmful effects, students from

European countries and particularly Japan were less convinced on the overall positive impact of science on their lives (Sjøberg & Schreiner, 2010).

There is little evidence as yet showing a similar attitude taken by pre-university students towards chemistry as a separate science discipline. However, at least one recent study on Pakistani higher secondary school students confirmed that students acknowledge the importance of chemistry in their daily life (Khan & Ali, 2012). Students can develop positive attitudes towards chemistry by recognising that it is a central science that left a significant impact on the quality of human life over the past fifty years. Chemistry has in fact proved to be a useful science by being crucial in the development of so many products linked with many aspects of life and by being also important in many aspects of economic development. Ware (2001a) suggests that chemistry also has the potential to solve problems faced by different countries as these struggle to achieve sustainable development. Hence, by exploring students' attitudes towards the interaction of chemistry and society, one would help understand better their overall attitude towards the subject.

### 3.7.2 Students' Attitudes towards School Chemistry

Research shows that the cognitive component and most importantly the affective component of science education were not always factored in past curriculum development (Hofstein, 1986). In fact for a number of years curriculum development in high school chemistry only used to provide what is regarded as 'education in chemistry' rather than 'education about chemistry' (Kempa, 1983). This means that students were deprived for a while of studying important aspects of chemistry in which they were really interested such as application of chemistry in technology, relevance of chemistry to the students' daily lives, cultural aspects of chemistry and the role of chemistry in today's society. In one of his studies, Hofstein (1986) showed how including some of these aspects of chemistry helped in imparting positive attitudes towards science in general and chemistry in particular. It was also found that negative attitudes towards school chemistry result from a combination of factors such as the perception that chemistry is a rather dirty discipline, that it is difficult to understand because of its abstract concepts and theories (De Jong, 2000) and the subject's lack of relevance to the student's everyday lives (Holbrook, 2005; Osborne & Collins, 2001). Other important aspects of school chemistry that influence the students' attitudes towards the subject are the applied method of teaching and the laboratory experience.

Four variables which are of special interest to this research project are the perceived difficulty of chemistry, its relevance to everyday life, the classroom environment and the school laboratory experience.

#### 3.7.2.1 Perceived difficulty of Chemistry

The fact that chemistry is often perceived by students as a difficult subject was investigated by Johnstone (1991) and Salta & Tzougraki (2004). They found that difficulty in chemistry is mainly related with the application rather than the understanding of concepts, symbols and problem solving. The real problem is that students cannot transfer so easily between the three levels (or dimensions) of understanding chemistry, i.e. the macroscopic, the sub-microscopic (or particulate) and the symbolic levels of chemistry concepts, which are also referred to as the three types of chemistry knowledge – experiences, models and visualisations (Talanquer, 2013). The macroscopic (or experiences) level involves understanding physical and chemical phenomena of chemistry, the sub-microscopic (or models) level involves understanding chemical behaviour at the atomic and molecular levels, while the symbolic level (or visualisations) involves understanding through the use of symbols, formulae, equations and mathematical expressions (Dori & Hameiri, 2003; Johnstone, 1991). Many chemistry teachers are not able to distinguish clearly between the three types of knowledge presented in class. Consequently students find it hard to build meaningful connections or transfer rapidly from one level to another for a given chemical system (Talanquer, 2013). Such difficulty to integrate continuously these different levels of understanding results in a fragmented picture of chemistry made up of disjointed parts that do not seem to fit together (Gabel, 1999). This applies also to practical work in chemistry where frequently students have to make their observations at the macroscopic level but then they are expected to interpret their results at the microscopic level (Johnstone, 1991). Ware (2001b) believes that many students find it hard to visualise the particulate models which they are expected to understand. Mahaffy (2004a) suggests that an effective pedagogical approach should include also a fourth dimension – the human element – which involves the impact of chemistry on society and particularly on the environment.

Another barrier to understanding chemistry is the use of language with unfamiliar terms (Cassels & Johnstone, 1983). Research also indicates that apart from difficulties in understanding and applying abstract chemical concepts such as atoms, molecules and mole, students found it hard to solve quantitative problems as a result of their inability to relate properly their mathematical skills to chemistry calculations (Gabel, 1999; Malone & Dolter, 2013; Salta & Tzougraki, 2004).

#### 3.7.2.2 Relevance to Everyday Life

The question of relevance of school chemistry to everyday life was investigated by several researchers (Holbrook, 2005; Lerman, 2003; Salta &Tzougraki, 2004; Walczak & Walczak, 2009). Relevance in the context of science education is sometimes divided into a number of sub-categories such as 'personal relevance' – connecting with students' lives, 'professional relevance' – associated with possible future professions, 'social relevance' – related to human and social issues, and 'personal-social relevance' – helping students become responsible citizens (Van Aalsvoort, 2004).

Although the aspect of relevance was not considered as important in the teaching of chemistry in the 1970s, this changed in the 1980s and 1990s when it became more regular to talk about how chemistry was relevant to the students' lives, to the environment and to the students' interest (Lerman, 2003). According to Holbrook (2005) many chemistry curricula 'tend to put the subject first, and applications a poor second'. This implies that the current curriculum approaches are doing very little in terms of conceptual learning to make chemistry as popular as it should be. The same Holbrook (1994) suggested that teaching has to present students with societal situations before treating scientific concepts if students were to appreciate more the relevance of science. Research evidence shows that using contexts as a starting point in the teaching of science would affect positively students' attitudes towards science (Holbrook, 2005; Bennett & Lubben, 2006).

With regards to chemistry, Walczak & Walczak (2009) reported several studies showing how attitudes to chemistry are enhanced by introducing 'real world' components (such as contemporary issues to chemistry) into the classroom and laboratory experiences. Students are aware that chemistry is useful to interpret various aspects of their everyday life (Malone

& Dolter, 2013). Some authors suggest that school chemistry should in fact start from the students' life experiences and include relevant contexts to make it more appealing for the same students (Marks & Eilks, 2009).

One of the aspects of chemistry that made it more relevant to students is that concerning environmental issues. In fact studies such as that conducted by Salta & Tzougraki (2004) show that high school chemistry students were optimistic that chemistry could solve environmental problems and improve the quality of their lives. Other literature showed how even university chemistry students agreed that chemistry concepts taught at post-secondary / high school level need to be related to daily life situations in order for chemistry to be learnt in a more effective way (Streitberger, 1985). Other authors such as Heikkinen (2010) argue that students' interest and involvement would be greater if chemistry is embedded within society rather than 'confining it to laboratory flasks, well plates and brown bottles'.

Other evidence shows also that students involved in 'cooperative learning activities' perceived chemistry to be more relevant to their lives, enjoyed lessons and developed more positive attitude towards school chemistry than other students who followed traditional chemistry programmes.

#### 3.7.2.3 The Classroom Environment

Students' attitudes towards chemistry are also related to the students' perception of the learning environment provided in the chemistry classroom. This aspect was researched by Hofstein, Gluzman, Ben-Zvi & Samuel (1979) who followed earlier work by Walberg (1969) and Lawrenz (1976) on the same area of attitude research. It was found that high school chemistry teachers can play a determining role in creating a positive classroom atmosphere which induces positive attitudes in students. If students show that they liked the way chemistry was taught and perceived the lessons as being interesting it means that that they would have developed a positive affective attitude towards the subject (Cheung, 2009). However, recent research suggests that the teaching of chemistry in high schools is not conducive and in fact is viewed by students as being unpopular, irrelevant, unchallenging (as it does not promote higher cognitive skills) and also static (Hofstein & Mamlock-Naaman, 2011).

#### 3.7.2.4 The School Laboratory Experience

The science school laboratory experience, including chemistry practical work, has long been featuring prominently in research in science education (Cheung, 2009; Hofstein & Lunetta, 1982; Hofstein & Lunetta, 2004; Hofstein et al, 1979; Lazarowitz & Tamir, 1994). Laboratory work usually forms an integral part of high school / sixth form science curricula and research shows that science students like carrying out practical sessions in the school science laboratories (Cheung, 2009; Dhindsa & Chung, 1999; Parkinson et al, 1998). Other studies confirm that students' attitudes are influenced positively by the school laboratory experience (Freedman, 1997). On the other hand, high school (post-secondary) students were found to lose interest for chemistry if they were deprived of the chance to perform any hands-on activities during their chemistry programme as shown in the case of Greek high-school chemistry students highlighted in the study by Salta and Tzougraki (2004).

More specific analysis of the impact of laboratory activities on school chemistry revealed a number of points such as:

- practicals can serve to promote important learning outcomes for students;
- teachers need to know how to exploit practical sessions by involving students both physically and intellectually;
- students' perceptions and behaviours in the school laboratory depend on a number of factors including teachers' expectations, methods of assessment and resources available;
- teachers need to understand the students' way of thinking and learning in the laboratory learning environment (Hofstein, Navon, Kipnis & Mamlok-Naaman, 2005).

In a separate study on the implementation of an inquiry-type laboratory programme for Israeli high school chemistry students, Hofstein et al (2005) found that such a laboratory experience which was more 'student-centred' than in traditional practical sessions, proved to be highly interesting for participating students. The reasons given by the same students were various but they liked, in particular, having the opportunity to develop scientific skills (such as independent and critical thinking) and be in control of their own learning, standing a better chance to learn through mistakes, sharing ideas and cooperating with other students, having teacher's support and encouragement, and enjoying a challenging laboratory learning experience.

Considering all literature in this area of attitude research, it is clearly evident that the school laboratory plays an important role in the shaping and improvement of the students' attitudes towards chemistry (Hofstein & Mamlok-Naaman, 2011).

### 3.7.3 Students' attitudes towards science / chemistry as a career

The students' interest in choosing science as a career starts at a young age. In fact in their analysis of data collected for a US national educational longitudinal study, Tai, Qi Liu, Maltese & Fan (2006) found that students aspiring for a science-related career by the age of fourteen, stand more than three times the chance to earn a physical science or engineering degree than students who show no such inclinations. Similar evidence from another study found that most scientists or science-graduates choose to pursue science before or during their middle / high school education (Maltese & Tai, 2010).

It also seems that school science is not doing enough to improve the students' science career aspirations. This is another finding of the ROSE project which revealed that in many European countries (and Japan) students thought that school science did not increase their chances of choosing a science-oriented career (Sjøberg & Schreiner, 2010). One of the factors which is potentially discouraging students from pursuing further science for a career is the perceived lower income of scientific professions with respect to other high-skilled occupations. This was found to be partly true as evidence shows that scientists are not earning as much as other high status non-science occupations (Xie & Achen, 2009).

There is not much research focussing on the students' aspiration to chemistry-related occupations but at least one study on Hong Kong students found that some students thought it was hard for them to get a chemistry related job in their country even though they knew that chemistry was important for them to pursue further studies in science (Cheung, 2009).

## 3.8 Students' Interest in Green Chemistry

Although there is a growing trend in many countries to include at least some basics of green chemistry into school chemistry curricula and examination syllabi / specifications, teaching of green chemistry is still evolving particularly at pre-university level (Anastas & Beach, 2009; Braun et al, 2006; Cann & Dickneider, 2004; Hjeresen et al, 2000; Warner, 1999) and little research has yet been done to evaluate the impact of such a curriculum development in chemistry education.

Green chemistry is not expected to take chemistry students completely by surprise. Indeed, some authors see it as the next logical step following the earlier introduction of environmental chemistry into most chemistry programmes. Authors such as Manahan (1999) proposed that environmental chemistry courses need to be redesigned to include the principles and practice of green chemistry, in order to show how chemistry can be done without the use of harmful chemicals and with the minimum impact on the environment.

It is possible that the favourable attitudes shown by students when learning about the chemistry of the environment are also expressed if not reinforced when learning also about green chemistry. This is so for a number of reasons. First of all, green chemistry deals with pollution prevention which represents one of the major efforts by chemistry to address environmental concerns of which students are very much aware. Secondly, students would learn that green chemistry is very relevant to their everyday lives and hence that it is closer to the outside world than other areas of chemistry. Besides this, students are already conversant in and sensitive to aspects of sustainable development which overlap significantly with the aims of green chemistry. Green chemistry also provides the opportunity for students to experience laboratory work using less hazardous and non-toxic chemicals. All these and similar factors would potentially have a positive impact on learning of chemistry and work against the negative perception / prejudice on the subject which students usually gain from different quarters such as family, peers, media and society at large (Warren, 2001).

American high school teacher Sarah Broussard wrote how elated she was with the students' positive reaction in her very first experience of teaching of green chemistry at her place of work. She described how students who were at first apprehensive and sceptic about the idea of learning about green chemistry turned enthusiastic and very cooperative once they discovered what it was all about, and that it concerned topics such as waste prevention, fuel cells and biodiesel which they found to be so interesting. She was so much impressed with her students' attitudes that she became convinced that the more students familiarised themselves with the fundamental principles involved, the greater was their chance of adopting green ideas for the rest of their lives (Broussard, 2010).

A Malaysian study on the implementation of a green chemistry approach in teaching of chemistry to pre-service teachers and secondary school students established that the proposed curriculum of a context-based chemistry course had a positive impact on students, bringing about substantial changes in knowledge, values and attitudes towards the environment. The study involved the introduction of green chemistry as a laboratory-based pedagogy and one of the findings was that students found it easier to learn chemistry concepts with green chemistry experiments (Karpudewan et al, 2011b). The study concluded that green chemistry had a tremendous potential in changing students' attitudes, motivations and values related to the environment and also in rendering chemical concepts more relevant to the same students (Karpudewan et al, 2012).

So literature indicates that by cultivating positive ideas among young chemistry students green chemistry stands a chance of motivating more students to further their studies in chemistry at a higher level. This is more or less in accordance with Anastas and Beach (2009) who suggest that green chemistry education at the K-12 level (primary, secondary and post-secondary education) has the potential to attract the brighter students to choose a future chemistry profession.

## 3.9 Students' Knowledge and Understanding of Chemistry and Green Chemistry Ideas

According to the National Science Education Standards, understanding an idea implies understanding a rich cluster of facts, concepts, and examples associated with the major idea (National Research Council, 1996). There is a wide range of terms and concepts that can be described as 'scientific'. Understanding a basic set of scientific concepts is essential as it allows students (or people in general) to understand the words and ideas expressed by science educators and by the scientific community to communicate important scientific information including new scientific and technological discoveries.

### 3.9.1 Understanding of Chemistry Concepts

Chemistry is often perceived and also experienced as a complex subject with too many abstract scientific concepts. It is a known fact that students who perform well in chemistry examinations may still have misconceptions on what may be described as personal 'naïve' theories in the subject and lack of basic skills to solve textbook problems.

A significant amount of research has been carried out on the various aspects of the problem which students encounter in trying to understand key chemistry concepts. Research findings indicate that problems arise from one or more of a number of learning difficulties.

- Students learn most things by heart (i.e. they resort to rote learning or memorisation) in order to create their own meanings (personal theories) of the material being taught.
- Many students already have a problem with understanding of fundamental chemical concepts at the very beginning of their studies. This makes it harder for them to understand in full more advanced concepts based on the fundamentals.
- Many ideas remain vague and students are unable to identify key concepts required to understand the subject content.
- Teaching may not present the key concepts or relationships between different concepts in a sufficiently clear way for students to understand them completely.

(Nakhleh, 1992; Pendley, Bretz & Novak,1994;).

Gabel (1999) identified a number of other possible barriers to the understanding / learning of chemistry concepts and theory. These may be summarised as follows:

- Many chemical concepts are abstract and cannot always be explained well with the use of analogies or models.

- As previously explained, chemistry explains matter in three different levels: the **macroscopic** (or visible) level; the **microscopic** (molecular or particulate) level; and the **symbolic** (formulae, equations) level. Students find it hard to transfer readily from one level to another, e.g. from a visible to an invisible level or vice-versa. Besides this, instruction usually occurs at the most difficult and abstract level, i.e. at the symbolic level (Johnstone, 1991).

- The main learning obstacle during practical work in the laboratory is that students are often expected to make observations at the macroscopic level but then they have to interpret theory at the microscopic level.

- Students do not perceive chemistry as being related to their daily lives and may get the overall impression that it is only related to strangely named chemicals that are often toxic or hazardous.

- The use of language and terminology used during chemistry lessons could also complicate matters.

- The chemistry curriculum is not always structured in a logical sequence that is suitable for instruction.

These barriers to chemistry learning, which are explained using an information processing model developed by Johnstone (1997) need to be identified and addressed accordingly (e.g. by modifying the teaching approach) in order to facilitate the learning process and address misconceptions.

In order to stress the importance of the human aspect in the learning of chemistry (Mahaffy, 2004a; Mahaffy, 2004b) suggests adding a fourth dimension to Johnstone's three learning levels of chemistry (the macroscopic, microscopic / molecular and symbolic levels) usually represented by means of a plane triangle. In fact he proposed to extend the planar triangle of understanding chemistry to a (three-dimensional) tetrahedron with a newly introduced fourth vertex – the human element – representing the web of human contexts for learning chemistry, as illustrated in figure 3.2. Mahaffy referred to his model as the 'tetrahedral chemistry education' with the newly added dimension addressing concerns about scientific literacy and understanding of the role of chemistry in everyday life.

The change proposed by Mahaffy (2004a, 2004b) may be represented as follows:

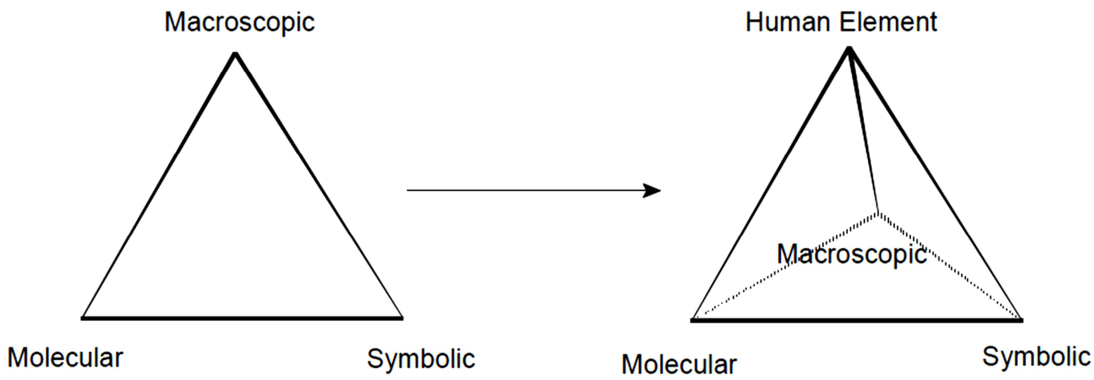



**Figure 3.2**
**Tetrahedral chemistry education with the new emphasis on the human element**

Research in chemistry education has already explained various aspects related with learning chemistry which promotes understanding of chemistry concepts. However various authors indicate that there are still areas which need to be explored further. These include further work on curriculum development, especially in view of possible wider use of technology, problem-solving, the type of chemistry required by different students with different career aspirations and making chemistry more relevant to social context (Ramsden, 1997; Gabel, 1999; Beasley, 2005). Some of these challenges are well in line with Mahaffy's concept of tetrahedral chemistry education, which underlines the importance of the human element of learning and aims to integrate content with context.

This is also emphasized by other authors such as Pellegrino (2002) who suggest that students' knowledge is best understood in its own context and 'embedded' in the situation where it was acquired. On the other hand authors such as Nieswandt (2005c) explain how 'conceptual understanding' of science, involves students development of new and complex concepts starting from single and simple concepts, and confirms the students' ability to apply learned scientific concepts to scientific phenomena occurring in real-life situations.

### 3.9.2 The Impact of Green Chemistry on Learning Chemistry

The idea that the main concepts of green chemistry are so important that they need to be considered in chemistry programmes at different levels of education is now gaining ground and reaching a wider consensus (Anastas & Beach, 2009; Beyond Benign, 2014c, 2014d; Carra, 1999; Ryan & Tinnesand, 2002). For example, graduate students attending the third annual American Chemical Society Green Chemistry School (GCSS) in Montreal, Canada, in 2005, were reported to have agreed that education would be 'significantly enhanced' if green chemistry were to be incorporated in all chemistry curricula, starting from elementary level and continuing throughout university courses (Kitchens et al, 2006).

Literature suggests that green chemistry has the potential to enhance learning of chemistry in a significant way by increasing the understanding of fundamental chemistry concepts (Hill et al, 2013). It has also been suggested that the incorporation of green chemistry principles in the school curriculum serves more than one aim. It could be used to remind students of the social and environmental impacts of the way chemistry is performed today (Braun et al, 2006). But it also contributes to the general aims of science education as it is considered as an important element in the development of scientific literacy within society at large (Karpudewan et al, 2012).

Research has also indicated that students' attitudes and perceptions towards chemistry and the environment are likely to improve significantly once high school students understand the link between chemistry and environmental issues and once they appreciate how relevant chemistry is to their personal lives (Mandler et al, 2012). This is in fact another reason why green chemistry has the potential to be a positive influence to the learning of chemistry. It provides students with the opportunity to relate the chemistry they learn at school with various aspects of their everyday life.

## 3.10 Ideas for Research Investigation

This literature review suggests that students' attitudes in science are multidimensional and influenced by several factors which all contribute to some extent to the cognitive, affective and behavioural components of such attitudes (towards science and towards chemistry) manifested by students.

Literature documents show how researchers in science education were always concerned with the students' alienation from science and the sciences, which was often found to be associated with their early experience of school science. Students from different countries were found to be disenchanted from school science for a number of reasons such as its perceived difficulty, lack of direct relevance to their everyday life and the demanding examination syllabi, even though they enjoyed carrying out practical work in the school laboratory and were attracted towards the enterprise of science. The same applies to school chemistry which is often viewed by students as mostly irrelevant and one of the hardest subjects at school, apart from its unfortunate out-of-school connotation with poisons, pollution and environmental degradation.

Research indicates that including an environmental component in chemistry curricula would boost the students' interest in the subject as students can relate quite easily with environmental issues given also their sensitivity and background knowledge (even though lessons in environmental education, education for sustainable development or environmental studies) to this aspect of chemistry.

Studies have also hinted that the inclusion of environmental issues has also improved the students' perception and liking of chemistry as these feature amongst the most important contemporary world problems which students generally enjoy discussing in class.

The recent rise of green chemistry which embodies the fundamental and universally accepted scientific principles of sustainable development has given another window of opportunity to science educators to explore whether students' attitudes would be affected by taking another perspective of the interaction between chemistry and the environment. This study therefore aims at building on the very few studies conducted so far on the impact of green chemistry on students particularly at the post-compulsory pre-university level of education.

Green chemistry has now been with us for about two decades but it has so far been taught mainly to undergraduates and post-graduates and limited to academic institutions. It is now slowly making its way to lower stages of education and it is therefore the right time, coinciding with the end of the decade (2005-2014) dedicated to 'Education for Sustainable

Development' (Eilks & Rauch, 2012) to evaluate the students' voices on its possible inclusion in chemistry curricula and future chemistry examination.

This study made use of both quantitative and qualitative techniques to extract attitudinal data from students and other data on their understanding of green chemistry following their first encounter with the unfolding area of green chemistry at school. The project recorded, processed and analysed what students had to say on various aspects of school chemistry particularly stating what they think about environmental issues and the principles and practice of green chemistry.

The methodology used and theoretical frameworks adopted to analyse data obtained from students will be discussed in chapter 4.

## 3.11 Chapter Summary

'Students' attitudes towards science' represents an area of science education that has been extensively researched for more than four decades in order to address a number of educational concerns such as decline in recruitment to science courses and careers and lack of scientific literacy among the general public.

Attitudes were found to be divided into a number of components and hence any evaluation requires taking consideration of all possible dimensions. Social psychologists look at attitudes from different viewpoints which all recognise that an attitude may comprise up to three different components – the affective, cognitive and behavioural dimensions. The theoretical framework used to analyse attitudes data in this study is based on the latent process viewpoint. Research work in education has also established that students' attitudes to science is also multi-faceted, being divided into a number of components such as value of science, enjoyment of school science, attitudes of peers and parents towards science and achievement in science. There is also an important difference between attitudes towards societal science and attitudes towards school science.

There is a large volume of evidence in the literature suggesting that students hold favourable attitudes towards science in society, but attitudes towards school science decline substantially during the period of compulsory education. It also appears that school science in most European countries tends to have a negative impact on the students' interest in science, with research evidence linking the more negative views mostly with physical sciences.

Evidence shows that the students' interest to pursue further studies in science gets largely crystallised by the age of fourteen. The chapter refers to studies investigating a number of aspects which students find interesting in science (such as practical work) and other aspects they found uninteresting (such as problem solving) as a school subject.

Students' attitudes that derive from school science experience have been assessed using different quantitative and qualitative techniques developed over the years by a number of researchers in science education. Literature also suggests that students' attitudes towards science and chemistry are to be assessed on the basis of attitudes towards the value of science / chemistry, attitudes towards school science / chemistry and attitudes towards a career related to science / chemistry. Research suggests that in the past, chemistry education was depleted of important aspects of chemistry such as its application to technology, relevance of chemistry to their daily lives, cultural aspects of chemistry and the role of chemistry in today's society. Evidence shows how these aspects help in imparting positive attitudes to school chemistry while negative attitudes result from other aspects such as perceived difficulty of the subject, its lack of relevance and the idea of chemistry as a dirty discipline. Another aspect of students' attitudes which was investigated by researchers was the students' motivation towards science or chemistry as a career.

In spite of being with us for only about twenty years, green chemistry has already made its way into some secondary and post-secondary chemistry curricula. Such a curriculum development has not yet been evaluated for its impact in chemistry education. Green chemistry is likely to be of interest to young students for a number of reasons as it deals with pollution problems of which students are very much sensitive, it is very relevant to their everyday lives and it is closer to them than other areas of chemistry.

The chapter also discussed some aspects of students' knowledge and understanding of scientific concepts with special reference to chemistry and green chemistry. Literature shows how chemistry is often thought to be a complex subject full of abstract concepts. It also refers to potential barriers and positive influences to the understanding and learning of chemistry concepts. Reference was made to the importance of including the human element in learning chemistry and the importance of integrating content and context. Literature also suggests that green chemistry can enhance chemistry learning particularly by improving understanding of basic concepts of chemistry and by relating chemistry to the students' everyday life experience. This chapter then concludes by highlighting how the literature review inspired the author in the shaping of this research project and the choice of the research methodology.

# Chapter 4

# RESEARCH METHODOLOGY

## 4.1 Introduction

This chapter describes the overall research approach taken to this project and the various research instruments used to generate data. The main techniques employed to gather data were the questionnaire method, focus groups and the personal research diary, but data was also collected through other sources such as students' activity worksheets, laboratory reports and posters prepared by student participants.

The chapter starts by referring to the naturalistic research paradigm and the case study as the main research strategy adopted in this investigation. It describes the samples and setting of the study and how research instruments were developed and piloted in year 2008/09. It also explains how the theoretical frameworks were designed in order to analyse the data gathered using the pilot and then the main research tools. The chapter also outlines the strategy chosen to assess the effectiveness of the main intervention package.

This is followed by a discussion on specific measures taken to ensure a high level of validity and reliability of the instruments used and of data analysis. It also ends by highlighting a number of limitations of the study particularly difficulties encountered in the use of the instruments for data collection.

## 4.2 Choosing the Research Paradigm

Research in education tries to explore and understand social phenomena which have an educational context. This is done using one of a limited number of methodological approaches known also as research paradigms.

The main research paradigms in education are the positivist paradigm which is associated with the philosophical ideas of French philosopher Auguste Comte (Beck, 1979; Opie, 2004) and the anti-positivist paradigm (Cohen, Manion & Morrison, 2010). These two major research paradigms represent two different perspectives of understanding social phenomena with the positivist model focussing on observed phenomena (emphasizing notions such as objectivity, measurability, controllability, predictability, etc.) and the antipositivist / interpretivist / naturalistic approach giving more weight to meanings and interpretations of the world in terms of its actors (Cohen et al, 2010). Positivists believe in an independent reality that can be accessed and investigated, while interpretivists support the idea that reality is not a fact that can be found but is constructed in the people's mind (Eslami, 2015). Some researchers refer also to a third paradigm based on a mixture of qualitative and quantitative methods. This is sometimes referred to as the 'mixed method approach' and assumes that the qualitative and quantitative approaches represent the extreme cases and 'there is a continuum between them' (Poni, 2014). The different approaches or paradigms in educational research are not necessarily in conflict with each other. They can be viewed as different methodological routes which lead to a multifaceted picture of the research problem (Husén, 1988).

The nature of this research inquiry which investigates how students react to the introduction of green chemistry in the A-level chemistry curriculum automatically aligned the researcher with the naturalistic / interpretive paradigm of educational research. This is so because the project involves observing and collecting data from a small group of students in their natural setting which is the ordinary classroom / school laboratory situation, while they were exposed to a curriculum intervention by being taught the basic concepts of a modern and revolutionary way of doing chemistry that can affect their personal lives. The study could also be described as interpretive due to the personal involvement of the teacher-researcher and for the fact that it tries to understand the actions (of students) and meanings (of what is said by the same students) rather than focus on causes. Such a study also aims to investigate even behaviour that is usually taken for granted. The naturalistic / interpretive approach uses mainly qualitative measures of data analysis but does not exclude the use of quantitative procedures. In fact the research techniques used in this project varied from questionnaires to the research diary to focus groups, which all allowed the teacher researcher to understand better the students' perceptions of the world around them. Bell (2006) explains how qualitative researchers usually seek 'insights' and not 'statistical perception of the world' and this is another feature of a naturalistic study of this type.

## 4.3 The Case Study Approach as the Main Research Strategy

There are several methodologies which can be adopted in educational research. These include action research, case study, survey, experimental style, ethnography, grounded theory and narrative inquiry (Bell, 2006). This project may be characterised as a case study as it is closely associated with this research approach in a number of ways.

Yin (2002) defines the case study research method as follows:

> The case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not already evident; and in which multiple sources of evidence are used.

In other words it is very much suitable where it is rather impossible to separate the variables of a phenomenon from its context.

The case study is regarded as the ideal methodology when an aspect of a research problem is studied in some depth (Bell, 2006). The aim is to 'focus on a particular instance of an educational experience', and then 'attempt to gain theoretical and professional insights from a full documentation of that instance' (Freebody, 2003). In other words, 'the case study approach is a study of an instance in action' (Adelman, Kemmis & Jenkins, 1980). Suter (2011) explains that case studies rely on the collection of abundant data over a period of time while keeping focus on a single person or entity (which could be one classroom or one school or one school district). According to Stake (1995) case studies are useful in the study of human behaviour as they are 'down-to-earth' and 'attention-holding'.

Cohen et al (2010) describe the case study as 'a unique example of real people in real situations' which allows better understanding of ideas than using theories and principles. On the other hand, Opie (2004) suggests that a case study is an 'in-depth study of interactions of a single instance in an enclosed system' involving a single person or a group of people in a setting (e.g. school, department or class). Hitchcock and Hughes (1995) outline a number of traits of a case study. These include:

- providing a rich description and a chronological narrative of events relevant to the case;
- blending a description of events with their analysis;
- focussing on individual actors or groups of actors, and seeking to understand their perceptions of events;
- highlighting specific events that are relevant to the case;
- involving completely the researcher in the case;
- attempting to portray the richness of the case in writing up the report.

All definitions and descriptions of a case study given point towards a number of features that were present in this project which can therefore be regarded as a case study. Table 4.1 summarises some of these features and compares them with similar features which characterise this research investigation.

**Table 4.1**

**Table comparing some features of case study with features of this investigation**

| | **Features of a Case Study** | **Features of this Research Investigation** |
|---|---|---|
| 1. | Investigates a contemporary phenomenon within its real-life context (Yin, 2002). | Research studies the interest of students towards one of the latest developments in science – green chemistry – put in a real-life context. |
| 2. | An aspect of a research problem is studied in some depth (Bell, 2006). | Students' attitudes towards chemistry and green chemistry is studied in some depth. |
| 3. | Focus on a particular instance of an educational experience (Freebody, 2003). | Focus on students studying chemistry during their first year of sixth form (post-secondary) education. |
| 4. | More interested in the process than in the outcomes (Laws & McLeod, 2004). | Researcher is interested in the students' reaction to the intervention as well as what was actually learnt in process. |
| 5. | Relies on the collection of abundant data over a period of time while keeping a focus on a single person or entity (Suter, 2011). | A lot of data was collected from one group of students over a period of nine months (one academic year) making use of various research tools. |
| 6. | 'Down-to-earth and attention-holding' (Stake, 1978). | The case study was explained in simple language and report kept as flowing as possible to keep reader's attention. |
| 7. | A unique example of real people in real situations (Cohen et al, 2010). | A unique example of a group of students (real people) embedded in a real learning environment (sixth form college). |
| 8. | Providing a chronological narrative of events relevant to the case (Hitchcock & Hughes, 1995). | Events forming part of intervention, data collection and analysis were described in a chronological sequence. |
| 9. | Focussing on individual actors or groups of actors and seeking to understand their perceptions of events (Hitchcock & Hughes, 1995) | The main focus of investigation was the group of students on which the study was carried out, trying to understand the way they perceived their own world. |
| 10. | Involving completely the researcher in the case (Hitchcock & Hughes, 1995). | Researcher was completely involved from the very beginning of the case, interacting continuously with student participants throughout the entire project. |
| 11. | In-depth study of interactions of a single instance in a closed system (Opie, 2004). | Project revolves round a study of interactions between students in a classroom or laboratory set-up. |

The case study research approach has got its strong points and weakness when compared to other research methods. These have been summarised by Nisbet and Watt (1984) as follows:

**Strengths of Case Studies**

One advantage of case studies is that results are easily understood by the layman as they are written in simple non-technical language. They are also clear and speak for themselves. They include important details which may be overlooked by other methods (which may include larger data) such as surveys but which may be crucial in understanding a particular situation.

Case studies are also strong as they depict real-life situations. They provide insights into other similar situations and cases and so help interpretation of other cases. Besides all this they can be carried out by a single researcher. One other advantage is that they can include and build on unpredictable events and uncontrolled variables.

**Weaknesses of Case Studies**

One major disadvantage is that generalisation is not always possible as this depends on how far a case study example is similar to others of its type. It is also difficult for researchers to cross-check information. This means that case-studies may be selective, biased, personal and subjective. Another shortcoming is that they are prone to problems related with observer bias despite efforts to address reflexivity.

Notwithstanding these issues and disadvantages, the case study approach is particularly useful in educational research of this kind, at least on two counts. First, it emphasizes context (Becker et al, 2005) by trying to understand as much as possible about an individual subject (or group of subjects) through ‘deep data’ and ‘thick description’ which allow research results to have a ‘more human face’. Secondly, it is a flexible method of scientific research (Becker et al, 2005) which emphasizes explanation (rather than prescription or prediction) and allows researchers the space to discover and address issues arising during their ‘experiments’.

Case study research generates a large amount of data from multiple sources. Such data is often richer than that obtained using statistical analysis. This research investigation generated data from various sources mainly from questionnaires, small group discussions (focus groups), research journal and documents from various students’ activities. This was mainly done in order to enhance reliability of the data collected and increase its trustworthiness. This also enables future readers to be able to evaluate findings and relate them to their own context.

Besides this, the researcher also adopted a number of strategies when collecting and analysing data in order to minimise any of the weaknesses of the case study method such as selectivity, inherent subjectivity and observer bias. These are described in later sections of this chapter.

## 4.4 Overview of Research Methodology

The background knowledge to the study was obtained through the literature review which started at the initial stages of the project but was kept going throughout the entire project duration. An early decision was taken to carry out a classroom intervention with a group of students attending the same sixth form college where the researcher worked as a lecturer of chemistry. The intervention was aimed to introduce basic concepts of green chemistry given that the local A-level chemistry curriculum was at the time devoid of any reference to environmental content. A number of areas of interest were identified and the intervention package was designed in order to allow students acquire a good background (theory and practice) of green chemistry over a period of one academic year.

Research instruments were then designed to collect data from a sample of students following the first year course in A-level chemistry at the same institution, which happens to be the main sixth form college in Malta. These consisted mainly of questionnaires, focus groups and the personal research diary but included other data such as student activity worksheets and presentations.

The pilot intervention was carried out during academic year 2008/09 and data was collected from a single cohort of students (**group A** – pilot GC class) before and after the intervention. Preliminary analysis was carried out on the data generated from the pilot study and this was followed by some modifications and fine tuning of the intervention package and research tools to be used for data gathering during the main study. The main intervention was carried out on a group of students (**group B** – main GC class) during the following academic year, i.e. 2009/10 with data being collected from the same group and from another class pertaining to the same cohort (**group C** – main non-GC class ) which was not involved in the main intervention and hence acted as a control.

The theoretical framework was designed in order to help the organisation of concepts emerging by the coding process during attitude data analysis. This was used to analyse data collected before, during and after the intervention. 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 could be drawn up. The various stages of the entire research methodology are summarised in figure 4.1.

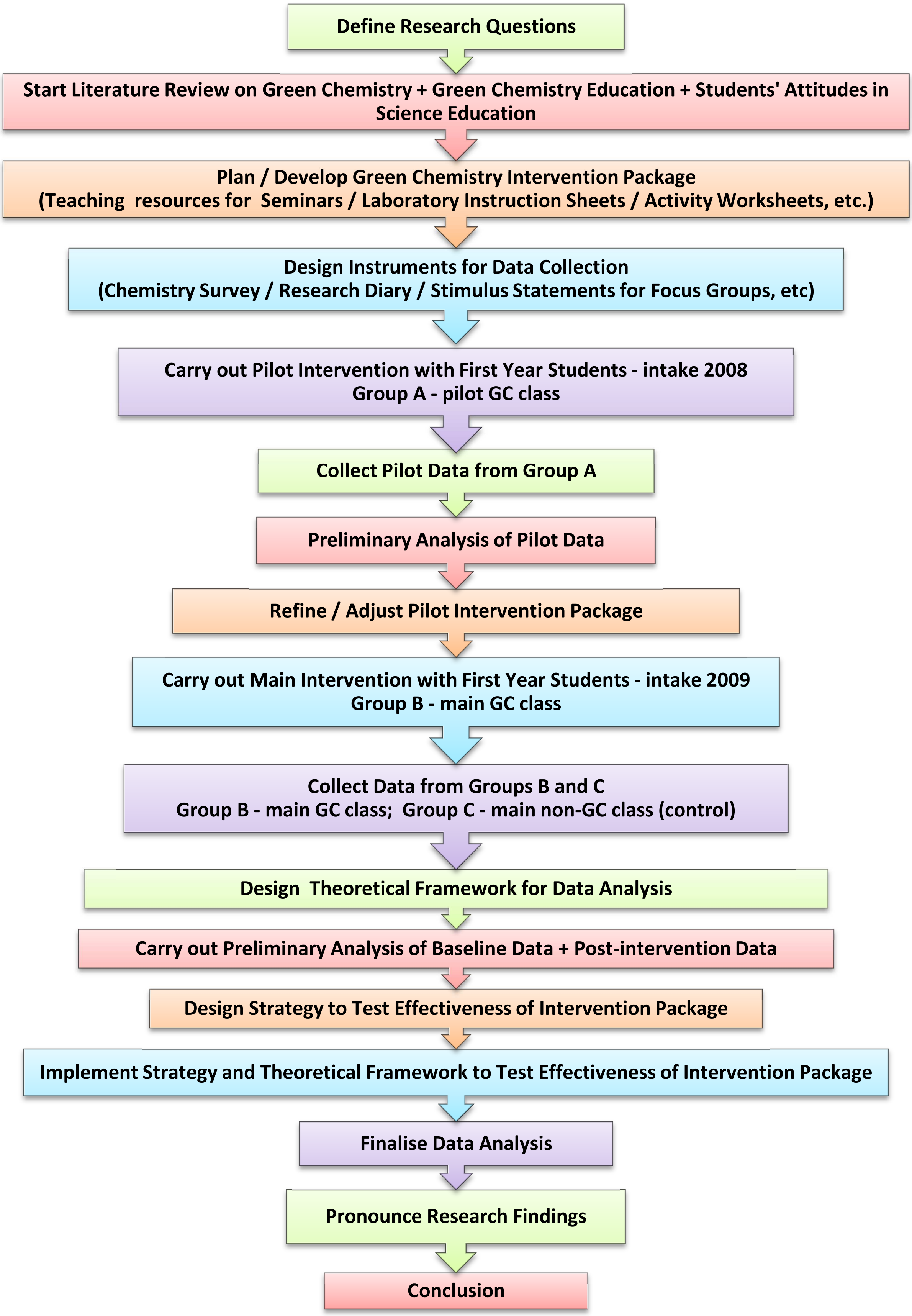



**Figure 4.1**

**Flow chart illustrating main stages of research methodology used to collect and analyse data**

## 4.5 The Samples

This research study was carried out with the participation of three groups of chemistry students attending the first year course of studies at the Maltese sixth form college. The following were the groups of participants involved in the project.

**Sample for Pilot Study – Group A (pilot GC class – intake 2008)**

The chemistry class (intake 2008) chosen for the pilot intervention was composed of 40 students, of which 39 completed the first year course of studies and one student dropped out by December 2008. The sample size considered for data collection and analysis was that of 39 students which represented 13.3% of all first year chemistry students registered during academic year 2008-09.

Most of the students participating in pilot study (31/39) were sixteen years old by November 2008, with the rest reaching the age of sixteen by the end of the academic year. The male-female ratio in this group was close to 1:1 with a slightly higher number of female students (17 males, 22 females). They came from different backgrounds, with more than half (21/39) having completed their secondary education in a Church-run school. All students in the group had chosen chemistry and biology as their two main advanced-level (AM-level) subjects while physics, English and philosophy were the most popular options made by the same students at intermediate level in view of the matriculation certificate which they were expected to obtain to qualify for university. All students studied 'systems of knowledge' as a compulsory fourth intermediate-level (IM-level) subject forming part of the matriculation certificate requirements (two AM-level and four IM-level subjects).

The majority of students forming part of this group aspired to study medicine at university, with others showing interest in other science related courses. Only one student was undecided on further studies at the beginning of the year. The information was compiled from the first part of the chemistry survey which was administered to students at the beginning of the year, prior to the intervention. The information is summarised in table 4.2.

**Table 4.2**

**Profile of Group A – pilot GC class (intake 2008)**

| **Characteristic** | **Figures (N = 39)** |
|---|---|
| Age (as on 05/11/2008) | fifteen years = 9; sixteen years = 30 |
| Gender | female = 22; male = 17 |
| Secondary school last attended | Church = 21; state = 13; independent = 5 |
| Second AM-level subject | biology = 39; other = 0 |
| Main three IM-level subjects | physics = 34; English = 29; philosophy = 15 |
| Target university course | medicine = 28; other = 10; undecided = 1 |

*AM = Advanced Matriculation; IM = Intermediate Matriculation*

**<u>Sample for Main Study – Groups B & C (intake 2009)</u>**

Two groups of students were 'randomly' chosen out of all students applying to study chemistry at A-level starting from October 2009. One of the groups, referred to as Group B – main GC group (or **GC class** in short), was made up of 31 students representing 14.0% of the first year chemistry student cohort enrolled in the A-level programme during academic year 2009-2010. The second group, referred to as Group C – main non-GC group (in short, **non-GC class**), was made up of 36 students representing another 16.3% of the first year chemistry A-level students during the same academic year. This means that a total of 67 students (amounting to 30.3% of chemistry first year student cohort) following the first year A-level course at the local sixth form college participated voluntarily in the project. Table 4.3 shows the number of students studying science subjects at advanced (AM) or intermediate (IM) level at the same Maltese educational institution at the beginning of academic years 2008-09 and 2009-10.

**Table 4.3**

**First Year Students studying Science at the Maltese College between 2008-2010**

| | **Maltese Sixth Form College Students** | **Intake 2008** | **Intake 2009** |
|---|---|---|---|
| 1 | Advanced (AM) level Physics | 409 | 376 |
| 2 | Intermediate (IM) level Physics | 608 | 496 |
| | **Sub-total A** (1+2) | **1017 (49.7%)** | **872 (46.8%)** |
| 3 | Advanced (AM) level Chemistry | 281 | 221 |
| 4 | Intermediate (IM) level Chemistry | 32 | 24 |
| | **Sub-total B** (3+4) | **313 (15.2%)** | **245 (13.1%)** |
| 5 | Advanced level (AM) Biology | 476 | 382 |
| 6 | Intermediate level (IM) Biology | 143 | 115 |
| | **Sub-total C** (5+6) | **619 (30.3%)** | **497 (26.6%)** |
| 7 | Intermediate level (IM) Environmental Science | 331 | 300 |
| | **Sub-total D** (7) | **331 (16.1%)** | **300 (16.1%)** |
| | **TOTAL NUMBER OF FIRST YEAR STUDENTS** | **2047** | **1865** |

*Source: Maltese Sixth Form College Administration*

The GC Class (Group B – intake 2009)

This group started the year with 33 students but two of them dropped out of the course within the first month of the year. Participants were predominantly female (24/31) with less than one fourth being male students (7/31). The majority of students were sixteen years of age by the beginning of the study with two repeaters being one year older than their classmates. Almost half of the students attended one of the local Church-run (or dependent) secondary schools, with another eleven having attended a state school and the rest coming from independent (i.e. private) educational institutions.

All participants but one studied biology along with chemistry at AM-level, the other student opting for AM-level pure mathematics. On the other hand the three subjects which were mostly taken at intermediate level where physics, English and philosophy. All students studied 'systems of knowledge' as an additional compulsory subject at intermediate level to complete the requirements for the Matriculation Certificate as the main entry qualification to the University of Malta.

Data from questionnaires forming part of the chemistry survey showed that most students intended to pursue a medical career at university with less than half showing interest in science-related courses. Table 4.4 summarises the main features characterising the GC group participating in the main study.

**Table 4.4**
**Profile of Group B – main GC class (intake 2009)**

| **Characteristic** | **Figures (N = 31)** |
|---|---|
| Age (as on 28/10/2009) | fifteen years = 6; sixteen years = 23; seventeen = 2 |
| Gender | female = 24; male = 7 |
| Secondary school last attended | Church = 15; state = 11; independent = 5 |
| Second AM-level subject | biology = 30; pure mathematics = 1 |
| Main three IM-level subjects | physics = 21; English = 20; philosophy = 14 |
| Target university course | medicine = 19; other = 12 |

*AM = Advanced Matriculation; IM = Intermediate Matriculation*

<u>The non-GC Class (Group C – intake 2009)</u>

As in the case of the other group (the GC class), most of the students in this class were sixteen years old with two students repeating the year and hence a year older. The class had

36 registered students divided into 18 males and 18 females. About two thirds students finished their secondary educational studies in a local Church school with the rest having attended state secondary schools or private institutions including one overseas (UK) school. All students except for one chose biology as their A-level subject, with physics being the most preferred subject studied at intermediate level, followed by English and philosophy. All students studied ‘systems of knowledge’ (compulsory) as in the case of their counterparts in the GC class. Most of the students in this group also declared their initial inclination to study medicine at university with one sixth (1/6) showing interest in other science-related courses and two being undecided on future aspirations, at the beginning of the year.

This class was not taught by the researcher during academic year 2008-09 but was chosen to act as the control group so as to provide parallel data at the same time data was collected from the GC group. Table 4.5 summarises the profile of the non-GC class participating in the main study during year 2008-09.

**Table 4.5**

**Profile of Group C – main non-GC class (intake 2009)**

| **Characteristic** | **Figures (N = 36)** |
|---|---|
| Age (as on 28/10/2009) | 15 years = 6; 16 years = 28; 17 years = 1;<br>18 years = 1 |
| Gender | female = 18; male = 18 |
| Secondary school last attended | Church = 21; state = 10; independent = 5 |
| Second AM-level subject | biology = 35; physics = 1 |
| Main three IM-level subjects | physics = 33; English = 21; philosophy = 19 |
| Target university course | medicine = 28; other = 6; undecided = 2 |

*AM = Advanced Matriculation; IM = Intermediate Matriculation*

## 4.6 The Research Setting

Both the pilot intervention and the main intervention took place in the same location, i.e. the Maltese sixth form college hosting this research study. The same applies to other related activities such as the students' seminars, laboratory sessions, chemistry survey (questionnaires) and focus groups of both the pilot and main studies, which were all held in the same place.

In both the pilot study and main investigation, the students participated on a voluntary basis in all the green chemistry and related activities during their free time. The following tables (4.6, 4.7, and 4.8) illustrate the extra commitment of students (in terms of contact hours) of the students participating in the pilot and main study.

**Table 4.6**
**Participation of Group A – pilot GC class (intake 2008)**

| **Activity** | **Duration (per student)** |
| --- | --- |
| Chemistry survey (pre-tests / post-tests) | 4 hours |
| Green chemistry seminars | 7 hours |
| Students' presentation seminars | 3 hours |
| Green chemistry laboratory experience | 2 hours |
| Practical evaluation session | 1 hour |
| Focus group participation | 1 hour |
| Concluding seminar | 1 hour |
| **TOTAL** | **19 hours** |

**Table 4.7**

**Participation of Group B – main GC class (intake 2009)**

| Activity | Duration (per student) |
|---|---|
| Chemistry survey (pre-tests / post-tests) | 4 hours |
| Green chemistry seminars | 10 hours |
| Students' presentation seminars | 2 hours |
| Green chemistry laboratory experience | 4 hours |
| Practical evaluation session | 1 hour |
| Focus group participation | 1 hour |
| Concluding seminar | 1 hour |
| **TOTAL** | **23 hours** |

**Table 4.8**

**Participation of Group C – main non-GC class (intake 2009)**

| Activity | Duration (per student) |
|---|---|
| Chemistry survey (pre-tests / post-tests) | 4 hours |
| Focus group participation | 1 hour |
| **TOTAL** | **5 hours** |

In order to organise the pilot intervention (seminars, laboratory sessions, chemistry survey, focus group and related activities), the researcher required a total of 24 extra contact hours with the pilot GC class, over and above his official time-table load. The researcher also lectured inorganic and physical chemistry (forming part of the official chemistry curriculum) to the same class during the same academic year. The record of activities organised during 2008-9 and linked with the pilot study is shown in *appendix 1*.

On the other hand, considering all the activities of the main intervention and relevant data collection sessions from the two groups of participants (the GC and non-GC classes), the author was involved in 28 contact hours with the GC class and another 7 hours with the non-GC class, summing up to a total of 35 hours of direct involvement with all participants during year 2009-10. The researcher also lectured regularly inorganic and physical chemistry to the GC group, but had no other (official) contact with any of the students belonging to the non-GC class. The detailed programme of activities forming part of the main intervention and data collection sessions organised during academic year 2009-10 is shown in *appendices 2 and 3*.

All programmed activities were held separately from the official college time-tables and none of them replaced any of the scheduled chemistry lectures of the teacher-researcher with the classes concerned. Whenever the author was constrained to use the time allotted for a scheduled lecture to hold a green chemistry seminar or any of the related activities of the main intervention, the lecture was rescheduled in agreement with the chemistry department and college authorities. This was done in order not to disrupt the core chemistry programme and to avoid any possible repercussions of this research work on the students' performance in the school examinations.

Another consideration made was the physical environment where the activities were held. The author made sure that all students would participate in as natural a setting as possible in order for them to behave as normally as possible in familiar situations. Several arrangements were therefore made so that questionnaires forming part of the chemistry survey could be administered in ordinary lecture rooms, seminars and student presentations were all held in the main media room equipped with audio-visual and computer facilities, the exhibition of students' work was held in the chemistry wing of the same college, while focus groups were organised in the spacious well-furnished conference room situated in one of the quietest corners of the college campus. All practical work was performed in the college chemistry laboratories even though participants had to adapt to the use of the second-year laboratories (with which they were less familiar) for the green chemistry practical sessions, for logistical purposes.

Summing it up an effort was made in order to minimise any negative impact of the project on the students' time-tables and to allow participants to act naturally and interact spontaneously throughout the study. This involved making several considerations on the logistics required to organise the programme (i.e. intervention + data collection activities) and provide students with natural back drops for all sessions held.

## 4.7 Development of the Main Study

The main research study was undertaken during academic year 2009-10 and was based on the modified version of the pilot intervention. This consisted of a number of presentations made by the tutor / researcher during a programme of classroom seminars along with laboratory and other activities all aimed at introducing different aspects and concepts of green and sustainable chemistry to a group of Maltese sixth form students studying A-level chemistry. Data was collected using previously piloted research instruments which were amended and fine-tuned following the evaluation of the pilot study. All data generated during the main study was eventually analysed using the theoretical frameworks described in sections 4.8 and 4.9 of this chapter.

### 4.7.1 The Participants

The two groups of students participating in the main study belonged to the same cohort of students joining the sixth form college in October 2009. The green chemistry intervention was carried out on one group – the **GC class** (Group B) while the second group – the **non-GC class** (Group C) served as a control. This group provided a second source for data collection at the pre-intervention and post-intervention stages mainly for comparative purposes. Both sets of students accepted to take part in the project on a completely voluntary basis and they also accepted to do so in their limited spare time in between lectures and other time-table commitments. All students involved were aware, right from the very beginning, that they were participating in an educational research investigation focused on a possible curriculum innovation. Another group of students (Group A) from a different cohort (intake 2008) was involved in the pilot study in the same setting and under similar circumstances.

It was decided that each group of GC students (i.e. Groups A and B) taking part in the intervention (both in pilot and main studies) would be divided into six smaller units or teams with one student from each sub-group acting as a 'team leader'. The leaders were chosen randomly given that the researcher was not yet well acquainted with the students at the beginning of the year. The idea behind the formation of small teams and team leaders was to encourage team spirit during all learning activities in class, to facilitate communication with the teacher-researcher in the organisation of in-class and out-of-class activities and to coordinate better the collection of data from such activities. The 'team' concept was tried out successfully in the pilot intervention and was then applied again throughout the main intervention.

### 4.7.2 Planning the Intervention

The early plans of the intervention involved literature review on green chemistry, green chemistry education, students' attitudes towards science and science education and understanding of chemistry / green chemistry concepts. A number of aspects / areas of green chemistry were considered for a short programme to introduce this new field of chemistry to sixth form students, parallel to the teaching of other traditional topics forming part of the A-level chemistry curriculum. This led to the identification of a number of key areas of interest which were further investigated for possible inclusion in a series of lectures / seminars forming the basis of the green chemistry intervention. These areas were shortlisted from an original longer list, after having considered the background level of chemistry required by students to follow the theory and concepts involved and the links with material already forming part of the core chemistry curriculum. The general idea was to relate basic ideas of green chemistry with A-level chemistry and the everyday life experienced by students.

It was also decided that the intervention programme would also include a laboratory experience in green chemistry to re-inforce the theory discussed during the seminars and to allow students a close encounter with the application of green chemistry.

Once the intervention plan was in place, a number of teaching and learning resources needed to be developed in order to be tried out during the pilot study. These consisted of a set of computer presentations slide shows and video clips for the main classroom seminars, a set of printed notes complementing the seminar presentation, a set of worksheets forming the basis of the students' learning activities held during the seminars and an instruction sheet for the green chemistry practical session. These were all trialled in the pilot study before being evaluated and modified to form the basis of the main intervention package during the subsequent academic year.

### 4.7.3 Designing Resources for the Intervention Package

The material used to produce the various resources of the intervention package were adapted from various sources. The content of the seminar presentations and activity worksheets were inspired by material published in journals and magazines such as *Green Chemistry* (the journal), *ChemMatters*, *Education in Chemistry* and *Chemistry Review*, as well as several educational resources available on the internet. Three important online sources of information and ideas were the Green Chemistry Educational Resources developed jointly by the Green Chemistry Institute and the Education Division of the American Chemical Society, resources provided by the Royal Society of Chemistry and available on the LearnNet educational website and the Greener Industry website hosted by the (UK) Chemical Industry Education Centre (CIEC, 2010) which are mostly aimed at post-16 chemistry students and chemical educators.

The content, aims and expected outcomes of the green chemistry package were discussed during several supervision meetings and thesis advisory panel (TAP) sessions preceding the pilot and main interventions. A summarised description of all activities planned for the main intervention is included in the form of a table in chapter 5 (table 5.4).

### 4.7.4 Developing the Research Instruments

Being a mixed method (but mainly qualitative) research investigation, a variety of techniques were employed in order to gather information from the participating students.

The research instruments used in the main study were the modified versions of the ones developed earlier and tried out in the pilot investigation.

The techniques applied were:

(i) questionnaires (pre-tests and post-tests which together formed the ‘Chemistry Survey’);

(ii) focus groups involving both the GC and non-GC participants;

(iii) personal research diary;

(iv) other documents such as the student (learning) activity worksheets, laboratory reports and students’ posters.

The two main sources of data in this project were the questionnaire method and the focus group (or small group discussion). The following are the main strengths and weaknesses of these instruments which are all extensively used in educational research.

#### 4.7.4.1 Strengths and Weaknesses of Questionnaires

In general the questionnaire method is an inexpensive method that is also less time consuming with respect to other methods. This is extremely important for a researcher such as the author with a full time job and other important commitments in life. The questionnaire method makes it relatively easy to access information from a group of people in a relatively short time. Another advantage of this technique is that the analysis of answers to closed questions is relatively straightforward as answers are predetermined and only their frequency needs to be measured. It also encourages honesty among respondents (Cohen et al, 2010).

The use of rating scales such as the Likert scale in questionnaires offers also a number of advantages over other tools of data collection. They are widely used in research as they allow for flexible responses and enable the researcher to determine frequencies, correlations and other parameters of quantitative analysis. They also allow the possibility to combine quantitative measurements with qualitative data such as opinion, perceptions and attitudes (Cohen et al, 2010).

The fact that questionnaires were assigned in this study in the form of a class written exercise provided other advantages as a result of personal contact between the researcher and respondents at the point of data collection. In fact, such personal contact made it possible for the researcher to explain personally the purpose of the survey, for students to complete questionnaires on the spot thereby securing a high response rate, and for a better cooperation from respondents.

Amongst the shortcomings of questionnaires as applied to this project one could mention the need for brevity and the use of relatively simple questions, the fact that misunderstandings cannot be corrected, the fact that only limited information can be sought especially through closed questions, the impossibility to check whether each respondent is telling the truth or whether any of the respondents would have wished to add any comments about any issue being investigated. One particular weakness that stands out in Likert-type scales is the tendency of respondents to avoid extreme poles at each end of the continuum of the scales, thereby reducing the number of optional responses. Another disadvantage of questionnaires over other methods such as interviews is that they tend to be filled in hurriedly and this may jeopardise complete understanding of the question and choosing the best answer (Bell, 2006; Cohen et al, 2010).

#### 4.7.4.2 Strengths and Weaknesses of Focus Groups

In this study, the focus group method was used as the primary means of gathering information on students' attitudes towards science, chemistry and green chemistry in particular, aimed at addressing the main research question. It is a method which is rapidly growing in importance in educational research (Cohen et al, 2010; Le Compte & Preissle, 1993). It relies on the interaction within a small group while discussing a topic proposed by the researcher. Cohen et al (2010) describes focus groups as 'contrived settings' whereby a small section of the population discusses a theme or topic and generates data and outcomes through interaction within the group. The fact that focus groups are 'contrived' (or fabricated) gives them unnatural settings which however allows the small group interview to be highly focussed on issues, extracting more information than from other straightforward interviews.

Another strength of focus groups is that they are economical in time and money, generating a lot of data at low cost and in a short time. Yet they do not generate the same volume of data as in the case of one-to-one interviews. Focus groups are able to gather qualitative data on attitudes, values and opinions. Unlike other methods they also allow participants including non-literate ones to have their own say in discussions. The focus group is also a platform that allows the treatment of more issues with respect to other methods (Bailey, 1984; Krueger, 1988; Morgan, 1988; Robson, 2002). In focus groups, responses can be developed to a greater depth and allow for further explanation. Response rate is also higher than that of questionnaires as respondents usually feel more involved and motivated when talking with respect to writing.

On the other hand, Cohen et al (2010) also cites a number of disadvantages using the focus group method. These include the fact that a focus group does not produce any quantitative and generalised data, data cannot be analysed in a simple way, the method yields less data than other methods (e.g. survey), some participants may dominate over others who may remain silent, it is limited over a number of topics covered, it may give rise to conflicts within the group and data may lack reliability.

### 4.7.5 Data Collection

Collection of data was sanctioned by the University of York ethics committee, the supervisor, as well as the Maltese sixth form college administration. This section describes how data from the separate instruments were gathered and analysed and what steps were taken to ensure reliability and validity of the data collection tools and data analysis. Table 4.9 maps all data sources used against the research questions of this investigation.

**Table 4.9**

**Mapping Data Sources onto Research Questions**

| Research Questions | Source 1 | Source 2 | Source 3 | Source 4 | Source 5 |
|---|---|---|---|---|---|
| | Chem Survey (Part 1) Questionnaire A | Chem Survey (Part 2) Questionnaire B | Focus Groups | Personal Diary | Other Documents (Worksheets ,Lab reports, etc) |
| How do Maltese sixth form students respond to the incorporation of green chemistry in the A-level chemistry curriculum? | ✓ | ✓ | ✓ | ✓ | ✓ |
| In what ways do students' attitudes change by including aspects of green chemistry in the core A-level curriculum? | ✓ | | ✓ | ✓ | |
| What understanding of green chemistry ideas is developed by students who do, or do not experience in the green chemistry intervention? | | ✓ | ✓ | | ✓ |
| What are the effects of the green chemistry intervention on the students' views of studying chemistry beyond A-level? | | | ✓ | | ✓ |

#### 4.7.5.1 Data Generated from the Chemistry Survey (Questionnaires)

The chemistry survey was conducted during academic year 2009-10 and consisted of two types of questionnaires designed to access the views of the participating students and of the control group on different aspects of chemistry and green chemistry, as well as their level of understanding of green chemistry principles. One of the questionnaires focused on the students' attitudes towards chemistry and green chemistry (pre-test A1 and post-test A2) while the second one was dedicated to learning of specific concepts of green chemistry (pre-test B1 and post-test B2). Each questionnaire was administered before starting the green chemistry intervention, hence being referred as the *pre-tests* (pre-test A1, pre-test B1) and then upon termination of the intervention, hence the term *post-tests* (post-test A2, post-test B2).

**Part 1 – Questionnaire A**

The first questionnaire which was administered to both classes (GC and non-GC groups) prior to the intervention (i.e. pre-test A1) consisted of 40 items which were divided into five parts: section A to section E.

Section A included eight questions seeking personal information such as name, age, school last attended, chemistry background, future aspirations and other subjects studied at post-16 (at intermediate or advanced level). This was done to enable researcher to obtain a general idea of the students' educational background and inclinations at this point in time. The other sections asked students to express their viewpoints on several statements on chemistry and green chemistry. Section B (10 items) accessed students' attitudes towards chemistry at school, section C (5 items) concerned students' opinions on chemistry in society, section D (5 items) considered students' intentions to follow a chemistry related career while section E (12 items) was linked to students' opinions on the idea of including the area of 'green chemistry' in future school chemistry curricula.

All questionnaire items in sections B to E of pre-test A1 were closed and structured and students had to respond to each question by choosing one of the options of the following five-point Likert scale.

**Table 4.10**

**Likert Scale used in Part A of Chemistry Survey**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

When this pre-test was piloted it included a sixth section (section F) on the students' general views of green chemistry. On that occasion, students found it hard to answer the last two sections of the questionnaire as they were not yet prepared to express their views on such a new section of chemistry when they had not even heard about it. When the matter was discussed with the other members of the Thesis Advisory Panel it was decided that the situation would be resolved by omitting completely the last section of the pre-test questionnaire for the main study but then re-propose it at the post-intervention stage (post-test A2). It was also agreed that the term green chemistry would be explained in a short paragraph preceding section E, which asked for students' ideas on the integration of green chemistry in the school chemistry programme. In this way students could figure out roughly what green chemistry was all about and give their very initial views of having it included in the chemistry curriculum, even at the pre-intervention stage. By eliminating section F from pre-test A1, students were saved from resorting to guesswork when asked to give their viewpoint on aspects of green chemistry when they were not yet competent enough to do so. This would also have risked undermining the validity of the exercise and data generated from it.

**Part 2 – Questionnaire B**

The second questionnaire which was also applied to students before the intervention (as pre-test B1) was divided in two parts. The first section was reserved to confirm personal information (8 items) while the second section aimed at collecting data about students' understanding of basic concepts of green chemistry. This second part consisted of fifteen items, and was a modified version of the pilot questionnaire B. The first twelve questionnaire items were designed to elicit data about the students' knowledge and understanding of the twelve key principles of green chemistry while the last three asked more basic open-ended questions on green chemistry. Some of 12 questions linked to the principles of green chemistry were diagnostic, while the rest were more of the recall type to check the students' knowledge of green chemistry and their level of understanding every principle of green chemistry at that point in time. After each question, students were asked to indicate their level of confidence in their response using a five-point Likert scale (1 = very unconfident, to 5 = very confident). This was done to measure the students' extent of self-confidence in green chemistry at the point of being tested.

The same questionnaires were used at the post-intervention stage. Post-test A2 was similar to pre-test A1 but included section F where students had to answer an additional 16 questions related to their own views on out-of-school green chemistry. The same Likert scale applied to the rest of the questionnaire was used to answer the new section. On the other hand, post-test B2 was identical in content to pre-test B1, the idea being that of measuring whether students, by the end of the intervention, were in a better position to relate with all the main principles of green chemistry. The questionnaires used in post-tests

A2 and B2 (similar in content to the ones in pre-tests A1 and B1) and forming part of the chemistry survey, are included as *appendices 20 and 21*.

Pre-test A1 was undertaken by 33 respondents from the GC group and another 36 from the non-GC group (i.e. the class serving as a control group). The other questionnaire, pre-test B1, was answered by 32 GC and 35 non-GC participants as one student from each class was unavailable on the day of the test. The pre-intervention tests were carried out between 28 October and 5 November 2009 which is within the first month of the academic year 2009-2010.

The post-intervention tests A2 and B2 forming the second part of the chemistry survey were administered between 4 and 11$^{th}$ May 2010. There were 30 GC and 36 non-GC respondents who took part in both post-test A2 (regarding students' attitudes to chemistry / green chemistry) and post-test B2 (on understanding of green chemistry principles). This means that there were two fewer GC respondents at the post-intervention stage (two students dropping out from course) with respect to pre-test, while all non-GC students participated in part 2 of the survey.

There were no ethical issues involved in conducting the chemistry survey. Both sets of questionnaires were previously piloted the previous year with a similar group of sixth form students and refined (using simpler statements) so that the final version contained as full a range of possible responses as could be reasonably foreseen. There were also no problems with the format and understanding of the language used in both questionnaires.

#### 4.7.5.2 Data Generated from Focus Groups

During the main study, all students forming part of the GC class were invited to participate in one of the focus group discussions organised at the end of the main intervention in May 2010. In fact all students still forming part of this class by the end of the academic year 2009-10 agreed to participate voluntarily in this exercise. This represents a participation rate of 100% which therefore contributed towards the validity of data gathered from this research instrument. The GC group was divided into four smaller sub-groups, each composed of seven or eight students. In the meantime, two thirds (24/36) of the students forming part of the non-GC class (control group) who did not experience the green chemistry intervention volunteered to take part in separate focus groups held during the same period of time. These were divided into three groups of seven to ten students each. The following table summarises the number of participants taking part in the focus group sessions in May 2010.

**Table 4.11**
**Composition of Focus Groups in Main Study**

| Class | Focus Group | Males | Females | Total |
|---|---|---|---|---|
| GC | A | 0 | 7 | **7** |
| GC | B | 3 | 5 | **8** |
| GC | C | 2 | 6 | **8** |
| GC | D | 2 | 5 | **7** |
| **GC Class Total** | | **7** | **23** | **30** |
| Non-GC | E | 5 | 5 | **10** |
| Non-GC | F | 2 | 5 | **7** |
| Non-GC | G | 2 | 5 | **7** |
| **Non-GC Class (Total** | | **9** | **15** | **24** |

The focus groups were organised in a similar way to those of the pilot study with the participants seated together with the teacher-researcher round an oval table in the same location which hosted the pilot focus groups the previous year.

All focus groups were convened in the first two weeks of May 2010, upon completion of the classroom intervention, with groups meeting separately in the main college conference room, in a quiet area of the main college block. All discussions were chaired by the teacher-researcher who was seated alongside the participants round the same table. These small group discussions were guided by a number of stimulus statements designed by the researcher and printed on postcard-size cards which were also laminated. This was done in order to keep discussion as focussed as possible to the topic of the research investigation.

The stimulus statements used were similar to the ones employed in the pilot focus groups and were agreed upon by the supervisor and thesis advisory panel. It was decided that the statements presented to the non-GC group would deal with chemistry in society and school chemistry (with no reference to green chemistry) while the GC group would have a different set of cards, each containing the original statements on chemistry and additional statements on green chemistry. Besides this, it was also agreed that the green chemistry logo which featured prominently in all material used in the pilot focus groups, would be removed from the new cards prepared for the main study in order to minimise extra emphasis on green chemistry particularly with the non-GC focus groups who were not involved in the intervention as their GC counterparts. As in the case of the pilot study, students taking part in each focus group were initially shown the entire pack of cards and were then allowed to decide individually on whether or not they could agree with the gist of the stimulus statement/s. In order to make it easier to shortlist these statements for discussion and keep record of personal preferences, each student was asked to indicate agreement or disagreement on each statement by sticking a small green or red label on each card. The cards were then collected and sorted out by the researcher to organise the order of statements upon which discussion was to be based.

The general rule adopted was the same as that used in pilot focus groups, i.e. to discuss at least three statements upon which there was general agreement and another three which were mostly opposed by the same group. Students were then invited to discuss freely the chosen statements, with the researcher acting more of a facilitator than as an additional participant in order to interfere as little as possible in the collection of data from students.

Every discussion was recorded on a digital voice recorder with all participants giving prior consent to being photographed and recorded during the session. All discussions were carried out in Maltese and English depending on the spoken language preferred by the participants and occurred in a very friendly and casual atmosphere. The contents of each discussion were then immediately translated to English and transcribed prior to undergoing preliminary data analysis. The transcripts were checked by another member of the teaching staff in an effort to improve reliability of this research instrument.

The focus group discussion plan (main study) and the sets of statements printed on the stimulus cards are shown in *appendix 22*.

#### 4.7.5.3 Other Methods of Data Collection

Other forms of evidence from this research inquiry were collected using other techniques such as the researcher's personal diary, students' learning activity worksheets, laboratory reports and students' posters.

The research journal included a detailed personal account by the researcher on all activities organised during the main study, including comments depicting feelings and situations created in the course of the intervention. Bell (2006) explains that the research diary can be invaluable in tracking the progress of the research and in recording names, personal data and even any good ideas that may crop up every now and then related to the project. The diary provided a source of observation which could be used 'to gather live data from naturally occurring social situations' (Cohen et al, 2010).

Another source of data used in this project was the students' activity worksheets which were collected after each classroom seminar forming part of the main intervention. The responses given by the participants in these documents were meant to serve as an immediate feedback by students and an additional way of testing the students' ability to understand the green chemistry themes presented to them during the intervention.

Participants were also asked to write and submit a laboratory report for each green chemistry practical session conducted in the school laboratory as part of the intervention. These reports were meant to serve as another indicator of the students' level of interest and understanding of green chemistry concepts previously discussed in class. They also provided an insight on how participants could relate such issues in a laboratory environment.

The main students' team activity was the preparation of a poster which was then presented by the same participants during the students' seminars to illustrate in a simplified way one specific aspect of green chemistry during the students' seminars. These posters provided another window of opportunity for the researcher to access how students viewed green chemistry upon being introduced to this new area of chemistry which did not form part of their official A-level chemistry programme of studies. All posters created by the participants were then put on display during a small exhibition on green chemistry which students set up in the same college upon their own initiative.

## 4.8 Testing the Effectiveness of the Green Chemistry Intervention Package

There are various possible approaches that may be adopted to carry out an evaluation study in education. Some of these approaches or 'models', differ significantly from each other but others tend to overlap in one way or another. The majority of evaluation studies usually apply concurrently more than one single approach or model (Bennett, 2003).

The approach used by the author of this research inquiry to assess the intervention package is the Robitaille model (Robitaille et al, 1993) which studies three different aspects of a new programme, i.e. the 'intended curriculum', the 'implemented curriculum' and the 'achieved curriculum'. This approach was developed by Robitaille and colleagues in the early 1990s for the International Studies of Educational Achievement (IEA Studies) carried out earlier (in 1970s and 1980s) and is now associated with the Third International Mathematics and Science Study (TIMSS).

The **Intended Curriculum** is the early stage of evaluation and focuses on the planning of the intervention. It refers to the aims and objectives of the curriculum / innovation set at the beginning of the plan and the materials such as textbooks and other educational resources required to introduce and implement the programme. This early stage of evaluation is also the stage were the curriculum innovator analyses the various factors at the place of work which in this case include the school chemistry curriculum, the learning environment, the local context, the students' aptitudes in science / chemistry, etc., and then carefully plans the curriculum intervention or innovation. In other words, the intended curriculum is meant to address the intentions of the curriculum innovator. The intended curriculum innovation at the centre of this research investigation has been dealt with in chapter 5.

The **Implemented Curriculum** is what really happens in the classroom or in any other school setting (including the school laboratories) and refers to the various activities experienced by students in order to achieve the intended curricular outcomes at school. It also involves the teaching approaches and materials (textbooks, technology) employed by teachers when using the programme (Bennett, 2003).

This second stage puts under the spotlight all classroom and laboratory activities occurring during the intervention. It therefore refers to what actually happened in class or in the laboratory during the intervention and hence evaluates all learning activities and other experiences gained by students during the intervention in order to achieve the expected curricular outcomes. The implemented curriculum will be dealt with in chapter 6.

The **Achieved (or Attained) Curriculum** refers to the curriculum outcomes of the programme such as knowledge, skills, understanding and attitudes of students during their learning experience. It is regarded as the 'product' of any curriculum development process and must match with the objectives and activities that were made, indicating performance with respect to the same objectives and activities. Hence it involves the analysis of learning outcomes and their interpretation. The third stage of evaluation is dealt with in more detail in chapters 7, 8 and 9 dealing with the analysis of data (on students' attitudes and understanding / knowledge of green chemistry) collected during the main study.

The entire curriculum evaluation process is therefore aimed at establishing how the 'implemented' curriculum is related to the 'intended curriculum' but also at exploring the various features of the 'achieved' curriculum and determining how these may overlap with the 'intended' and 'implemented' versions of the same curriculum innovation.

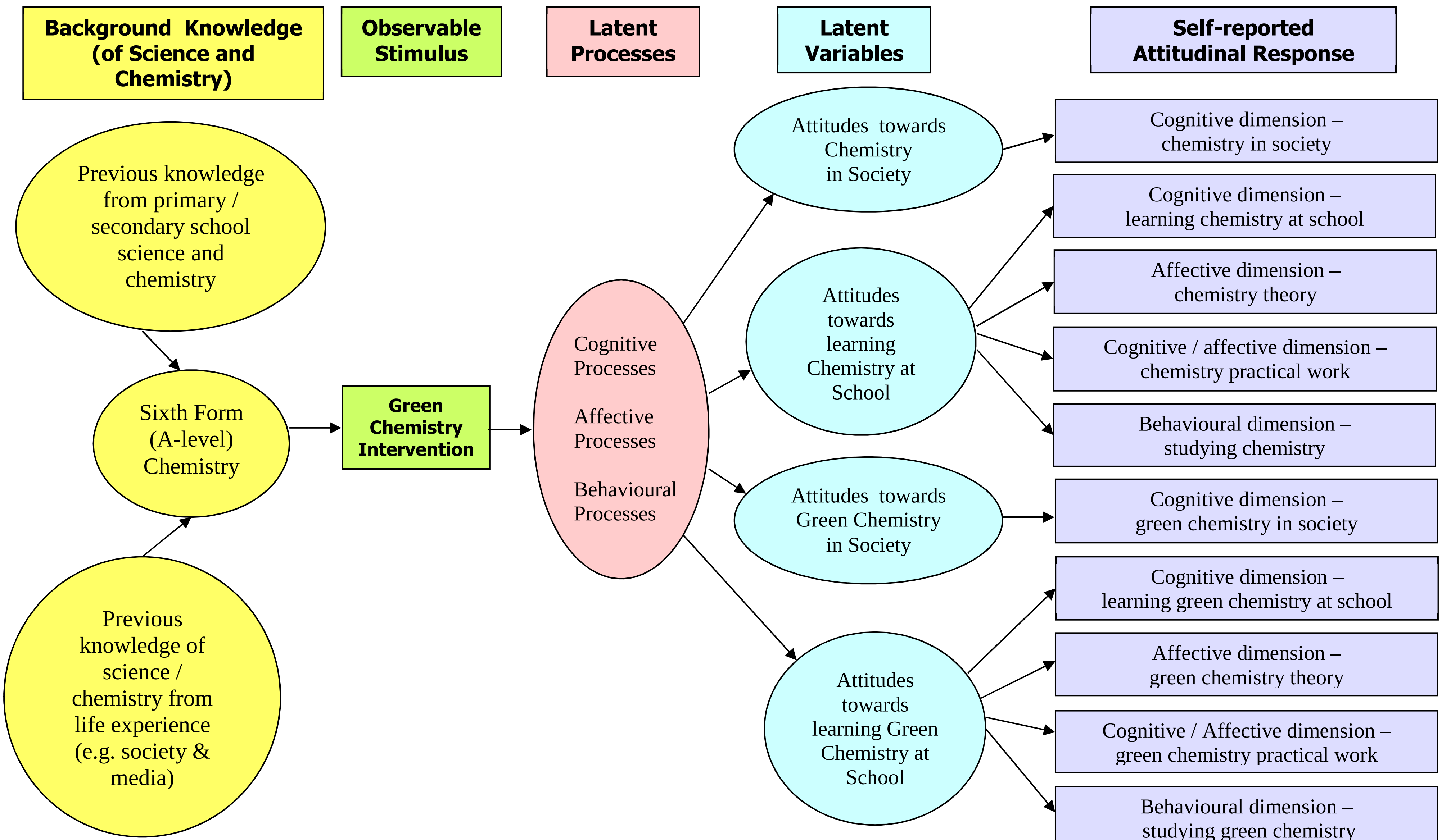
## 4.9 Developing a Theoretical Framework for (Attitude) Data Analysis

The framework used to analyse data concerning students' attitudes to learning chemistry and green chemistry was based on the work of Cheung (2009) who studied the students' attitudes towards chemistry lessons in Hong Kong secondary schools as part of a curriculum evaluation. The framework used by Cheung in his study is based on the latent process viewpoint which is one of the major theoretical viewpoints proposed by several psychologists to describe attitudes (Oskamp & Schultz, 2005).

Literature suggested that there is an agreement among contemporary attitude researchers that attitudes are not uni-dimensional. They are formed by processing cognitive, affective and behavioural information about an attitude object and translating such information in the form of cognitive, affective and / or behavioural responses (Eagly and Chaiken et al, 2005; Oskamp and Shultz, 2005; Fabrigar et al, 2005). According to the latent process viewpoint (De Fleur & Westie, 1963), attitudes cannot be observed directly as they consist of a latent (or internal / hidden) variable but they can be measured from the observable responses. It has been suggested that an attitude need not generate all the three types of responses (Zanna & Rempel, 1988; Breckler, 1984).

Attitudes towards science involves feelings, beliefs and values towards an attitude object. In the theoretical framework which was specifically created and applied to this study, the researcher included four attitude objects – science in society, school chemistry, green chemistry (as a new discipline) in society and green chemistry at school. Attitudes towards these four distinctive objects potentially give rise to a total of ten different types of attitudinal responses (or dimensions) as shown in figure 4.2.

**Figure 4.2: Conceptual Framework on Students' Attitudes towards learning A-level Chemistry & Green Chemistry**



The following are the main reasons behind choosing these ten dimensions of students' attitudinal responses resulting from the green chemistry intervention.

### 4.9.1 Cognitive dimension – chemistry in society (Dimension 1)

Beliefs are considered as the foundations of attitudes (Eagly & Chaiken, 1993) and involve making a value judgement about an attitude subject, in this case chemistry in society. Various studies show that one of the frequently measured components of attitudes to science is the value or importance of science (Osborne et al, 2003). However, according to Ramsden (1998), the term science is an umbrella term encompassing biology, physics and chemistry. This dimension is focused on students' cognitive attitudes towards chemistry as a separate science rather than on science in general.

There are five items in the chemistry survey (part 1) focussing on 'chemistry in society' dimension. These were included in section C of the relevant attitude questionnaire. The items were:

C1. Chemistry contributes to the improvement of the quality of life.

C2. Chemistry has a beneficial effect on the environment.

C3. Chemistry is doing enough to control the production and release of toxic substances on land, in the sea, or in the atmosphere.

C4. Chemistry tries to protect the environment by identifying possible sources of pollution and treating pollutants, but it should be doing more than that.

C5. Chemistry is still responsible for most environmental problems.

There were also three stimulus statements used in focus groups which also addressed this dimension. These were:

S1A. Chemistry can make the difference in the quality of our lives.

S2A. Chemistry was instrumental in the progress achieved by mankind.

S3A. Chemistry is doing nothing to address the environmental problems created in the past.

Most of these items referred to the impact of chemistry on the environment. Such an emphasis was made in order to explore the students' views on the environmental aspect of chemistry given its association with green chemistry.

#### 4.9.2 Cognitive dimension – learning chemistry at school (Dimension 2)

One way of measuring the students' attitudes towards school chemistry is by analysing their cognitive responses towards chemistry theory lessons, i.e. how important and useful are such lessons forming part of the school curriculum. Several studies featured the use of attitude items to measure the importance and value of chemistry theory lessons (e.g. Dhindsa & Chung, 1999; Menis, 1983; Salta & Tzougraki, 2004). Analysis of this dimension sheds light on several important issues such as the perceived difficulty of chemistry, the influence of the teaching approach, the gap between O-level and A-level chemistry and relevance of chemistry to everyday life. The following were the questionnaire items in the chemistry survey which were associated with this dimension of students' attitudes towards school chemistry.

B2. Chemistry concepts are always abstract and difficult to understand.

B6. Studying chemistry improves your aptitudes in the other sciences.

B7. Students perform better in other subjects if they do well in chemistry.

B9. Ways of teaching chemistry must change in order to appeal more to students living in today's society.

B10. The chemistry curriculum needs to be updated to replace existing topics with new ones to reflect better the present and future contribution of chemistry to society.

A number of relevant statements were also discussed in small group sessions. These were:

S4A. The A-level chemistry programme is no longer relevant to everyday life.

S5A. More than ever, the world today needs people studying and doing research in chemistry.

S7A. The A-level curriculum is overburdened with unnecessary topics and activities.

S10A. Understanding key chemistry concepts depends mostly on the teaching approach and facilities available to students.

The latter stimulus statement was intended to seek any connection between classroom variables and learning of chemistry theory at school.

### 4.9.3 Affective dimension – chemistry theory (Dimension 3)

This third dimension measures the students' affective attitudes towards chemistry as a school subject. Attitudes are sometimes defined simply as 'likes and dislikes' (Bern, 1970; Nieswandt, 2005b) and so this type of response seeks to explore those attitudes when students show a liking or disliking towards school chemistry theory lessons. This dimension was frequently used by science educators to measure students' attitudes towards science lessons (e.g. Parkinson et al, 1998). Both the chemistry survey and focus groups address students' affective attitudes towards school chemistry.

The following were the questionnaire items related to this dimension.

B1. At secondary level, I always found chemistry to be interesting.

B4. I study chemistry only to pass examinations and possibly make it to university.

B5. Studying chemistry has to be made more interesting in order to make it easier to pass examinations.

B8. I do not regret having chosen chemistry as one of my A-level subjects.

The following were the statements used in the focus groups which address the same attitudinal dimension.

S6A. Studying chemistry at secondary level (for O-level exam) was far more enjoyable than studying it at sixth form level (for intermediate or A-level exam).

S8A. Chemistry is a science subject that no longer appeals to the younger generation.

S9A. Learning chemistry would become more interesting with the inclusion of environmental topics.

### 4.9.4 Cognitive / affective dimension – chemistry practical work (Dimension 4)

Practical work was always considered as a key component of science education and was well researched over the years. Laboratory work features very prominently in high school / sixth form science curricula. Several researchers have included this dimension in their analytical instruments to measure students' attitudes in science (e.g. Dhindsa & Chung, 1999; Murphy & Beggs, 2003; Parkinson et al, 1998). Research indicates that students tend to like doing practical work in science (e.g. Freedman, 1997; Parkinson et al, 1998).

This dimension was mostly investigated in the chemistry survey through the following item.

B3. Chemistry is more interesting and exciting in the laboratory than in the classroom.

It was also measured through the focus group interviews when discussing the following statement.

S12A. More emphasis should be laid on laboratory work in A-level chemistry.

### 4.9.5 Behavioural dimension – studying chemistry (Dimension 5)

The behavioural dimension of attitudes consists of an action tendency to respond to a particular way to the attitude object (e.g. chemistry theory lessons) (Eagly & Chaiken, 2005). Items which express a behavioural tendency are usually related to the students' intention to follow a particular career or their aspirations to undertake further studies in the subject, or to stop studying chemistry.

A small section of the chemistry survey was dedicated to careers in chemistry and was intended to measure to some extent behavioural responses of students towards this attitude dimension.

The following items formed part of the attitude questionnaire of the chemistry survey and concerned students' behavioural attitudes towards learning chemistry.

D1. I want to pursue further studies in chemistry on leaving the Junior College.

D2. I intend to choose a career / profession involving chemistry upon finishing my studies.

D3. Showing how chemistry relates to everyday life makes me more interested in choosing a career / profession involving chemistry.

D5. I find it hard to imagine myself have a career / profession involving chemistry.

Although there was no direct reference to such a dimension in the stimulus statements used in focus groups, this matter was brought up by students when discussion referred to students' future career aspirations.

### 4.9.6 Cognitive dimension – green chemistry in society (Dimension 6)

The students' evaluative beliefs about green chemistry represent the students' viewpoint about the importance and usefulness of green chemistry particularly after experiencing the green chemistry programme at school. Students' cognitive attitudinal responses towards green chemistry were mainly measured through one of the sections of the chemistry survey and also through focus group discussions which followed the main classroom / laboratory intervention.

The following were the items of the chemistry survey measuring the students' cognitive attitudes towards green chemistry in society.

F4. Green chemistry is just a more catchy term for 'environmental chemistry'.

F5. Green chemistry is a new dimension of environmental chemistry.

F6. Green chemistry tries to prevent pollution before it starts.

F7. Increasing awareness and practice of green chemistry would have a positive impact on the quality of our lives.

F9. Green chemistry is vital in securing a sustainable future for the next generations.

F10. Green chemistry principles address environmental problems by using a new and more effective approach.

F12. Investing in green chemistry research is a safeguard to a healthier future civilisation.

F13. The principles of green chemistry are difficult to apply.

F14. Green chemistry consists of a set of dreams that can never be implemented by the industry.

F15. Green chemistry principles are too expensive to be used widely.

F16. Chemistry can never be rendered 'green' as chemical processes always consume huge amounts of energy and create some form of pollution.

There were also two items in the stimulus statements discussed during the focus group sessions that were related to this dimension of students' attitudes to green chemistry.

S1B. Green chemistry aims to improve safety in human health and the environment.

S3B. Green chemistry safeguards future generations from past mistakes.

### 4.9.7 Cognitive dimension – learning green chemistry at school (Dimension 7)

The cognitive aspect of students' attitudes towards green chemistry theory lessons could be observed through a number of value judgements they made about the learning of green chemistry at school, as expressed by the student participants at the end of the green chemistry intervention. This dimension of students' attitudes could therefore be measured through statements showing for example that students thought that green chemistry was not difficult to understand or that it was different from other topics of chemistry, or that it was more relevant to their lives than other aspects of chemistry, or that they feel it can be taught at lower levels of education.

The following were the questionnaire items linked to this attitudinal dimension.

E1. It is important to start promoting the basic principles of green chemistry in secondary and post-secondary schools.

E2. Green chemistry helps students change the wrong perception of people that chemistry is the main cause of environmental hazards.

E6. It is more important to study the foundations of chemistry than to introduce green chemistry in secondary schools.

E7. Green chemistry is a fundamental area of chemistry and should be considered in future examination syllabi and examination papers.

E8. The best way to introduce green chemistry to A-level students is by studying it as a separate topic.

E9. Green chemistry is ideally integrated in the programme of studies in different stages throughout the A-level programme.

E11. Adding the principles of green chemistry to an already vast examination syllabus would make it harder for students to pass the A-level examination in chemistry.

E12. It is useless studying green chemistry for A-level if there are yet no suitable textbooks and educational resources available.

F8. Learning about green chemistry increases the level of awareness of students about environmental problems.

F11. A sound background knowledge of general chemistry is needed to understand the role of green chemistry.

A good number of stimulus statements were also related to this dimension measuring the students' cognitive attitudes towards learning green chemistry at school. These were:

S9A. Learning chemistry at this level helps students understand better the crucial role of chemistry for a sustainable future.

S2B. Studying green chemistry has become increasingly important.

S3C. With green chemistry students acquire a more positive picture of chemistry.

S4B. Chemistry would become more relevant to us if one understands the basics of green chemistry.

S5B. Green chemistry should only be studied at university level or limited to research work.

S7B. Green chemistry concepts should not be presented as a separate topic but integrated in the main A-level chemistry programme.

S9B. There is room for green chemistry concepts in the A-level chemistry curriculum.

S10B. Green chemistry principles are relatively simple and straightforward to understand.

S11B. Green chemistry should be made compulsory and examinable at sixth form level.

### 4.9.8 Affective dimension – green chemistry theory (Dimension 8)

This dimension of affective attitudes towards school chemistry focusses solely on students' responses towards liking or disliking of the theoretical part of green chemistry as a new aspect of chemistry, which students only had the chance of discovering through the green chemistry intervention forming part of this study. Students were provided with the chance of expressing themselves favourably or unfavourably on learning green chemistry at school both in the chemistry survey and in focus group discussions.

The following were the items related to the measurement of this dimension in the attitude questionnaire forming part of the chemistry survey.

E3. Students are generally more interested in learning about green chemistry than about more traditional topics (of chemistry).

E4. Studying green chemistry makes me more interested in studying general chemistry.

Students were also given the chance to express themselves on this dimension during focus group sessions by debating the following statements.

S6B. Green chemistry gives an extra motivation to students to study and specialise in chemistry.

S8B. Chemistry would become increasingly popular with the inclusion of green chemistry topics.

### 4.9.9 Cognitive / affective dimension – green chemistry practical work (Dimension 9)

Having had the opportunity to carry out some experiments in green chemistry, students were also in a position to express themselves on their liking or disliking of practising green chemistry in the school laboratory as part of the A-level curriculum. This is another dimension of attitudes to science which was never measured before this study. Once again, participants of this project were given the chance to respond to a number of questions particularly in the chemistry survey and focus groups, related to their first green chemistry laboratory experience.

The questionnaire items (of the chemistry survey) concerning this attitudinal dimension were:

E5. Practical work can be more useful and interesting if designed to illustrate green chemistry principles.

E10. The best way of demonstrating green chemistry principles is by designing relevant practical sessions.

Reference to green chemistry practical sessions was also made during free discussion of different focus groups with the following serving as the stimulus statement measuring this dimension.

S12B. One concrete way of illustrating green chemistry principles is by introducing green chemistry experiments in the A-level chemistry programme of studies.

### 4.9.10 Behavioural dimension – studying green chemistry (Dimension 10)

This last dimension was included to seek any connection between learning green chemistry concepts and any action tendencies of students as a reaction to the classroom / laboratory intervention. There was some reference to this dimension in the free discussion held during some of the focus group sessions. However the main item measuring this attitudinal dimension was included in the chemistry survey attitude questionnaire.

D4. Studying green chemistry makes me more interested in choosing a career / profession involving chemistry.

## 4.10 Assessing Knowledge & Level of Understanding of Green Chemistry

The study also attempted to investigate students' knowledge of green chemistry and the ability to understand some of the basic concepts of green chemistry. It aimed to address the following research sub-question:

> *"What understanding of green chemistry ideas is developed by students who do, or do not experience the green chemistry intervention?"*

The research instruments used to collect data relevant to this aspect of the study were:

- a fifteen-item questionnaire (part B of the chemistry survey) which was applied to both student groups before and after the intervention;

- a set of worksheets and laboratory handouts which included a number of open-ended questions and calculations, each being assigned at the end of a green chemistry seminar or laboratory session;
- separate focus groups involving students from both classes (GC and non-GC groups).

The framework used to extract (and help in the analysis of) data related to students' knowledge / understanding aspect of green chemistry consisted of the same list of statements created by Anastas and Warner to delineate the twelve fundamental principles of green chemistry (Anastas & Warner, 1998). In fact questionnaire B was specifically designed to cover some aspect of each of these principles of green chemistry which were introduced in 1998 and which are still considered as the golden rules for understanding and practising green and sustainable chemistry. On the other hand each worksheet (learning resource) was designed in the form a short exercise on some area of green chemistry covered during the intervention seminars. The laboratory reports related to green chemistry experiments also included questions seeking to assess further the students' ability to understand and recall basic facts on green chemistry.

The students' responses in part 2 of the chemistry survey (questionnaire B) were analysed using the assessment criteria (or evaluation scheme) described in table 4.12, adapted from Çalik and Ayas (2005) who studied the level of understanding of secondary (eight grade) Turkish students and science student teachers, of a number of chemistry concepts. These criteria were used to classify students' responses in the pre-test and post-test survey and compare the knowledge gained and level of understanding between the two groups. Scores obtained using similar criteria were also used by other researchers in the assessment and analysis procedure for statistical analysis (Abraham, Willamson & Westbrook, 1994; Haidar & Abraham, 1991).

**Table 4.12**

**Criteria for Assessing Knowledge & Level of Understanding of Green Chemistry Concepts**

| Level | Criterion Code | Criterion Description |
|---|---|---|
| 4 | Sound Understanding **(SU)** | Responses that included all components of the acceptable response; OR a correct calculation. |
| 3 | Partial Understanding **(PU)** | Responses that included at least one of the components of an acceptable response; OR a correct calculation with a minor mistake in values. |
| 2 | Partial Understanding with Specific Alternative Conception **(PUSA)** | Responses that showed understanding of the concept but also made a statement which demonstrated a misunderstanding or incomplete understanding; OR correct calculation using incorrect values. |
| 1 | Specific Alternative Conception **(SA)** | Responses that included illogical / incorrect / incomplete information on chemistry / green chemistry, but still contained a hint of the correct answer; OR attempted calculation using some correct values. |
| 0 | No Understanding **(NU)** | Repetition (rephrasing) of question; completely irrelevant or unclear response; blank space (no response); OR wrong calculation using wrong values; wrong answer with no working. |

*Adapted from Çalik and Ayas, 2005*

Students were also asked to express how confident or unconfident they were to answer each of the first 12 questions, according to the following five-point Likert-type scale.

**Table 4.13**

**Students' (Self-Assessed) Levels of Confidence**

| Confidence Level | Description |
|---|---|
| 5 | Very confident |
| 4 | Confident |
| 3 | Neither confident nor unconfident |
| 2 | Unconfident |
| 1 | Very unconfident |

The students' answers in the worksheets, the laboratory reports and the presentations made during the students' seminars, which reflected the effort by small groups (teams) of the GC participants rather than by the individual students, were analysed differently by assigning a raw mark for every exercise, according to a specific mark scheme. This mark was then standardised and converted to a ten-point score for comparison purposes.

## 4.11 Reliability and Validity of Research Instruments & Data Analysis

This section describes the steps taken to ensure reliability and validity of both the data collection instruments used and of the analysis of data generated from the same instruments.

### 4.11.1 The terms 'Reliability' and 'Validity'

The term reliability has been defined as 'the extent to which a test or procedure produces similar results under constant conditions on all occasions' (Bell 2006). Yin (1994) suggests that reliability shows that 'the operations of a study such as data collection procedures, can be represented with the same results'. According to Lincoln and Guba (1985) reliability is not the right term to apply in the case of qualitative research and better alternatives would be terms such as ‘consistency’ , ‘credibility’ and ‘trustworthiness’.

Validity is more complex as a concept and determines ‘whether an item or instrument measures or describes what it is supposed to measure or describe’ (Bell 2006). It is concerned with the closeness or accuracy of what is being measured with respect to what on intends to measure (Roberts, Priest & Traynor, 2006). Literature suggests that reliability is a necessary but insufficient condition to satisfy validity.

#### 4.11.2 Reliability and Validity of the Chemistry Survey Questionnaires

Two questionnaires were used in the data collection stages of the research investigation. One questionnaire attempted to access the students’ different aspects of chemistry and green chemistry (both in society and in school) while the other concerned students’ knowledge and understanding of some of the main concepts of green chemistry.

Both questionnaires in the chemistry survey were designed and word-processed by the researcher following as closely as possible the guidelines found in the literature (Cohen et al, 2010; Bell, 2006). The contents were seen and approved by the University of York ethics committee and discussed with the other members of the advisory board prior to being piloted with a class of thirty eight A-level chemistry students attending the same college, and with similar characteristics to the students participating in the main study. The wording of the questionnaire items were all checked to avoid ambiguity, imprecision, assumption or double questions, leading questions, presuming questions, hypothetical questions, complex questions, irritating questions and questions that offend or contain sensitive issues or the use of unfamiliar jargon. It was also ensured that all questions were worded using simple language to facilitate understanding by respondents. An effort was also made in the design of questions / statements to make sure that the questionnaire items used in the chemistry survey would get the same or similar responses if carried out by another researcher.

During the pilot study students were asked to complete a separate form giving feedback on each questionnaire. This feedback form asked students the time it took them to complete the questionnaire, whether the instructions were clear, whether there were any vague questions, whether they objected to any part of the questionnaire, whether they thought any major aspect was left out, whether they liked the layout and whether they had any general comments to make on the whole exercise (Bell, 2006). The feedback received was vetted but no major suggestions were made to change and / or improve the questionnaire apart from some minor changes in the choice of words in some of the statements and in layout details.

The reliability of the first questionnaire regarding the students' attitudes was subjected to a statistical procedure known as Cronbach's alpha coefficient (Cronbach, 1963), using the SPSS (statistical package for the social sciences) software package. This is a 'split-half' test of reliability consisting of the random splitting of all responses into two sets, counting the scores of the two sets and estimating the correlation between the same two sets of values. This reliability test was used to assess the internal consistency between a number of related items in part A of the chemistry survey. Cronbach's alpha has an upper-bound value of 1.0 but is unbounded from below. A Cronbach's alpha coefficient exceeding 0.7 indicates excellent internal consistency. A value within the range of 0.5-0.7 indicates acceptable internal consistency, while Cronbach's alpha lower than 0.5 indicates questionable internal consistency.

Such a reliability test was carried out using post-test pilot data, on 40 out of 48 items (i.e. on 83.3%) of the attitude questionnaire (i.e. sections B to F of the first part of the chemistry survey), which covered eight out of the 10 dimensions of the theoretical framework used to analyse such data. Each dimension (sub-scale) was measured by averaging the rating scores provided for respective items after reverse-coding of a limited number of negatively worded items. Section A of the questionnaire included only personal details on students while six items were dropped because of poor correlation with the other items.

The results of Cronbach's alpha reliability test conducted on data from part A of the chemistry survey are displayed in the form of tables in *appendix 32*. The reliability test for the attitude questionnaire gave acceptable values of Cronbach's alpha coefficient based on standardised items (with coefficient exceeding 0.700 in all cases measured) and this meant that the instrument used had internal consistency and was reliable. It was decided that the items that were not considered for the test would still be retained in the questionnaire for the main study to give complimentary / additional information on the students' attitudes considering also that this study was mostly based on qualitative rather than quantitative treatment of data. The two dimensions (i.e. dimensions 4 and 10) upon which Cronbach's alpha test was not performed was each represented by a single questionnaire item.

The reliability of the second questionnaire regarding students' knowledge and understanding of green chemistry was ensured by using the established (widely accepted) twelve principles of green chemistry in the design of the first twelve (out of a total of fifteen) questions in section B, with section A reserved again for personal information on the respondent. Therefore each of the first twelve questions was linked to one of the key principles of green chemistry in order to ensure that most of the aspects of green chemistry are covered in this instrument. The last three questions asked students to explain the term 'green chemistry' in their own words, to explain briefly any three of the principles of green chemistry and to describe a concrete example of how society can benefit from green chemistry. Data generated from this questionnaire was then analysed using a five-point scale based upon criteria adapted from Çalik and Ayas (2005) as described earlier.

Reliability and validity of both questionnaires in the chemistry survey were improved through piloting and subsequent revision of the instruments following the feedback of participants of the pilot study (which was carried out with a similar group of students in an identical setting) and the advice from the supervisor and a colleague teacher at work. In fact the student feedback on the understanding of the questionnaire items / statements, both in the pilot study and main study, indicated a high degree of validity of this instrument.

### 4.11.3 Analysis of Data from the Chemistry Survey Questionnaires

Once the chemistry survey was completed and all questionnaires collected, the researcher carried out a preliminary analysis of all data collected. In the case of the attitude data, this consisted in converting data first into tables and then into bar charts and pie-charts to facilitate comparisons and basic statistical analysis (percentages, means and standard deviations). In the case of the understanding data generated by the second questionnaire, these were transcribed by the researcher, stored in an electronic format and then evaluated on the basis of the five-point criteria as explained earlier. All data generated by the chemistry survey was double-checked by a colleague member of the staff in an effort to improve further the reliability of analysis.

Quantitative data was processed by the researcher using the Excel programme. This helped to check that the data scores transferred to the spreadsheets tallied with the actual scores of data present in the hard copies of the completed questionnaires. The Excel programme was deployed to calculate percentages, mean scores and graphical representations (e.g. bar charts and pie-charts) which helped in the interpretation of results. The Excel software also helped to enhance the validity in the analysis of data gathered by the questionnaires.

The quantitative data gathered from this instrument were subjected to a number of statistical tests. These included the **Kolmogorov-Smirnov** and the **Shapiro-Wilk tests** which were both used to assess the normality assumption of the rating score distribution of each item within each questionnaire which formed part of the chemistry survey. The null hypothesis for these tests specifies that the rating score distribution is normal and is accepted if the p-value exceeds the 0.05 level of significance. The alternative hypothesis specifies that the rating score distribution is skewed (i.e. non-normal) and is accepted if the p-value is less than the 0.05 criterion. It turned out that all p-values obtained from the Kolmogorov-Smirnov and Shapiro-Wilk tests were less than 0.05, indicating that all the rating score distributions were skewed and did not follow the normality assumption. This applies to both the 'attitudes' (part A of survey) and 'understanding' (part B of survey) data. This determined the use of non-parametric tests in the quantitative analysis of data obtained from the chemistry survey. The results of these tests of normality are shown in *appendices 26, 27 and 28*.

The **Mann-Whitney U test** (or MW test) was then applied to compare mean rating scores between the two independent participating sets of students (i.e. the GC and non-GC groups) once it was established that the rating score distribution was skewed. The null hypothesis in this test specifies that the mean rating scores vary marginally between the two groups and is accepted if the p-value exceeds the 0.05 level of significance. The alternative hypothesis specifies that the mean scores vary significantly between the two groups and is accepted if the p-value is less that the 0.05 criterion. The MW test is a non-parametric alternative to the independent samples t-test.

The data from the chemistry survey was also subjected to the **Wilcoxon Signed Ranks test** (or WSR test) in order to compare mean rating scores of each group of students before and after the green chemistry intervention. In this case, the null hypothesis specifies that the mean rating scores vary marginally between the pre- and post-evaluations and is accepted if the p-value exceeds the 0.05 level of significance. The alternative hypothesis of this test specifies that the mean rating scores vary significantly between the pre-test and post-test and is accepted if the p-value is less than the 0.05 limit. The WSR test is a non-parametric alternative to the paired samples t-test.

Results of the Mann-Whitney tests and Wilcoxon Signed Ranks tests on the 'attitudes' and 'understanding' data generated by the chemistry survey are shown in *appendices 30-31* and *38-41*, and commented upon in the analysis chapters.

A further Mann-Whitney test was then carried out using the difference between the 'understanding' data scores per student between the pre-test and post-test, comparing the averages for these differences between the GC and non-GC group, after confirming that such data did not following the normal distribution. The normality test output on such data is shown in *appendix 29*, while the results of this MW test are shown in *table 9.3*.

The analysis of part A of the chemistry survey (on students' attitudes) is discussed in chapters 7 and 8, while part B (on understanding of green chemistry concepts) is discussed in chapter 9.

#### 4.11.4 Reliability and Validity of Focus Groups

In all, seven focus group sessions were held once the green chemistry intervention was over. Four of the focus groups were held with the GC participants (representing 100% of the GC group) while the other three involved two thirds (i.e. 66.7%) of the non-GC group. Six of the focus groups were made up of seven or 8 students while one of the non-GC focus groups included 10 students. The choice of students forming each group was done on a random basis (depending mostly on their availability to attend the session) and one of the GC groups turned out to be all-female. This was almost inevitable due to the higher ratio of female to male students in the GC class.

In the case of qualitative research, reliability is regarded as a measure of trustworthiness of the procedures used and data generated (Stiles, 1993). It ensures that the results of a study are repeatable in different circumstances (Bryman, 2001). One of the measures taken to ensure reliability is to draw up a list of stimulus statements related with the research questions and use them in three pilot focus group sessions. The stimulus statements were meant to form the basis of the discussion held in each focus group. All statements were previously discussed with the other members of the thesis advisory panel. Reliability of focus groups was enhanced through careful piloting which served to gain feedback from students on the statements used to instigate the discussion but also to gain experience (training as an interviewer) on how to conduct and manage a small group interview.

All focus group sessions were recorded on a digital voice recorder (with the prior consent of all participants) which was the same device used in the pilot study. Once all focus group interviews were concluded, the recordings were translated from Maltese to English (unless the participant chose to speak in English) and simultaneously transcribed so that most of the data would be available in printed form and ready for processing. Cohen et al. (2010) explains that many experienced researchers strongly recommend that all voice-recordings should be transcribed so that transcriptions are made available for scrutiny if the need arises. Both the digital voice recordings and the transcript version of the focus group discussions were stored electronically for immediate reference and retrieval of data. A hard copy of the transcribed conversations was also forwarded to the supervisor and another copy served as a working document to be immediately available for the researcher during the data analysis process. It is thought that the tape-recording of interviews such as focus groups and the related transcripts help to improve reliability even though transcripts may omit some important non-verbal expressions made during the session (Peräkylä, 1997). An attempt was made during all sessions to capture some of the subtle expressions using notations which record instances such as pauses, emphases, laughter and interruptions. Reliability was further increased by ensuring technical accuracy in recording of all sessions and especially during the process of transcribing.

As expected, preparing the full transcripts of all seven focus group sessions turned out to be a time-consuming exercise. However this had its own benefits, the main one being that it minimises bias which could have resulted from being selective in transcribing only parts of the conversations involved. Bias has been defined by Lansing, Ginsburg & Braaten (1961) as “a systematic or persistent tendency to make errors in the same direction, that is, to overstate or understate the ‘true value’ of an attribute.”

In order to avoid bias and ensure a high degree of validity, the researcher made an effort to be as clear as possible in the wording of the stimulus statements and as accurate as possible in the translation and transcription of all focus group discussions. Bias was also minimised by means of respondent validation whereby students were given the chance to check for themselves and give feedback of the faithfulness of the relevant transcribed focus group account.

One additional advantage of a full focus group transcript was that it made it easier for full quotations to be made and for the data to be transferred and processed in a faster and more efficient way using a computer assisted qualitative analysis software (CAQDAS) package such as Atlas.ti which was used on this occasion. The use of the Atlast.ti package was another way of enhancing reliability by making use of the rules built into the same programme (Roberts & Woods, 2000; Robson, 1994).

Having all focus group sessions transcribed into a printed form allowed also the researcher to go over the discussions several times to the point of being “immersed” in the data as suggested by several authors such as Miles and Huberman (1994) and Roberts et al (2006). The length of time dedicated to the translation and transcription process allowed also the researcher to be as accurate as possible in presenting and quoting data and this increased reliability of the same data. The researcher sought help of his wife (an assistant headteacher of a primary school) and his eldest daughter (a university student) to solve /

interpret the difficult parts of the conversations that took place during the focus groups, especially in situations such as when a voice became muffled or faded, or when two or more voices crossed each other.

#### 4.11.5 Analysis of Focus Group Data

The first stage of analysis of data generated from focus groups involved assigning of codes to pieces of data by going through the transcript of each focus group conversations and repeating the process several times. Oppenheim (1992) warns that inconsistent coding of responses during data analysis could be another possible source of bias in interviews such as focus groups. Hence coding of data was rehearsed with the pilot focus group transcripts and then applied scrupulously with the main focus group transcripts.

The initial coding process represented the first attempt in the categorisation of data and was facilitated with the use of the Atlas.ti computer software package, which proved to be extremely useful with the rapid retrieval of coded data and the subsequent clustering phase. Clustering involved the grouping of codes related to a particular aspect of the research question and categorising these clusters according to the structure of the theoretical framework of analysis used in this study. Once coding was complete, certain patterns could be observed and themes starting to emerge and eventually be developed into generalisations. The entire coding process was repeated all over again in a few months' time in order to improve reliability of the method. This is confirmed by Roberts (1999) who suggests that one particularly reliable approach to handling of qualitative data is to create codes and then confirm them by revisiting previously coded data periodically to check whether these become stable over time. The second round of coding resulted in very similar categories and only required minor changes from the original version.

Another measure taken, possibly the most effective one, to enhance the validity of qualitative research was triangulation which is the concurrent use of other methods of data collection such as questionnaires, the use of the personal research diary and published literature. Triangulation is thought to assist with consistency, comprehensiveness and robustness of the study (Roberts et al, 2006). Yet another way to improve validity during data analysis was the continuous effort of the researcher to remain as objective and as disinterested in the interpretation of data as possible. Some qualitative researchers claim that it is practically impossible to remain completely objective or detached from the research process (Guba & Lincoln, 1981; Stiles, 1993). However it is still important that the research process is transparent to enable reader to follow all the decision processes related to various stages and aspects of the study (Roberts et al, 2006).

The analysis of focus group data is discussed in detail in chapters 7 and 8.

## 4.12 Strategy applied in Data Analysis

The data that emerged from *part A of the chemistry survey* was first analysed using descriptive statistics. This exercise helped in organising and describing the basic features of the attitude data gathered in this study. On the other hand, the qualitative attitude data generated by the *focus groups* was first coded with the aid of the Atlas.ti computer software package as explained earlier. These codes were then clustered and converted into categories, giving rise to a number of themes which were mapped out against the various attitudinal dimensions of the theoretical framework created specifically to analyse such data.

Complete analysis of the attitude data was eventually carried out by describing how the emerging themes helped in defining the separate dimensions, which in turn qualify the four main types of students' attitudes (see section 4.9) towards chemistry in general and green chemistry in particular. Any attitudinal changes indicated during the qualitative analysis of focus group discussions were subsequently compared with the results of qualitative analysis of the first questionnaire of the chemistry survey. Reference was made both to descriptive statistics and inferential statistics to highlight any important / significant differences observed between the attitudes held (at the same point in time) between the attitudes of the two groups of students participating in the study.

Data collected from *part B of the chemistry survey* was mainly qualitative and was first processed using a number of assessment criteria as explained in section 4.10. The quantitative data which resulted from such a preliminary analysis was then subjected to a statistical analysis to compare the students' performance in this part of the chemistry survey before and after the classroom / laboratory intervention, with respect to their knowledge and understanding of green chemistry concepts as laid out in the original twelve principles formulated by Anastas and Warner (1998). All questionnaire items in part B of the survey were then analysed separately, continuously comparing the students' responses before and after the intervention and integrating findings with the results of the statistical analysis (of the quantitative data) to determine whether or not any observed variations (within each group of students) were to be regarded as statistically significant. Inferential statistics were also used to confirm or otherwise any significant differences in the responses given by the two sets of participants particularly at the end of the curriculum intervention.

## 4.13 Limitations in Research Procedures and Data Collection

The technique used in this research inquiry imposed a number of limitations on the type and amount of data that could be collected and documented. The following points summarise some of the main difficulties encountered in the use of research instruments for data collection during the main research study.

### 4.13.1 Sample Chosen

This case study investigation was carried out on a class of first year sixth form students whilst following a course in A-level chemistry at the Maltese sixth form college during academic year 2009-10. The group (GC class) could be described as an opportunistic sample of students as it was chosen by the subject coordinator (head of department of chemistry) who is the person authorised to assign classes and duties to the lecturing staff at the beginning of the year. The group chosen might not have been a true reflection (i.e. a representative sample) of the entire cohort of A-level students attending the same institution, in terms of intellectual skills and academic abilities. The same applies to the choice of the other class (non-GC class) which served as a 'control' of the 'GC group'.

### 4.13.2 Potential Gender Bias

Another problem was the overrepresentation of female students in the main sample (GC group) chosen, which might have introduced some kind of bias in the data that was eventually collected. In fact college statistics of the 2009 intake of students show that the total number of chemistry students choosing A-level chemistry was divided into 89 males (40.3%) and 132 females (59.7%). This means that the GC group was significantly under-represented by male students (with only 7/31 or 22.6% of class population being males). In contrast, the non-GC group was overrepresented by males (with 18/36 or 50% of class population). With the exception on one focus group (which happened to be all-female), all other groups / teams participating in this project included both male and female representatives. To avoid any gender bias, no questions or statements made at the data collection phase made any reference to gender differences.

### 4.13.3 <u>The Hawthorne Effect</u>

One other limitation of this study was the possible occurrence of the Hawthorne Effect where 'human subjects of an experiment change their behaviour simply because they are being studied' (Cohen et al, 2010). In this project, members of the GC group were very much aware that they were being observed and studied for doing something different and so they could have modified their behaviour in a number of ways. Shuttleworth (2014) suggests that the Hawthorne effect (similar, in a way, to the placebo effect in medicine) constitutes an unavoidable bias (reducing validity) that the researcher must be aware of when analysing data. It is very difficult to quantify the change in behaviour when human research subjects are aware that they are part of an experiment. This issue was partly addressed by employing the control (non-GC) group in the study. This group of students did not receive the same green chemistry treatment as the GC group. In a way the non-GC control group also knew that it was being observed (in the pre- and post-intervention stages) and was expected to exhibit similar changes in behaviour as the experimental group, therefore minimising the Hawthorne effect.

### 4.13.4 <u>Time-Table Limitations</u>

The choice of the extra slot in the students' time-table at the beginning of the year, to be able to organise the green chemistry activities forming part of the intervention, was far from ideal. In fact while showing interest to participate in the project, the students were quite reluctant initially to give away the only free hour available on a Wednesday morning to have an additional chemistry commitment, almost on a regular basis. Unfortunately this turned out to be the only possible solution which could be negotiated when students' and teacher's time-tables were considered. This made the green chemistry commitment be initially viewed by some of the participants as being an extra burden adding extra pressure on their loaded time-tables. However with time, students got used to the idea of the green chemistry commitment and none of the students objected to the extra time-table 'burden'.

### 4.13.5 Limited Time for Students' Activities

One other drawback in the main study was the lack of sufficient time for students to be able to give feedback during the seminars. In fact in most occasions, participants did not have enough time to finish off the activity/worksheet that was originally planned to be a form of class assignment. The seminars turned out to be so intense that such work had to be given out in the form of a short homework to be completed by the next session. This might have affected the way students worked to produce their responses (which were aimed to reflect a team effort).

### 4.13.6 A Moral Dilemma

One ethical problem encountered usually in educational research using an experimental style is the use of control groups in curriculum innovation. In such situations, the teacher-researcher is always faced by a dilemma on the use of a control group if this is deprived from the potential benefits of being taught extra knowledge / skills with respect to another group concurrently placed in the same setting.

Although this research investigation was not experimental in approach, the use of a second group of students as a means of control to compare attitudes and other characteristics with those of the main GC group gave rise to a similar moral dilemma. In fact the author found it hard to invite students to participate in the project without being given the chance to experience the same curriculum innovation of the other group.

Other limitations of the research instruments and data collection would be dealt with throughout the rest of the thesis.

## 4.14 Chapter Summary

This chapter describes the methodology adopted by the researcher to collect and analyse data from two groups of chemistry students (the main GC class and the control non-GC class) following a course of studies in a sixth form college, as part of this research project.

The author explains how the major decisions, which were illuminated by various sources of literature, were taken to choose the research strategy, the instruments used to extract data and the approach to be followed to analyse the data gathered from the same student participants. The chapter describes also the sample of students taken for this investigation, the setting of the study and the way the intervention package was designed and piloted during academic year 2008-9. The author also explains in detail the way the research instruments were developed, piloted, and improved upon prior to being applied in the main study during year 2009-10 in order to gather enough data (from the students) to be analysed and address the research questions. A section of the chapter was dedicated to the approach chosen to evaluate the green chemistry intervention package. Other sections described how the theoretical framework for data analysis was developed and used to analyse the attitude data, as well as the technique employed to assess students' understanding of the green chemistry concepts. The author also gave an account or the measures taken to safeguard and enhance reliability and validity of methods of procedures adopted during data collection and data analysis.

The last section discusses some limitations of the study particularly in the use of research instruments for data collection despite the efforts made by the research to eliminate bias and remain as impartial, consistent and objective as possible throughout the entire investigation.

# Chapter 5

# THE GREEN CHEMISTRY INTERVENTION PACKAGE (THE INTENDED CURRICULUM)

## 5.1 Introduction

Research suggests that students are particularly interested in those aspects of science which are mostly relevant to their everyday lives. Other research shows that teaching of chemistry concepts at post-secondary level would be more effective if related to daily life situations. Students are found to be particularly engaged in science, and chemistry in particular, when learning about the chemistry of the environment as it is one of those aspects which they regard as relevant to their lives.

Maltese students who enrol in the A-level chemistry programme at the Maltese sixth form college already have some background of environmental chemistry as this forms part of their O-level examination syllabus and is therefore covered during their three-year chemistry programme of their secondary education. The chemistry students' interest in environmental issues is not likely to develop further at post-secondary level as curricular references to environmental topics are rather limited and isolated.

The main idea behind this 'green chemistry intervention' was therefore to exploit such a 'green vacuum' in the local A-level curriculum to introduce new environmentally-related chemistry concepts in the curriculum, under the framework of green or sustainable chemistry. This is not the same as expanding on basic ideas of environmental chemistry.

The challenge was to use the platform of environmental chemistry in order to gauge the students' disposition to learn about green chemistry which is an innovative way of doing chemistry showing maximum respect towards human health and the environment of present and future generations.

## 5.2 Objectives and Learning Outcomes

The main goal of the classroom & laboratory intervention in green chemistry was that A-level students studying chemistry at post-16 would gain a general idea about green chemistry and recognise its important role in the sustainability of the world. Hence the intervention was designed so that students would understand the essence of green chemistry and appreciate how the concept which originated in the US in the 1990s evolved slowly but steadily and was diffused in different parts of the world until it became established as a new distinct area of science. It is expected that through this programme, students would realise that green chemistry now represents the reaction of the worldwide chemistry community, including chemistry educators, to the growing public concern on pollution and other environmental problems frequently associated with the mounting activity of the chemical industry and of other related industries.

The intervention aimed to show students that applying green chemistry involves doing chemistry in a safer and more sustainable way by making the right decisions as early as at the planning stage of a chemical reaction or process. Students would learn that green chemistry eliminates waste, safeguards human health and the environment and avoids committing any of the past mistakes which resulted in gross environmental disasters. The activities forming part of the intervention package were also planned in such a way that students could relate green chemistry to other topics of the school chemistry curriculum but also to their everyday life. Students would also be able to realise that green chemistry is not only based on sound chemical theory but is also feasible on many counts (e.g. environmentally, economically and socially) and hence truly sustainable.

The programme (curriculum innovation) seeks to equip the students with sufficient background knowledge and some basic laboratory experience on the emerging field of green chemistry, in order to enable the researcher to look into any changes in students' attitudes and understanding upon completion of the intervention. The following table summarises the main learning objectives and intended learning outcomes of the main green chemistry intervention.

**Table 5.1**

**Main Objectives and Intended Learning Outcomes of the Green Chemistry Intervention**

**Main Objectives**

1. Introduce green / sustainable chemistry to sixth form students presenting it as alternative way of doing chemistry, emphasizing safety and pollution prevention.
2. Explain the key principles of green chemistry and show how these can be applied to safeguard human health and the environment.
3. Relate aspects of green chemistry to the traditional concepts of chemistry.
4. Relate green chemistry to real life situations.
5. Demonstrate the application of some of the principles of green chemistry in the school laboratory through green chemistry practical sessions.

**Intended Learning Outcomes**

1. Students are able understand some of the basic ideas and values of green chemistry.
2. Students recognise the positive impact of green chemistry on humanity.
3. Students become conversant in the various terms and aspects of green chemistry.
4. Students are able to relate applications of green chemistry with everyday life.
5. Students experience the application of some of the basic principles of green chemistry in the school laboratory.

## 5.3 Designing the Green Chemistry Intervention Package

The green chemistry intervention package was designed after having consulted a body of literature on the emerging field of green chemistry and on the parallel developments in green chemistry education. A number of O-level and A-level chemistry examination specifications have also been reviewed for any direct or indirect references to concepts of environmental chemistry and green chemistry. This exercise resulted in the identification of a short list of areas of focus that could possibly be presented to a sixth form audience of students in a series of presentations dedicated solely to the introduction of green chemistry. Such areas of interest were chosen primarily as they could easily be related to the students' everyday lives but also to fundamental concepts of chemistry covered throughout the A-level curriculum.

The following were the main areas of focus which were originally shortlisted for the pilot intervention.

### 5.3.1 The Green Chemistry Principle of Atom Economy

Atom economy is a major green chemistry originated by Barry Trost (1991), a professor of chemistry at Stanford University, USA, in 1991, in a bid to design chemical processes which make better use of the raw materials and create less by-products and waste. Atom economy is one way of measuring the efficiency of a chemical reaction. It was thought that this key principle of green chemistry could easily be linked with the section of the A-level curriculum dealing with moles and stoichiometry and particularly with the concept of percentage yield with which students were already accustomed.

### 5.3.2 Renewable Energy from Fuel Cells

This theme was chosen to illustrate an example of a renewable source of energy which uses hydrogen or a hydrogen-rich fuel without polluting, given that the only product of the electrochemical process involved is warm water. Such a theme could be related to the traditional chemistry concept of oxidation and reduction, together with important applications of such reactions in redox potentials and electrochemical reactions, all forming part of the A-level chemistry programme.

### 5.3.3 Liquid or Supercritical Carbon Dioxide as a Green Solvent

The use of liquid or supercritical carbon dioxide is making its way in industry, to replace other toxic and hazardous organic solvents in processes such as dry-cleaning operations, extraction of essential oils and decaffeination of coffee. So this theme has been chosen as an example of a green solvent, i.e. a solvent that is non-toxic, non-hazardous and non-polluting. The preparation of liquid or supercritical carbon dioxide involves a reference to phase diagrams which students usually encounter at a later stage of their A-level chemistry course as part of the topic ‘phase equilibria’.

### 5.3.4 Designing for Plastic Material for Degradation

Biodegradable plastic consists of a material produced mainly from plant-based products (renewable resources) which is degraded by the action of microorganisms which convert them into harmless substances. This topic was chosen to illustrate the green chemistry principle of biodegradability and relate it to the section of the chemistry A-level curriculum dealing with polymers and polymerisation reactions. This section of the local curriculum already makes reference to biodegradable polymers but makes no connection of their environmental credentials with any green chemistry principles involved in its production, use and disposal.

### 5.3.5 Biodiesel from Vegetable Oil

Biodiesel was chosen as a typical example of a home-grown 'green fuel' that is produced from a renewable resource and is less polluting than petroleum-derived diesel. The synthesis of biodiesel involves converting vegetable oils (triglycerides) into a liquid mixture known as 'fatty acid methyl esters' (FAMEs). The 'green' process which synthesizes biodiesel involves a chemical change known as the 'transesterification reaction'. A-level students would already be familiar with the group of organic compounds known as esters which are produced by a reaction known as 'esterification'. Biodiesel consists of a mixture of esters produced by a somewhat similar reaction and hence students would already be equipped with some groundwork to this theme thanks to their basic knowledge of organic chemistry.

### 5.3.6 Bioethanol from Carbohydrates

The synthesis of bioethanol is another 'green process' which students would have already treated to some extent when learning on the chemistry of fermentation reactions which produce alcohol. Bioethanol is another biofuel which is used as a petrol substitute for road transport vehicles. It is produced by fermentation of sugar obtained from energy crops or from organic waste (biomass). This theme has the potential to illustrate a number of green chemistry principles such as the use of renewable raw materials, biocatalysis (catalysts preferred from stoichiometric reagents) and energy efficiency.

Since the research investigation required collection of data from students particularly before and after the intervention, it was also decided that the presentations would be made in a series of classroom seminars dedicated entirely to green chemistry, spreading them over a number of weeks, rather than integrating the green chemistry topics in different parts of the two year A-level curriculum  This approach was chosen to keep the focus on green chemistry and cover as many aspects as possible in a limited time without interfering with the official examination oriented chemistry curriculum.  It was also decided that students would be given the chance to apply the principles of green chemistry in practice through a laboratory session including an experiment based on theory previously explained and discussed in class.  The green chemistry experiment planned for the pilot intervention involved the synthesis and analysis of biodiesel.

The intervention package allowed also space for students to explore green chemistry further by researching in small groups a specific area of green chemistry and presenting their work in one of a number of student seminars.  This was done in order to further gauge the students' interest in green chemistry and evaluate their level of understanding of green chemistry concepts to which they were being introduced.

The following table (table 5.2) summarises the main activities planned for the pilot green chemistry intervention.

**Table 5.2**

**Pilot Green Chemistry Intervention Plan**

| Session | Duration | Theme & Brief Description |
|---|---|---|
| 1 | 1 hour | **General Introduction to Green Chemistry**<br>Lecture / presentation introducing the definition, aims and an explanation of the basic principles (with some applications) of green chemistry. |
| 2 | 1 hour | **Green Chemistry and Atom Economy**<br>Lecture / presentation / activities illustrating the green chemistry principle of **'atom economy'** and hence stressing the minimisation of waste products. This is to be linked to curriculum topic of mole concept and stoichiometry. |
| 3 | 1 hour | **Green Chemistry and Fuel Cells**<br>Lecture / presentation / activities illustrating the green chemistry principle of **'energy minimisation'**. Topic is to be related to the chemistry of redox reactions and electrochemistry. |
| 4 | 1 hour | **Green Chemistry and Liquid Carbon Dioxide**<br>Lecture / presentation / activities illustrating the green chemistry principle of **'using harmless solvents'**. Theme shows the unusual role of carbon dioxide as a green solvent. The session is to be linked to the second year topic dealing with phase equilibria but is also associated with other topics such as gas laws and the kinetic theory. |
| 5 | 1 hour | **Green Chemistry and Degradable Plastics**<br>Lecture / presentation / activities illustrating the green chemistry principle of **'designing for degradation'**. This is to be linked to the theory on polymerisation reactions and properties of plastics. |
| 6 | 1 hour | **Green Chemistry and Synthesis of Bioethanol**<br>Lecture / presentation / activities illustrating the green chemistry principle of **'using catalytic reagents'** and the **'use of renewable resources'** to produce clean energy. This is linked to the curriculum topic: chemistry of alcohols. |
| 7 | 3 hours | **Green Chemistry and Biodiesel**<br>Practical / presentation / activities illustrating the green chemistry principle of **'using renewable resources'**. Students will experience the green synthesis of biofuel from renewable resources. This session may be also be linked to the chemistry of alcohols and the chemistry of hydrocarbons, citing the composition of biodiesel as a substitute to diesel (produced by fractional distillation of petroleum). May also be linked with the second year topic: chemistry of esters. |
| 8 | 3 hours | **Student Seminars**<br>Three sessions for student presentations of various aspects of green chemistry prepared by 12 different groups of students. |

## 5.4 Developing Educational Resources for the Pilot Intervention

A number of educational resources were prepared in order to make each presentation more effective. These consisted in a series of slide shows (PowerPoint presentations), short video clips and handouts containing relevant information, references for further reading and a list of associated chemistry topics forming part of the A-level curriculum.

A students' activity worksheet was also designed in order to be discussed and filled in by the students at the end of each presentation. These worksheets were meant to stimulate student participation but also to serve as an immediate student feedback to the tutor by the end of each green chemistry seminar. One of the worksheets consisted of a list of guidelines for the student presentation seminars.

One of the first activities planned for the pilot intervention was a slogan competition between the twelve groups of participants. This was done in order to test the extent to which students were able to understand, right from the very beginning, the gist of the green chemistry principles by inviting each group to rephrase one of the 12 statements into a short expression which captures the essence of the message behind the principle.

## 5.5 Planned Changes for the Main Intervention

Once the pilot study was complete the focus turned on the evaluation of the pilot intervention package, research approach and research instruments used in the study, which enabled the author to decide on any changes required for the main study.

It was decided that the basic structure of the pilot intervention would be retained but the original scheme was further developed to include an additional three classroom seminars, and a second practical session on green chemistry, and to modify the assignment for the student seminars.

The first change involved dividing the introduction into two parts, dedicating one seminar to the general introduction to green chemistry, leaving a separate session for the explanation and discussion on the twelve key principles upon which green chemistry was founded. This was done for a number of reasons but mainly to allow enough time to explain the aims, recent evolution and some applications of green chemistry. The first session was also meant to illustrate further some important points making use of visual resources. The 'green chemistry principles' deserved being treated separately to allow students more time to grasp (and discuss) some of the many concepts involved and to allow space for the viewing of the video clips prepared.

The other new seminars were planned to expand on biofuels and treat separately the green chemistry principles and different processes involved in the production and use of biodiesel and bioethanol which are the most widely used fuels in the world. Such developments were planned following the interest generated among students during the biofuel seminar and practical session of the pilot intervention. The new seminars aimed at giving priority to the use of renewable sources of energy and address related issues such as the 'food versus energy crop' debate and sustainability of the environment. They also allowed more space for the classification of biofuels and related general information such as the difference in the use and production of biofuels in different parts of the world. The change also allowed more time for the use of visual resources such as the short video 'Climate Change and

Biofuels' produced by the National Non-Food Crop Centre (UK). It also allowed students to participate more in the seminars through discussion and questioning and to prepare themselves better for the practical session which involved the laboratory preparation and analysis of biodiesel.

Given the students' interest and participation in the practical session on biofuels in the pilot study, it was also decided to extend the green chemistry laboratory experience by adding an extra practical dedicated to the synthesis of biodegradable bioplastic. This second laboratory session was meant to provide students with another close encounter with the real-life application of green chemistry principles such as the use of renewable resources and design for degradation. The laboratory experience in green chemistry also allowed students to prove that chemistry could in fact be rendered green using less toxic and less hazardous chemicals which generated harmless products.

Another change that was made to the intervention regarded the number and type of student presentations. The pilot intervention allowed three sessions for students to work in groups on a short presentation about one aspect of green chemistry after carrying out some research mainly through the internet. Given the students' crammed time-table, the significant time required by students to collaborate and eventually produce such an 'extra-curricular' assignment, and the limited potential of such activity to generate useful data for the study, it was decided that the assignment would be transformed into a series of poster presentations to be carried out over two one-hour sessions. This was done to reduce this extra commitment from students and convert it into an equally meaningful but less time-consuming exercise. Another reason was that if material produced by students was of acceptable standard it could then be used in a future college based exhibition on green chemistry.

All these changes required updating of most of the educational resources used in the pilot intervention. This involved modifying the content of some of the presentations (computer slide shows) preparing new background information sheets (printed notes for students with references for further reading / research) and creating new worksheets and laboratory instruction sheets for all student activities.

Another novelty was the launching of an original logo to mark the introduction of green chemistry in Maltese schools. The design (figure 5.1) was created with the help of UK cartoonist David Dale and featured a frog, recognised worldwide as a symbol of sustainability, embracing the Maltese eight-pointed cross. This logo was launched during the main intervention for immediate visual impact to remind participants continuously of the advent of green chemistry in Malta.


**Figure 5.1**
**Original logo used in the main intervention**

## 5.6 The Revised Intervention Package

Following the changes made to the pilot intervention, the revised intervention package now consisted of a set of nine classroom seminars on various themes of green chemistry, a number of activities assigned to students at the end of each seminar aimed to re-enforce what was learnt in class, two practical sessions in the chemistry laboratory and two student seminars involving the presentation of posters prepared by the same student participants.

Table 5.3 shows the schedule of activities planned for the group of Maltese sixth form students participating the main green chemistry intervention during academic year 2009-10.

**Table 5.3**

**Planned Schedule of Events of the Main Green Chemistry Intervention**

| **Phase 1: October – December 2009** | |
|---|---|
| **SESSION** | **EVENT DESCRIPTION** |
| 1 | Seminar - A general introduction to green chemistry |
| 2 | Seminar - The 12 principles of green chemistry |
| 3 | Seminar - Green chemistry and atom economy |
| 4 | Seminar - Green chemistry and fuel cells |
| 5 | Extra Christmas Seminar - An overview of themes discussed and student activities performed in phase 1.<br>Launching of student seminar presentations. |
| **Phase 2: January – March 2010** | |
| **SESSION** | **EVENT DESCRIPTION** |
| 6 | Seminar - Green chemistry and liquid carbon dioxide |
| 7 | Seminar - Green chemistry and degradable plastics |
| 8 | Seminar - An introduction to biofuels |
| 9 | Student Seminar - Students' Poster Presentation (Part 1) |
| 10 | Student Seminar - Students' Poster Presentation (Part 2) |
| 11 | Seminar - Green chemistry and biodiesel |
| 12 | Seminar - Green chemistry and biosynthesis of ethanol |
| **Phase 3: April – May 2010** | |
| **SESSION** | **EVENT DESCRIPTION** |
| 13 | Practical Session 1 - Producing & analysing biodiesel |
| 14 | Practical Session 2 - Producing a biodegradable bioplastic |
| 15 | Final Seminar - Follow-up to discuss results of green chemistry practicals |
| 16 | Conclusion & presentation of tokens of participation to all participants |

The whole intervention was divided into three phases with phase one consisting of four seminars, phase two including five seminars and the two student presentation sessions and phase 3 divided into two green chemistry practical sessions.

Table 5.4 features a brief description of each of the events planned for the green chemistry intervention during academic year 2009-2010.

**Table 5.4**

**Main Green Chemistry Intervention Plan - Part 1**

| Session | Duration | Theme & Brief Description of Planned Activities |
|---|---|---|
| 1 | 1 hour | **General Introduction to Green Chemistry**<br>A seminar with a tutor presentation introducing the definition, aims and some applications of green chemistry. It presents green chemistry as a powerful tool to achieve sustainability. |
| 2 | 1 hour | **The 12 Principles of Green Chemistry**<br>Another classroom seminar with a presentation explaining the meaning behind each of the 12 universally accepted principles of green chemistry (first published in 1998 by P. Anastas and J. Warner) that ensure that chemical processes and products are clean and safe. Green chemistry is presented as a 'reducing agent' aiming to reduce raw materials / energy requirements / use of toxic chemicals / pollution / waste products. |
| 3 | 1 hour | **Green Chemistry and Atom Economy**<br>A third seminar with a presentation on the important green chemistry principle of 'atom economy' (originally developed by B. Trost in 1991) which aims to minimise waste by-products and emphasize reaction efficiency by choosing greener chemical reactions / processes. This theme is related to the mole concept and stoichiometry. Students will be shown how to compare and determine the efficiency of a chemical reaction by considering both percentage yield and atom economy. |
| 4 | 1 hour | **Green Chemistry and Fuel Cells**<br>This seminar introduces the fuel cell to illustrate three green chemistry principles: renewable resources, waste prevention and increased energy efficiency. The presentation refers to the electrochemistry of the fuel cell, some of its applications and technical limitations in its use. This theme is linked to the traditional chemistry concept of oxidation and reduction and to the theory of electrochemical cells. |
| 5 | 1 hour | **Green Chemistry and Liquid Carbon Dioxide**<br>This session consists mainly in a presentation on toxicity of solvents used by the chemical industry in contrast with the use of liquid carbon dioxide as an example of a 'green' (i.e. harmless and non-polluting) solvent. The presentation explains the conditions required to produce liquid or supercritical carbon dioxide and some of its applications in the chemical industry. Reference is also made to the fundamental chemistry concept of phase equilibria and the theory of detergency. |
| 6 | 1 hour | **Green Chemistry and Degradable Plastics**<br>This seminar focusses on the green chemistry principle 'design for degradation' with a presentation dealing with the theory of polymerisation reactions, the chemistry of plastics, the problem of plastic waste / recycling, photodegradation and biodegradability of plastic material. It also distinguishes between photodegradable and biodegradable plastics and highlights advantages and disadvantages of using biodegradable plastics. |

**Table 5.4 (continued)**

**Main Green Chemistry Intervention Plan - Part 2**

| Session | Duration | Theme & Brief Description of Planned Activities |
|---|---|---|
| 7 | 1 hour | **Green Chemistry and Biofuels**<br>This seminar introduces biofuels as a concrete application of the green chemistry principle emphasizing the importance of using renewable rather than depleting resources. The session outlines the three different classes of biofuels, raw materials used for their production and examples of commonly used biofuels. It also discusses some general advantages and disadvantages of using 'green' fuels over fossil fuels. |
| 8 | 1 hour | **Green Chemistry and Biodiesel**<br>Following the introduction to biofuels, this seminar focuses on the properties, uses and manufacture of biodiesel as an example of a green fuel which is used to replace petroleum derived diesel. The tutor outlines the chemistry of the transesterification reaction after making reference to esterification reactions. The presentation ends with a list of benefits and limitations in the use of biodiesel when compared to petrodiesel. |
| 9 | 1 hour | **Green Chemistry and Biosynthesis of Ethanol**<br>This seminar illustrates the green chemistry principles of renewable resources, the use of catalysts and energy efficiency via the fermentation of sugars and other carbohydrate-rich biomass to produce alcohol. The session compares the main methods of production of ethanol and discusses the 'green' options and current technology available. Reference is also made to the basic chemistry of alcohols and the pros and cons of replacing petrol with bioethanol in road transport. |
| 10 | 2 hours | **Green Chemistry Experiment 1: Producing & Analysing Biodiesel**<br>This practical session provides a hands-on opportunity for students to experience the laboratory preparation of biodiesel starting from different types of vegetable oils. It also gives them the chance to work out the atom economy and percentage yield of the reaction and carry out some qualitative analysis of their product, comparing its properties with those of other fuels provided. |
| 11 | 2 hours | **Green Chemistry Experiment 2: Producing a Biodegradable Bioplastic**<br>This second practical session allows students to have another hands-on opportunity in green chemistry, this time experiencing the making of a biodegradable plastic starting from a renewable source such as potatoes after having already learnt about the green chemistry credentials of biodegradability. Students have to extract starch from the potato tubers, convert it into a bioplastic and then test its properties which make it 'degrade naturally' without polluting the environment. |
| 12 | 2 hours | **Student Poster Presentations**<br>Two sessions dedicated to the presentation of posters on various aspects of green chemistry, prepared by different groups of students. |

## 5.7 The Main Intervention Package Materials

The following is a short description of the main package materials prepared for the classroom / laboratory intervention, including reference to some changes made from the pilot intervention.

### 5.7.1 Seminar 1 – General Introduction to Green Chemistry

The idea behind this seminar was to introduce the general concept of green chemistry, presenting it to students as a new way of planning and doing chemistry by emphasizing safety and minimising waste / pollution. The tutor presentation aimed at launching a definition of green chemistry and linking its goals with the goals of sustainable development. The first session aimed also to expose students to some examples of real life applications of green chemistry and to some organisations that were already involved in research activity and in the teaching of this new area of chemistry. Resources prepared for this seminar included a video clip featuring university students and professors of chemistry sharing some ideas and experience on green chemistry, proving that it is in fact already being taught in some universities and other educational institutions.

At the end of the seminar students were to be invited to describe in their own words their first impression of green chemistry, writing also short statements summarising some of its main aims. Unlike the case of the pilot intervention, the first session does not make any reference to the 12 ‘cardinal’ principles of green chemistry. It was thought that being the first seminar students would be more engaged and more relaxed if they simply get to know some basic facts about the very existence of this contemporary development of chemistry rather than being overwhelmed with the entire ‘set of rules’ governing the new science.

### 5.7.2 Seminar 2 – The Twelve Principles of Green Chemistry

The second seminar was designed to explain to the students how green chemistry is based on twelve universally accepted principles that guarantee that chemistry is rendered free of hazards and free of pollutants… and so more sustainable. The main presentation of the seminar aimed to simplify and explain each of the twelve statements introduced by Anastas and Warner in 1998 to serve as the main framework for the practice of green and sustainable chemistry.

One of the changes made from the original seminar presentation used in the pilot study was to highlight the fact that several principles of green chemistry emphasized the concept of 'reduction' applying it to various factors related to the production of chemicals, such as raw materials, energy requirements, toxic and hazardous reagents, pollutants and waste products. This was done so that students would gain a better understanding of the interrelationship between the 'rules of green chemistry'. Another novelty for this session was the introduction of mnemonics to facilitate the visual presentation (and memorisation) of the entire set of green chemistry principles.

The learning activity proposed for this seminar was a green chemistry slogan competition. Students would be given some time, to work in small groups, and create a short slogan to convey the message of one of the principles of green chemistry to a wider audience which would include non-chemists. This exercise was meant to encourage class participation and provide more feedback to the researcher on the way students understood the basic concepts of green chemistry.

### 5.7.3 Seminar 3 – Green Chemistry and the Principle of Atom Economy

This session was planned to focus on the fundamental green chemistry principle of 'atom economy'. The aim of the seminar was to explain how to calculate the atom economy of a given chemical reaction and show how this can be used to measure the 'greenness' of a reaction. Students were to be shown how a chemical process can be rendered greener, producing less waste, by choosing reactions, at the planning (or molecular) stage, with a high atom economy. During the seminar students were expected to realise that a reaction with a high percentage yield may still produce a lot of waste. They would also learn how to evaluate the efficiency of a reaction by considering both the atom economy and the percentage yield. Students would find out that the higher the overall efficiency, the greener will the reaction / process be.

The learning activity linked with this seminar is a set of twelve problems each comparing alternative methods of preparation of a specific chemical product. Each team (small group) of students would be asked to calculate the percentage yield, atom economy and reaction efficiency for two different synthetic routes of the same product and decide on the greener option. In doing so students were expected to appreciate that green chemistry metrics such as atom economy are important to consider in order to secure the sustainable production of chemical products.

### 5.7.4 Seminar 4 – Green Chemistry and Fuel Cells

The main idea behind this seminar was to illustrate a number of green chemistry principles involved in the use of fuel cells. The classroom presentation would explain the electrochemical process involved to generate electricity without causing any pollution and without contributing to global warming. The students would then be shown various applications of fuel cells and they will be involved in a discussion on some advantages and limitations in the use of such an alternative source of energy.

At the end of the seminar, students would be asked several questions related to the green chemistry principles involved in the operation of the fuel cell, sources of hydrogen and some advantages and disadvantages of using it with respect to other traditional sources of energy relying mainly on fossil fuels.

### 5.7.5 Seminar 5 – Green Chemistry and Liquid Carbon Dioxide

This seminar intended to introduce the idea that toxic organic solvents commonly used by the chemical industry can be replaced by safer greener solvents such as liquid or supercritical carbon dioxide. Students would learn how the use of green solvents by the chemical industry is an important aspect of pollution prevention. They would also learn how carbon dioxide gas, which is non-toxic and abundant in air, can be converted to the liquid state or to a supercritical fluid and then used in various applications such as dry cleaning and extraction of essential oils, saving the environment from huge amounts of toxic vapours from commonly used organic solvents.

The learning activity linked to this seminar aimed to test students on the understanding of traditional chemistry and green chemistry principles involved in the use of green solvents such as liquid / supercritical carbon dioxide. At the end of the seminar students were expected to know what the features of a green solvent are and discuss advantages and disadvantages of using liquid carbon dioxide as an alternative industrial solvent.

### 5.7.6 Seminar 6 – Green Chemistry and Degradable Plastics

The sixth classroom seminar aimed to focus on the green chemistry principle 'design for degradation' which underlined the important aim of green chemistry to eliminate the accumulation of waste chemical products in the environment. Students would first be reminded how plastics which are made from non-renewable raw materials, have wide applications in everyday life but are hard to degrade and so cannot be disposed safely. Participants would then be introduced to the chemistry of alternative polymers made from renewable sources and designed with special features so that they degrade naturally into harmless products. The seminar was also meant to prepare students for a practical session involving the preparation of one such type of biodegradable plastic.

At the end of the seminar students would be invited to participate in an exercise similar to a quiz where they would be challenged to answer to a set of questions related with the use, chemical composition and properties of degradable plastics and the green chemistry principles involved in the production and disposal of such material.

### 5.7.7 Seminar 7 – An Introduction to Biofuels

This seminar was meant to introduce the green chemistry principles involved in the production and use of biofuels. It was one of the new sessions added to the main plan following the interest but limited knowledge shown by students on this topic during the pilot intervention. It was also meant to give students an overview of developments made so far, terminology used and some issues encountered in this growing area of green chemistry before being allowed the chance to take a closer look at the green chemistry of the two mostly used biofuels in the world.

The main presentation aimed to explain how biofuels are made from renewable resources and why using them would not have an impact on the carbon footprint. The seminar would look at different types of biofuels which require different raw materials and different methods of production. Students would also be given the chance to discuss some of the main advantages and disadvantages of producing / using biofuels including the debate on energy crops. Students would also be shown a short video clip on the link between 'biofuels and climate change'.

At the end of the seminar students would be asked to answer a number of questions related to the main presentation and the video. The questions in the students' biofuels worksheet would refer to the definition, different raw materials, green chemistry principles involved, classification and advantages / disadvantages of biofuels over fossil fuels.

### 5.7.8 Seminar 8 – Green Chemistry & Biodiesel

This session would focus on the chemical composition, properties and production of biodiesel as one of the most commercially important biofuels in the world and the only biofuel available locally to date. A comparison would be made between the chemical composition of biodiesel and petrodiesel. The seminar presentation would deal also with the chemistry of transesterification reaction which converts oils and/or fats into biodiesel, relating it with the chemistry of the esterification reaction, covered in the core chemistry curriculum. The session would also refer to benefits and limitations in the everyday use of biodiesel.

The learning activity associated with the seminar consists of another worksheet whereby students would be asked to answer questions dealing with the composition, raw materials and production of biodiesel. Students would be asked to compare properties of diesel with those of petrodiesel and discuss advantages and disadvantages in the use of this biofuel. They would also be reminded that they would soon have a chance of experiencing the laboratory preparation of biodiesel in a few weeks' time, towards the end of the green chemistry programme.

### 5.7.9 Seminar 9 – Green Chemistry and Bioethanol

This is the third in a series of seminars on biofuels and was meant to focus on the various green chemistry principles involved in the commercial production of ethanol – the most widely used biofuel in the world – by fermentation of sugars and other raw materials rich in carbohydrates. The seminar would discuss the different options available to synthesize ethanol and would explain the features which render biosynthesis of ethanol a greener process compared to catalytic hydration of ethene. Students would also be taught how development in biotechnology has increased the range of renewable raw materials (biomass) from which this biofuel can be produced. They would also have the chance to view a short video clip related with the production of bioethanol from biowaste.

As a learning activity, students would be asked to explain why bioethanol is considered as a green fuel and why its production is a green process. Students would also be asked about the steps required to utilise biowaste in the production of this biofuel and the advantages / limitations of replacing petrol by ethanol as a fuel for transportation.

### 5.7.10 Green Chemistry Experiment 1 - Producing and Analysing Biodiesel

This is the first of two practical sessions intended to provide an opportunity for students to perform green chemistry experiments in a school laboratory using safe chemicals / raw materials and mild reaction conditions to produce green products.

The first green chemistry practical session involves the synthesis of biodiesel starting from different vegetable (cooking) oils and followed by a number of tests to analyse the quality of the product and compare it to that of other fuels (e.g. commercial biodiesel, petrodiesel, petrol). The pilot intervention had included this practical session which however was dedicated solely to the laboratory preparation of biofuel from one type of vegetable oil. The second part of the practical involving analysis of the product and other samples of fuels was added in the main intervention so that students would be able to test their product and compare its properties with those of other fuels available on the local market.

Eventually, students would be expected to write a laboratory report which includes calculations such as percentage yield, atom economy and reaction efficiency of the transesterification reaction. They also have to answer to a number of questions related with the experiment and the green chemistry principles involved in this preparation.

### 5.7.11 Green Chemistry Experiment 2 - Producing a Biodegradable Bioplastic

This second laboratory session was planned to provide another chance for students to apply green chemistry concepts in the laboratory by producing a biodegradable plastic from a renewable resource. Students would again be expected to be prepared for this session as they would have already covered the relevant theory and green chemistry principles in the seminar on the same topic of degradable plastics. This practical was designed to extend the laboratory experience in green chemistry following the positive feedback of students who participated in the pilot practical session.

The experiment would involve extraction of starch from raw potatoes, conversion of starch in the bioplastic and analysis of the product, including some tests on its biodegradability. The students would be expected to submit a laboratory report on this practical and answer a number of questions related with terms encountered in the experimental procedure, as well as properties and uses of biodegradable plastics.

#### 5.7.12 Students' Poster Presentations

The number of students' seminars organised in the pilot intervention were meant to allow students to prepare a short computer presentation about one aspect of green chemistry after being encouraged to carry out some research mainly using internet resources. Given the fact that students are already committed with so many assignments as a result of a loaded time-table, the seminars were transformed into a number of (less demanding) short (5-10 minute) presentations, with each group of students creating a poster and using it to illustrate what they would have learnt about a particular aspect of green chemistry. All students present for these sessions would be given the chance to vote for the best presentation, basing their judgement on a number of pre-set criteria. This would be done in a bid to increase interest and participation from all students, but also to possibly provide further evidence to the researcher on the students' attitudes and understanding of different aspects of green chemistry.

The lesson plans including aims, contents, student activities and learning outcomes for each of the nine classroom seminars are summarised in *appendices 4-12*. On the other hand, the lesson plans of the two green chemistry laboratory sessions planned for the final phase of the intervention are shown in *appendices 13 and 14*.

The background information sheets which were provided to students during the classroom seminars were meant to serve as a set of printed notes to help students in the understanding of the themes discussed during the seminars in class. Each information hand-out included also a list of references for further reading. Students were also provided with a number of worksheets to be used as part of the student activities linked with the seminars, as well as laboratory instruction sheets for the two green chemistry experiments. At the end of the intervention, students were also supplied with model answers to correct any misconceptions or inaccurate information / calculations which they might have included in their work. *Appendix 15* lists the number of slide shows (PowerPoint presentations) created for the classroom seminars while *appendix 16* list the number of audio-visual resources (video clips) used during the seminars. *Appendix 17* shows the guidelines for the student seminar presentations.

## 5.8 Chapter Summary

This chapter highlights the main features of the curriculum intervention (intended curriculum) aimed at introducing green chemistry to a group of first year students enrolled in the A-level programme of studies provided by the main sixth form college in Malta.

The students participating in this project already had a background of environmental chemistry as this formed part of the O-level chemistry curriculum. However the local A-level programme does not continue to build on what was started in secondary education in what appears to be a vacuum on environmentally-related issues. The green chemistry intervention was planned to fill this curricular gap by introducing a new methodology in chemistry (referred to as green or sustainable chemistry) which is based on a set of fundamental principles aimed primarily at protecting human health and the environment. The chapter specifies the main objectives and learning outcomes of the intervention and then explains how the themes were chosen and developed in a series of classroom seminars and a laboratory session with a number of related activities. This required the design of a set of educational resources which formed part of the intervention package used in the pilot intervention with a group of students during academic year 2008-2009.

The intervention package was revised upon completion of the pilot study to allow a number of changes. Such changes mainly involved extending the number of classroom seminars and the laboratory experience in green chemistry, and modifying the type of student activities including those related with the student seminars. All changes were also reflected in the updated resources which formed of the main intervention package.

The chapter then outlines the complete schedule of events forming part of the green chemistry intervention carried out with a different set of students during academic year 2009-2010 and describes briefly all the activities involved.

# Chapter 6

# THE IMPLEMENTED CURRICULUM

## 6.1 Introduction

This chapter tries to find out how the planned green chemistry intervention (the intended curriculum) was implemented in the classroom and laboratory during year 2009-2010. The author describes what actually happened during the intervention and explains whether the activities (seminars, presentations, practical sessions, written exercises, etc) were actually carried out as planned or modified for some reason. The chapter also discusses the difficulties encountered by students throughout the intervention and any other issues that cropped up in due course.

## 6.2 Overview of the Learning Objectives of the Green Chemistry Intervention

The overall aim of the green chemistry classroom and laboratory intervention was to introduce green chemistry to a group of Maltese students studying A-level chemistry, presenting it as an innovative and smarter methodology of doing chemistry in a more sustainable way, minimising the impact on human health and the environment.

One of the first objectives was to explain the general concept of green chemistry and then introduce the widely accepted basic principles which govern this new area of chemistry.

Another objective was to relate aspects of green chemistry to the traditional concepts of chemistry taught at this level. The intervention was also expected to relate green chemistry to real life situations and demonstrate how green or sustainable chemistry was not only theoretical but could also be applied in a school laboratory and in a real life situation.

## 6.3 The Classroom Seminars

The classroom seminars represented the main component of the green chemistry intervention package. Each seminar consisted of a presentation by the teacher-researcher on one aspect of green chemistry followed by a discussion and a brief learning activity. The presentations were usually made using computer slide shows (PowerPoint presentations) prepared by the author, with the help of other resources such as video clips, information hand-outs and other educational literature. Learning activities usually involved students collaborating in small groups to answer a number of questions or work out calculations related to the topic/s treated during the seminar. All seminars were held in one of the college media rooms which was provided with a computer, projector, large screen and audio visual equipment. The following were the main observations made during these seminars.

### 6.3.1 Introducing the aims, definition and context of green chemistry

The first seminar introduced students to the new world of green chemistry by highlighting the important differences between this novel way of doing chemistry and traditional chemistry. The seminar was based on a computer presentation through which the researcher / tutor explained the aims, definition, context and some of the major achievements of green chemistry since its inception in the early 1990s.

Just before this presentation, students were divided into twelve small groups (each consisting of two or three participants) with one student from each group being randomly chosen to act as a team leader. This was mainly done to encourage group work and students' participation in small groups, and for better coordination of all activities related with the intervention. Such a teaching strategy was applied successfully in the pilot study and was therefore retained for the main study.

The first general impression of the students on green chemistry was positive as can be confirmed in the author's field note entry on the day.

> "All students attending the seminar were very attentive throughout and some of them even jotted down additional notes supplementing the information provided in the hand-out. Students continued to talk and ask questions on green chemistry even when the seminar was over, that is when students normally rush out for the next lesson / break."
>
> (Field note: class seminar – 11/11/2009)

In actual fact students were not expected to copy down any notes during the presentation as they were provided with the first of a series of information hand-outs covering the salient points of the topic discussed in class together with a list of references for further reading. The latter included a number of internet websites of some international organisations, research centres and educational institutions which were already involved in green chemistry activities.

The presentation lasted about thirty minutes and students appeared to have grasped the main idea behind this new area of chemistry. Participants had the chance to raise a few number of questions at the end of the tutor's explanation. The general feeling was that students were completely unaware of such a development in chemistry although they remarked that that had done some topics in environmental chemistry which they regarded as somewhat related to the green chemistry they were just learning.

The learning activity of this first seminar consisted of a short exercise where students were asked to write a suitable alternative expression to describe in their own words the term 'green chemistry' and then write also five short phrases to summarise some of the aims of green chemistry. The exercise, given in the form of a worksheet, was discussed by each team, and included also space for student feedback on this introductory seminar.

The session went as smoothly as planned except for a technical fault in the computer speakers which forced the tutor to postpone showing the participants some short video clips related to the presentation. Another issue was that there wasn't sufficient time for the learning activity to be carried out as originally planned. In fact the end-of-seminar exercise was meant to stimulate a short small group discussion leading to a commonly agreed response for every question asked in the worksheet. However, given the time required for the tutor presentation, the space allocated for questions / whole class discussion and for announcements on the rest of the green chemistry programme, there was no room left for the planned exercise to be carried out in class. Hence students were allowed to keep the 'activity worksheet' and work on it as a team, in their free time, before returning it to the tutor by the following seminar. It was good to note that students cooperated well in this first learning activity and in fact all worksheets were duly completed and returned (by the team leaders) in their original 'brown envelopes' in two days' time and ahead of the second seminar.

The interest generated among students through this first seminar on green chemistry could be confirmed by instances such as when the only student who missed the seminar (admitting that he had forgotten about the extra appointment) showed his genuine disappointment for having lost the first chance to learn more about the 'new topic' in chemistry, which he said his colleagues had described as being 'exciting', 'very different' and 'very enjoyable'.

### 6.3.2 Launching the Twelve Principles of Green Chemistry and Creating a Slogan

The second seminar was planned to focus entirely on the twelve key principles of green chemistry upon which all research and other activities of green chemistry were based. The sessions started with students receiving a second hand-out which included short notes and relevant explanation on 'the twelve principles green chemistry' as proposed by green chemistry founders Paul Anastas and John Warner in their influential book 'Green Chemistry – Theory and Practice' (Anastas & Warner, 1998). The tutor presentation involved the use of a second slide show introducing and explaining briefly each of the 'twelve principles' with the aid of some of their applications in industry and in everyday life. Students were also shown the documentaries and short video clips originally planned for the first seminar, including one featuring the views of a chemistry university student and of chemistry professor Martyn Poliakoff (one of the leading figures in green chemistry) about their experience of green chemistry. The presentation and videos were well received by the participants who appeared again very receptive throughout.

The student activity linked with this seminar was an exercise which took the form of a competition between the participating teams to create a slogan which best represents the spirit behind one of the twelve principles defining green chemistry. The tutor assigned randomly one principle to each of the twelve teams, and students were allowed two days' time to study the statement and come up with a catchy phrase that would summarise and simplify the green chemistry concept in the form of a message intended for the general public. The idea behind this exercise was to see whether students were able to understand the essence of the principle involved and re-propose it in a relevant shorter version that would appeal to the general public, which may be unfamiliar to scientific terminology. Quoting from the author's research diary:

> "It was encouraging to note that all slogans were submitted by the stipulated time even though some of the phrases proposed were rather lengthy and seemed to lack the required punch and clarity of the message they were meant to convey."
>
> (Field note – class seminar 18/11/2009)

The voting for the best slogan took place a month later in an extra session held just before the Christmas recess. The students were each given the full list of proposed phrases / slogans and each participant then had to indicate the best or most favourite idea based on simplicity, clarity of message and immediate impact on a non-science audience. The sheets were then collected and the number of preferences counted by two of the team leaders. Participants were not allowed to vote for their respective teams. The first two phrases received the same number of points and so a second vote was required to establish the overall winning slogan. The top three slogans were:

- **First** *"Use more energy… and the earth will decay!<br>Use less energy… and the earth says hooray!"*

This was a reference to the principle emphasizing the need to increase energy efficiency during a chemical change / process.

- **Second** *"For greener reactions, catalysts are the best,<br>As they are recycled and work without rest!"*

This slogan tried to explain the principle stating that using catalysts is by far better than using stoichiometric reagents.

- **<u>Third</u>** *"Think of the end before you get to it!"*

This was based on the principle which underlines the importance to maximise 'atom economy' through the careful planning of synthetic pathways.

The whole exercise served its purpose of enabling students to understand better the main messages imparted by the twelve fundamental principles which inspire green chemistry. It turned out also to be an enjoyable experience for all participants as can be confirmed by this diary entry:

> "… the green chemistry slogan competition also instilled an increased sense of teamwork among students and, why not, some fun and excitement too."
>
> (Field note: class seminar – 16/12/2009)

Although this session was less intense than the introductory session of the pilot intervention, it was still dominated by teacher-talk and allowed very limited time for teacher-student interaction. Looking back things could have been improved if participants were provided with a simplified version of the set of green chemistry principles so that more time would be allocated for whole class discussion and answering questions. There was also too much emphasis on the competitive aspect of the slogan exercise which could have been modified to a concerted effort by the whole class to produce a set of short and simple statements promoting green chemistry ideas to a non-science audience.

### 6.3.3 Improving Reaction Efficiency by Maximising Atom Economy

This seminar was entirely dedicated to the fundamental green chemistry principle of 'atom economy' originally proposed by Professor Barry Trost in 1991. This concept introduced one important way of measuring the extent of ‘greenness’ of a chemical synthesis by calculating the percentage conversion of raw materials into the desired final product, taking into account the balanced equation for the reaction and molar masses of reactants and products. The tutor presentation included a number of examples of how atom economy is calculated and how such a value can be used to compare the efficiency of different ways of producing the same chemical substance. Students were supplied again with a background information handout which included notes and further examples of calculations involving atom economy and percentage yield, the latter being a parallel concept already covered by students for their O-level exam.

At the end of the presentation, each team was assigned a different problem in which students were asked to calculate and compare the ‘percentage yield’, ‘atom economy’ and ‘reaction efficiency’ of two different synthetic routes which produce the same chemical product. Then students had to determine which of the two was the greener method on the basis of their calculations. On this occasion, students had sufficient time to finish their exercise in time and hand in their worksheets by the end of the seminar. It could be noted that some of the students had problems in working these calculations particularly in the use of the mole concept. However, the fact that students were working in small teams allowed them to share their difficulties and learn from each other. Most of the teams fared well in this learning activity indicating that the majority of students were able to arrive at the correct value of atom economy and then use it to evaluate the sustainability of a chemical process. Students were later given a complete set of model answers to the 12 problems which the class had to work out during this exercise on such an important metric of green chemistry.

Although generally speaking the class performed well in this exercise indicating a good understanding of the green chemistry principle involved, one could observe that some of the students struggled to solve, on their own, the problem assigned to their team. This confirms what was already highlighted in the literature review regarding the students' difficulty to solve quantitative problems due to their limited ability to apply basic maths to chemistry calculations. This explains also why it was decided to introduce model answers in the main intervention. In this case, the model answers allowed students the chance to check all working involved in the calculations which were required to solve such problems in atom economy and reaction efficiency. Class correction would have certainly been more effective but this was not possible given the time available for the entire programme.

### 6.3.4 Generating Green Energy from Fuel Cells

The fourth of a series of seminars on green chemistry was dedicated to the concept of the fuel cell as an alternative form of clean energy, illustrating a number of green chemistry principles such as the use of renewable resources, increasing energy efficiency and waste minimisation. The main presentation outlined the basic chemistry and technology of the fuel cell as one of the alternative sources of clean energy. Students were informed that this technology was already being implemented in the use of various applications including modern transport, electrical installations, computers and other electronic equipment. The presentation tried to illustrate how the fuel cell operates, the electrochemical reaction involved, classification based on the electrolyte used, as well as advantages and limitations of using such fuel to replace traditional sources of energy produced from depleting resources. Participants were so interested in the presentation that they asked several pertinent questions at the end of the presentation such as why the technology was still expensive to date and how was it possible to overcome the problem of providing a cheap and steady supply of hydrogen to keep the fuel cell charged.

The student activity linked to this seminar consisted of a two-page worksheet where participants were asked a number of questions to explain the basic features of fuel cells. The worksheet was given to each of the team leaders at the end of the seminar. All worksheets were completed and returned by the end of the same week. Almost all teams scored a high mark in this assignment indicating once again a high level of interest and understanding of the material discussed in class.

### 6.3.5 Concluding Phase One of the Intervention (The Christmas Seminar)

This 'unscheduled' seminar had no specific theme and was added to the first set of seminars because of the need for extra time to conclude unfinished jobs and allow more student feedback on the intervention.

The session started with a continuation of the previous seminar theme where students were shown the pending video clips on the fuel cell operation and applications. This took about 15 minutes, including also a short discussion, with students referring to further information on the topic which they had accessed by searching the web. This was another confirmation that students were being motivated by these seminars to take the initiative to do further reading / personal research.

The second part of this session was dedicated to the launching of the green chemistry student research seminars whereby students were expected to carry out some team-based research on a single aspect of green chemistry, particularly by referring to internet websites and other (online) educational resources already indicated to them in the information hand-outs (printed notes). Students were encouraged to work in small groups (using the usual team set-up) and produce either a poster or a short computer slide show to help them make a presentation of their chosen theme to the rest of the class during one of the two student seminars scheduled in early March 2010. Participants were informed that all presentations were to be assessed and their marks were to form part of term two chemistry assessment. This move was previously sanctioned by the chemistry department in order to give credit to students for their extra commitment towards the subject (chemistry) particularly through their participation in this educational project. Students were invited to submit their proposed ideas by the end of January 2010 for approval before they start working on this assignment.

In conclusion students were briefed on some of the topics planned for the second phase of the intervention which was to resume in January 2010. They were informed that this second part of the green chemistry programme was to include the students' presentations as well as a laboratory experience.

Once again students showed their interest in this new dimension of chemistry and appeared quite enthusiastic about the idea of carrying out some form of research about it on their own. Once the seminar was over, one of the students remarked that she found the subject of green chemistry so appealing to her that she thought it would be a pity if it would not be included as a small section in the chemistry A-level syllabus as 'it was easier to follow' than some other traditional topics. Other students approached the tutor after this session to ask more about the possible areas of interest they could look up during their Christmas holidays in view of the presentations they had to prepare for the students' seminar. The researcher considered this session as crucial as it allowed more breathing space for students to voice their ideas and to get more involved in the green chemistry intervention. In the same time, it served as another opportunity for the tutor / researcher to obtain direct feedback from the students on the intervention which was still in progress.

### 6.3.6 Opting for a Green Solvent such as Liquid / Supercritical Carbon Dioxide

This was the first green chemistry seminar of year 2010 and marked the start of phase two of the green chemistry intervention. The seminar featured the use of liquid or supercritical carbon dioxide as an example of a 'green' solvent which could replace more toxic solvents in industry (e.g. in dry-cleaning and extraction of essential oils). Once again the seminar started with a computer presentation complemented by a number of short video clips, on the role of liquid phase carbon dioxide as a harmless and environmentally friendly solvent which could potentially be used by the industry instead of commonly used toxic organic solvents. The short features shown to the students concerned the use of liquid carbon dioxide as a solvent in a dry cleaning operation (replacing a highly toxic organochlorine solvent) and in the extraction of essential oils such as limonene (from citrus fruit) and caffeine from coffee. The students were again very much attentive throughout the whole presentation and were particularly engaged watching the short videos about the unusual role of carbon dioxide as a solvent. Some of the students were again noticed taking down notes during the presentation. They also asked a few questions towards the end of the seminar. This was further evidence that by then, all participants had learnt how green chemistry was in this case applied through the use of harmless solvents and safer reaction conditions, but also by making use of a renewable resource (i.e. carbon dioxide) which does not pollute.

A short discussion followed at the end of the presentation and the session concluded with team leaders receiving the 'brown envelope' which included the student assignment related to this seminar. The learning activity consisted of another short assignment which could easily be carried out if participants followed the main seminar presentation. All envelopes were returned in a few days' time. Not all teams scored high marks on this occasion but all students were able to distinguish, for example, between the advantages of green solvents over other more commonly used solvents in industry. They also understood the conditions required to convert gaseous carbon dioxide into the unusual liquid form or to a supercritical fluid (an application to the curriculum topic of 'phase equilibria') before being used as a solvent in several industrial applications.

### 6.3.7 Designing Plastic Material for Degradation

The next session of the green chemistry programme consisted of a seminar on the production and use of degradable plastics as another concrete application of green chemistry. This seminar was again well-attended by students and started with the distribution of background notes and other colourful educational literature on biopolymers donated by the UK Non-Food Crop Centre (NNFCC) based in York. The session was held as usual in the media room on a Wednesday morning and dealt with the green chemistry principles of 'designing for degradation' and 'using renewable rather than depleting resources', with particular reference to biodegradable plastics.

The tutor's explanation was again based on a slide show presentation which referred to the properties, uses and chemistry of different types of plastic material. Reference was also made to plastic waste disposal and the concepts of photodegradation and biodegradation. Students were able to follow most of the presentation which included also a revision of the basics of polymerisation reactions, a reference to the use and disposal of plastic material, an outline of the chemical synthesis of degradable polymers and benefits versus limitations in the use of such environmentally friendly plastic material compared to other forms of plastic. Participants were also shown a short feature concerning the separation and recycling of plastic and another one on the production of biodegradable plastic made from corn flour.

Students attending this seminar were generally absorbed during the presentation and asked a few questions on the content. Unfortunately there wasn't enough time for a wider whole class discussion due to the rather long presentation, which again involved the use of some other audio-visual resources.

As in the case of previous sessions, the student activity consisted of a written exercise (worksheet) linked to this seminar topic, and this was again given as extra work with students being allowed some days to discuss in small groups and answer the questions in the exercise related to my presentation. All teams except one performed well in this exercise providing evidence that most of the students were able to understand the green chemistry principles involved in the design, production, use and disposal of plastics.

### 6.3.8 Biofuels as a Renewable Form of Energy

The eighth session of the green chemistry intervention was a seminar which introduced the theme of biofuels underpinning green chemistry principles such as 'the use of renewable resources' as greener alternatives to other (finite) resources such as petroleum derived fuels. On this occasion students were provided with the usual background information hand-out and other printed educational literature (newsletters) related to biofuels and biomass, once again produced and supplied by the NNFCC for this project.

The main focus of the seminar was a computer presentation on the increasing importance of producing and using biofuels in a global effort to reduce reliance on fossil fuels. The seminar dealt with different possible sources of biofuels, a distinction between first, second and third generation biofuels, some statistics on the use of biofuels in Europe and other countries including Malta, and a discussion relating to the pros and cons of using biofuels. Students participated actively in the discussion and were later also shown edited parts of a twenty minute documentary on Climate Change and the impact of using biofuels, also produced and supplied by the NNFCC.

Judging from the students' feedback, it appeared that this session appealed to the students and in fact several participants expressed their wish to be able to work on a presentation related to this theme, given the progress registered to date in this area of green chemistry.

Towards the end of the seminar, students were supplied with a new worksheet containing an exercise related to the seminar topic. Once again it was decided that students would be given ample time to go through the questions (in worksheet) in small groups and submit their assignment for assessment. All worksheets were returned in time over the weekend and this time all teams performed well in the exercise.

### 6.3.9 Producing Biodiesel from Edible Oil

This ninth classroom seminar followed two sessions dedicated to the students' own presentations which will be discussed in section 6.4 of this chapter. It was, in a way, a continuation of the previous seminar which introduced students to the important role of biofuels in green chemistry. This particular session was planned to focus mainly on the process which produces biodiesel which is the most commonly used green fuel in the European continent including Malta.

The presentation started with a comparison of the chemical composition and physical properties of petrodiesel (a fossil fuel) with those of biodiesel (an alternative green fuel). The tutor then explained how the properties of biodiesel allow it to be blended with traditional diesel and to be used either as a mixture or on its own to replace mineral diesel in fuel injection vehicles. Reference was also made to different possible raw materials used to produce biodiesel and the chemistry of the transesterification reaction which converts one type of ester (triglycerides present in vegetable oil) into another type of ester (fatty acid methyl esters, FAMEs) and glycerol (by-product) using methanol and an alkaline catalyst. The seminar also discussed a list of advantages and disadvantages in the use of biodiesel, compared to diesel which is obtained by fractional distillation of crude oil (a fossil fuel and hence a depleting resource). Students did not find it hard to follow the chemistry of transesterification, which is the crucial step in the production of biodiesel. This is so because they were already familiar with the chemistry of esterification reactions which is usually covered in class during organic chemistry lectures.

Some of the students wanted to discuss in more detail the controversial issue of growing crops for energy purposes instead of exploiting land to grow food or animal feed. Although such a food-energy debate on biofuels was a very relevant and topical issue, the author preferred to limit the class discussion to the chemistry and green chemistry principles involved in the production of this biofuel This was perhaps a missed opportunity which could have allowed students to explore and express themselves (even though for a few minutes) on an important socio-economical aspect of green chemistry.

The last part of the presentation was dedicated to a video demonstration of a small-scale preparation of biodiesel, which served as a remote preparation to one of the green chemistry practical sessions which were planned for the same students as part of the intervention package.

The learning activity took the form of another short exercise where students were asked a number of questions related to the seminar presentation. Questions concerned the difference between the chemistry of mineral diesel and biodiesel, the raw materials required for biodiesel production, and details on reaction conditions, reagents, products, and purification steps involved in this chemical process. Students were also asked to outline a number of benefits and shortcomings in the use of biodiesel compared to other fuels. All teams but one performed very well in the exercise, giving acceptable answers to most of the questions asked.

### 6.3.10 Green Fuel from Sugars and Other Carbohydrates

The last of a series of green chemistry seminars was another one related to biofuels, this time dedicated to the production of bioethanol which is regarded as the world number one alternative fuel used to replace partly or completely petrol in fuel combustion engines.

Students were again provided with printed notes and educational literature on the subject ahead of the presentation. They were reminded that such notes and references were being provided to enable them to expand their knowledge on any of the aspects covered during the seminars and to be included in their ‘green chemistry file’ which they were encouraged to keep throughout the entire programme.

The main presentation started with reference to the increasing demand for bioethanol which the tutor explained was significantly diffused in countries such as Brazil and the USA. A comparison was made between the synthesis of ethanol from ethene (produced by cracking of petroleum) and its biosynthesis from sugars by fermentation. Students were also taught how biomass and other waste material (including agricultural waste and even domestic waste) could potentially be used to produce this biofuel. The presentation was concluded by inviting students to help the tutor draw up a list of advantages and disadvantages in the use of bioethanol, compared to petrol, as a way of evaluating the sustainability of the product. Once again the presentation was straightforward and students found no problem in following the explanations. It appeared that students were unaware that ethanol was so extensively used as a biofuel. This was no surprise as unlike biodiesel, bioethanol is not yet available from local service stations and is only marketed here as a smokeless fuel for a certain type of fire-place.

Participants were finally given a short assignment consisting of a set of questions on the topic discussed during the seminar. In contrast with previous assignments students were given more time to work out and return the worksheet as this seminar happened to be the last activity of the green chemistry intervention before the Easter recess. All assignments were returned by the team leaders after the Easter break and in most cases the answers given were reasonably correct.

## 6.4 The Students' Research Seminars & the Poster Exhibition

The students' seminars provided a window of opportunity for students to carry out some research on their own, collaborate with each other and then present their work to their colleagues through a poster and a short (5-10 minute) explanation. The students were quite enthusiastic about this assignment and all teams gave in their proposals by the end of January 2010. So each team of participants had about one month chance to research the green chemistry topic of preference and come up with a poster highlighting the main points which they learnt about it. Students were encouraged to use the internet, particularly the resources indicated in the background information sheets which they were given during the main classroom seminars.

The original assignment for these student seminars was a choice between a poster and a PowerPoint presentation, but then, in order to reduce pressure on students, it was decided to scrap the computer slide show option, used in the pilot intervention, as it was a more time-consuming exercise for the students. There were no major objections from students on this as no team had started working on the assignment by the time the change was announced. The following is the complete list of posters prepared by the 12 teams of participants for the students' seminars.

**Table 6.1**

**List of Posters for Students' Seminars**

| No. | Poster Title | Team |
|---|---|---|
| 1. | Maximising atom economy on an industrial scale. | Lithium |
| 2. | The production and use of degradable materials. | Beryllium |
| 3. | Ways of reducing pollution by applying green chemistry. | Boron |
| 4. | Biofuels as renewable energy resources. | Nitrogen |
| 5. | The fuel cell and other ways of using non-hazardous sources of energy. | Oxygen |
| 6. | The accumulation and prevention of toxic wastes. | Fluorine |
| 7. | Bioplastics from starch and from other renewable resources. | Neon |
| 8. | Waste minimisation and the use of renewable resources from organic material. | Hydrogen |
| 9. | Increasing energy efficiency by the use of green chemistry processes. | Helium |
| 10. | Using safer and non-hazardous solvents. | Carbon |
| 11. | Living a healthier life by appreciating and using biodegradable plastics. | Magnesium |
| 12. | Bhopal (India) – 1984. How it occurred and what could have been done to prevent this disaster from happening. | Sodium |

The attendance and participation for the first students' seminar was very encouraging as the majority of students turned up at the media room for this session.

In the introduction to this seminar, students were reminded that their performance was going to be assessed by the audience present, with 50% of the mark being assigned by the students themselves and the rest by the tutor. In fact all students were given an evaluation sheet which included the list of poster presentation titles and then explained how each student had to award a mark (from 1 to 5) for each presentation, basing one's judgement on the content and clarity of poster, the way the team delivered the explanation and to what extent, in their opinion, was it related to green chemistry. The idea of the students' participation in the evaluation was to boost further the students' interest in the subject by increasing their level of participation through such learning activities.

In all, a total of seven presentations were made during the first session. Judging from the interest and enthusiasm manifested by most of the students before and during their presentation of work, along with the attention received by the rest of the class during the same presentations, one could easily conclude that the first student seminar was successful in generating further interest in the subject. It is true that some of the participants resorted to reading from a prepared note but the material presented was very relevant to green chemistry and reflected the students' extra effort made to explore and discover more about it. At the end of the seminar, all evaluation sheets were collected so that no changes could be made till the following students' seminar session.

The second students' seminar was held a week later and this time it was attended practically by the whole class. In all there were four presentations as one of the teams backed out despite having prepared the poster for this occasion. The four presentations delivered by the students were as interesting as the previous set of seven presentations and it was rather disappointing that the work submitted by the remaining team was below standard and the two students concerned failed to turn up for any of the two days of the seminar.

Students were satisfied with their participation in this activity and this was confirmed by the fact that they suggested using their posters to set up a small exhibition on green chemistry in some suitable area of the college to be appreciated by other college students. The author took up this proposal and promised to seek advice (and relevant authorisation) on the feasibility of such an event. Such an initiative was further proof of the students' growing interest in green chemistry.

In his next encounter with the GC class, the author gave out the mark which each team obtained for its presentation during the students' seminar. The marks received by students in this activity (a combination of tutor and student evaluation) ranged from 63% to 88%. The only exception was the team which managed to produce a poster but then failed to turn up for the seminars, thereby losing the chance to present its work to the rest of the class. The team concerned was awarded the lowest mark (25%) thereby being credited only for the effort in preparing the poster. The guidelines for the students' presentations together with the evaluation sheet used by the students and tutor during these seminars, are included as *appendices 17 and 18.*

On the same occasion students were informed that both the chemistry department coordinator and the college principal had approved of the green chemistry poster exhibition and it was decided that the posters designed by the students were to be displayed on fixed stands in a prominent place in the chemistry department wing, close to the lecture rooms and laboratories. A total of 5 boards were made available for this exhibition which carried the title "Green Chemistry – for a Sustainable Future" (see *appendix 19*). The exhibition was launched in less than a week and attracted a good number of students and members of the staff.

## 6.5 <u>The Green Chemistry Laboratory Experience</u>

The last activities of the intervention package consisted of a set of two green chemistry experiments which did not form part of the A-level laboratory programme. The green chemistry experiments did not replace the routine examination-oriented practical sessions but were held in a different time slot which depended on the availability of the laboratory facilities.

### 6.5.1 Producing and Analysing Biodiesel

The first green chemistry practical session was the laboratory preparation and analysis of biodiesel as an example of a biofuel made from renewable resources. In his introduction, the author explained that given the space limitations, students were going to work in twelve small groups and some of the tests were to be confined to the fume cupboard in order to minimise potential hazards. All students were given a laboratory instruction hand-out which included an introduction, a list of materials / reagents required, safety precautions to be observed, the experimental procedure, a section for results, space for calculations and a set of questions related to the experiment.

The first part of the practical session involved the synthesis of biodiesel starting from vegetable oil (a renewable resource) and methanol, using aqueous potassium hydroxide as the catalyst. Each group was provided with one of a number of cooking oils as its main raw material, together with other reagents and glassware required for this preparation. Students were expected to write a laboratory report by the end of the session.

The second part of the practical consisted in a set of qualitative tests to analyse and then compare the properties of the freshly prepared biodiesel (B1) with those of three samples of fuels provided: commercial biodiesel (B2), mineral diesel (D) and petrol (P). The sample of petrol was placed in a fume cupboard and treated as a fire hazard due to its high volatility and flammability and a low flashpoint. The students had to carry out a total of five tests on every fuel sample including the biodiesel they had just produced in this experiment. They had to test the products for properties such as density, pH value, combustion, freezing point and solubility in methanol.

The students enjoyed doing this practical but did not have sufficient time to complete the full analysis of their product and the other fuel samples. In fact most of the tests had to be carried out in the form of a class demonstration with students taking note of the observed changes to write their report. Towards the end of the session it was decided that part of the biodiesel produced would be stored in the laboratory for further analysis which was then carried out in the second laboratory session. Despite these shortcomings, the outcome of this session was still positive, considering the interest and cooperation of the 30 students participating in their first direct experience of green chemistry in practice. Besides this all students seemed to have enjoyed doing such a 'different practical session' on a topic which was already treated in some detail during the green chemistry seminars.

### 6.5.2 Producing a Biodegradable Bioplastic

The second practical session in green chemistry aimed at demonstrating several principles of green chemistry through the laboratory preparation and analysis of a biodegradable plastic made from potato starch which is a renewable resource.

Following a short introduction to this second green chemistry experiment, students were given a hand-out with instructions on the laboratory procedure, safety precautions, space for observations and results and a short exercise related to the same experiment. Students were also given additional literature on renewable polymers including a pamphlet donated by the NNFCC.

The experiment was divided into three parts. In the first part, students had to extract a small quantity of starch from a sample of potato tubers (raw material) using a simple technique. The second part consisted in the conversion of starch into bioplastic. The students who were again working in small groups of two or three, prepared two samples of bioplastic solution, one of which included glycerol as an additive (plasticizer). The solutions were colour-coded using green food colouring for the sample containing glycerol and red pigment to code the glycerol-free solution. The solutions prepared were then poured into labelled petri-dishes and allowed to dry out for one week before final inspection and analysis of the solid product.

The last part of the practical was meant to involve simple tests which students had to carry out on the solidified samples in order to check the quality of the starch-based polymers they had just prepared. However, given the fact that the product was still in the drying stage, the last part could not be performed and was left for the following week to be concluded during a laboratory follow-up session.

Towards the end of the session, students were allowed to resume with their analysis of biodiesel and other fuels started in the previous practical session. This included tests on pH, combustion, solubility and freezing point.

It was evident that students enjoyed also their second hands-on experience in green chemistry. They were particularly satisfied that they were able to synthesize environmentally friendly products starting from commonly occurring raw materials rather than traditional laboratory reagents which are in many cases toxic and / or hazardous chemicals.

### 6.5.3 Conclusion to the Green Chemistry Laboratory Experience

The last session of the green chemistry intervention was held to follow up and conclude the students' laboratory experience in green chemistry, held over the previous two weeks. During this session, the students were able to finalise their reports by going over calculations and sorting out difficulties which they had encountered in answering the questions at the end of each practical hand-out.

The first part of this session consisted of a discussion of results obtained in the biodiesel practical. Students could also compare their observations and results of the tests they had carried out on their product and on a number of sample fuels provided.

The second part of the session was dedicated to the experiment on the preparation of the biodegradable bioplastic. The students were provided with the samples of the dry and solidified plastic which they had produced the previous week and which they had allowed to dry out in the laboratory at room temperature. Participants had the chance to inspect the material produced and to notice the difference in texture between the soft and flexible green-coloured starch-based polymer (which included glycerol as an additive) and the red-coloured plastic which was free of glycerol and had a harder and brittle texture. The students also performed a number of tests on some of the samples of products they had produced, particularly to illustrate the degradability of the material with respect to other non-biodegradable plastics.

Students were overwhelmed with the results obtained in this experiment and they were extremely satisfied for having been successful in converting a renewable resource such as raw potatoes into a biodegradable plastic. The author added the following remark in his research diary:

> "You could read from their eyes the sense of satisfaction for such an achievement. Students were so pleased with what they had done that they asked me whether they could take home a small sample to show it to their parents and friends."
>
> (Field note: finalising laboratory reports – 04/05/2010)

This session allowed enough time for students to finish off their reports and hand them in for marking. Hence the last session proved useful to conclude all the work performed during the additional practical sessions and discuss the outcome as a whole group. A copy of 'sample reports' was also provided to the students so that they could compare them with their own work. These included typical observations made during the experiments, calculations, results of tests performed, as well as model answers to the relevant questions asked in the same exercises.

## 6.6 Critical Analysis of Implemented Curriculum

There is no doubt that an appreciable effort was made by the author to reach the main objectives of the intervention through the programme of activities organised over a span of seven months with a group of A-level chemistry students participating in this case study. The author has already indicated in this chapter that generally speaking most of the activities were held according to the original plan. However a number of important changes were made on the pilot intervention while other changes were imposed as a result of a number of unforeseeable circumstances and other limitations. The following is a short critical analysis of some of the changes affected with respect to the pilot intervention and the intended curriculum and how things could have been modified to improve the learning outcomes.

### 6.6.1 Choice of Green Chemistry Topics

The theory of green chemistry was introduced via a number of classroom seminars which was increased from seven (in the pilot intervention) to ten (in the main intervention). This was done to allow more space for the explanation of the twelve principles of green chemistry and to expand the section on biofuels, giving more prominence to the separate synthesis of biodiesel and bioethanol (the two most commercially important biofuels to data). The seminars covered a good range of aspects of green chemistry so that students could have a good grasp of the subject and also be able to be conversant in it.

If the author had to revise his choice of topics, he would have certainly reduced the content on biofuels to allow space for the treatment of another fundamental area of green chemistry such as Life Cycle Assessment. Life cycle assessment (LCA) is a useful tool for green chemistry as it evaluates the environmental impacts of a chemical product or chemical process “from cradle to grave”. Such a technique underlines the philosophy of green chemistry as it illustrates how decisions are only taken after examining every stage of the life cycle of a product / process including the use of raw materials, manufacture, distribution, use, possible re-use or recycling, and the ultimate disposal of any waste products. Although LCA was considered as one of the possible themes for a class seminar, it was later excluded for a number of reasons such as the time required to explain the many concepts involved (e.g. climate change, energy and water conservation, nutrient loading, biodiversity, waste disposal, etc.), its relatively weak connection with the current A-level chemistry curriculum and the students’ overall scientific background.

### 6.6.2 Use of Teaching Resources & Space for Discussion

The main resource used in the classroom seminars was the computer (Powerpoint) presentations, all prepared by the author, which included the frequent use of custom animation and short video clips to make the presentation more lively and appealing. Students were always provided with a background information handout just before each presentation which included a summary of the same presentation illustrated by diagrams (where applicable) and a list of internet websites for further reference. The handout also referred students to the A-level chemistry topics associated with each seminar presentation. Students were also occasionally given additional printed information such as Newsletters and pamphlets published by organisations such as the NNFCC (UK) and the Green Chemistry Institute of the American Chemical Society, all related to the topic of the seminar. At times even the whiteboard was used by the tutor to emphasize or elaborate on some point raised by the students during each seminar. Although the computer presentations and accompanying audio-visual material were very effective as a teaching strategy, the author believes that they would have been equally appealing if not more effective had they been kept shorter (using fewer slides and other resources per presentation). This would have allowed more space for students to be directly involved in the seminar through activities such as questioning, whole class discussions and small group exercises. In fact, one of the limitations of the classroom seminars was that there was not sufficient time allocated for more student participation following each tutor presentation. This was even pointed out to the author in the feedback comments made by the students at the end of the intervention.

### 6.6.3 Laboratory Work

There was an improvement of the green chemistry laboratory experience from the pilot study, but there were also a number of drawbacks in the organisation of such activities. The fact that the number of green chemistry practicals was increased from one to two sessions per student increased the students' exposure to the applied side of green chemistry. However it also created a problem in the logistics due to limited availability of the college chemistry laboratories. In fact more sessions would have been required if the class were to be divided into two smaller groups (to increase safety) as was the case of the pilot intervention.

Besides this the type of practicals chosen required more time and it would have been more appropriate had a third session been added or had the duration of each session been extended by an hour. This could have relieved students from the pressure to complete all tasks (e.g. reading instructions, following procedures, writing down results and observations, working out calculations and completing report) in the same session.

### 6.6.4 Learning Activities

The idea of dividing the class in small groups (teams) for the learning activities also had its strengths and weaknesses. It certainly helped in creating group dynamics and increasing student participation by involving practically all students in the class in every activity. It also facilitated the interaction between tutor and students with team leaders keeping the rest of their group continuously informed with the progress of the programme and coordinating discussion and any assignments including work on poster presentation. The main weakness of this strategy was that the appointed leaders were not necessarily the best students for the job and a few of them lacked basic leadership skills. Besides this, the work submitted did not always reflect the team effort as originally intended as each assignment was often regarded as an extra homework with students sometimes preferring to take it in turn to tackle each exercise included in the ‘activity worksheets’.

The end-of-seminar assignments were meant to serve as an immediate feedback for the author to check whether students were able to follow and grasp the concepts and theory explained during each seminar. Although the participants generally did well in these exercises, it was clear that for some of them it was like an extra burden especially when it was given as an extra homework. One could perhaps have been more creative by designing different activities which need not necessarily take the form of a written assignment. For example, the ‘slogan competition’ which was also previously piloted, generated a lot of interest among students and certainly reached the aim of urging students to hold small group discussions on a focussed area of green chemistry before agreeing on a common phrase. The same could be said of the poster presentations, which saw most of the students competing with one another and trying their utmost to come up with a good presentation.

The implemented curriculum was similar in many ways to the intended curriculum and reached the expected objectives and intended learning outcomes. Students were presented with a programme which introduced them to an alternative way of doing chemistry which emphasizes safety and pollution prevention at the molecular level. It also showed them how green chemistry is related to traditional chemistry and how it could be applied to real life situations. It also gave students the opportunity to apply some of the principles of green chemistry in a laboratory setting. The consistently high attendance and active participation of students in all seminars, laboratory sessions and other activities of the green chemistry intervention suggests that participants were receptive and predisposed for this curriculum innovation.

## 6.7 Chapter Summary

In order to explore how the intended curriculum intervention was implemented in the classroom and laboratory, the author tried to describe how the planned activities took place and how students reacted as the programme unfolded week after week. The author explains also why certain changes had to be made and how students responded to such changes.

The green chemistry intervention was divided into three parts. The main section consisted of a series of ten classroom seminars each of which normally included a tutor presentation on a chosen theme, followed by classroom discussion and a short learning activity involving direct participation of all students present. Another section was dedicated to students' short presentations based on posters highlighting some aspect of green chemistry. The third part was reserved to the green chemistry laboratory experience illustrating some of the principles of green chemistry.

The chapter describes how each of the green chemistry seminars was organised, including reference to the venue, student participation, teaching and learning resources used and the student activity assigned at the end of each session.

The chapter describes the students' participation in the learning activities and how in most cases the assignment which was originally planned to be carried out in class in small teams ended up as a home assignment. Two of the learning activities that generated most interest among students were the green chemistry slogan competition and the students' poster presentations. In the last part of the intervention, participants were given the chance to experience the applied side of green chemistry by performing two experiments, one involving the laboratory preparation and analysis of biodiesel, the other on the production of a biodegradable bioplastic.

The chapter concludes with a brief critical analysis of some aspects of the implemented curriculum, with particular reference to the choice of green chemistry topics, use of teaching resources, laboratory work and learning activities carried out by the participants.

# Chapter 7

# THE ATTAINED CURRICULUM – PART 1

# Data Analysis: Students' Attitudes towards Chemistry and Green Chemistry in Society

## 7.1 Introduction

This chapter analyses the data generated from various sources to identify any changes in students' attitudes towards chemistry and green chemistry in society, which had an influence on the learning outcomes of the green chemistry intervention and hence on the quality of the attained curriculum. The chapter is the first part of the analysis of attitudinal data mainly obtained from the chemistry survey (pre-test A1 and post-test A2) and several focus groups. It compares results obtained from the GC group (i.e. the set of students participating in the green chemistry classroom / laboratory intervention during academic year 2009/2010) with the non-GC group (i.e. the class of chemistry students acting as a control, without experiencing any green chemistry in the same setting).

The analysis of students' attitudes from data collected using various research instruments has been carried out using the theoretical framework as explained in the methodology chapter. The data analysed in this chapter involves only the students' cognitive attitudes about chemistry (as a science) in society and their cognitive attitudes about the value of emerging field of green chemistry in society, both of which form part of the ten dimensions describing the self-reported students' attitudinal responses in the same analytical framework.

## 7.2 Cognitive Dimension – Chemistry in Society (Dimension 1)

The following were the most important attitudes observed on the influence of chemistry in society as expressed by students from both the GC and the non-GC classes. The account includes also changes occurring in attitudes following the period of classroom / laboratory intervention.

### 7.2.1 Theme 1: Chemistry improves the quality of human life

Students thought that chemistry or rather the activity of the chemical industry supported by research, has made a positive impact on human civilisation. In fact, students from both the GC and non-GC groups agreed that *chemistry contributes to the improvement of the quality of human life*. The chemistry survey found that such a consideration was strongly pronounced by both groups of students, with the GC group showing a more appreciable increase in level of agreement from the pre-test to the post-test point (**item C1**: 69.7% → 83.3% GC; 80.6% → 86.1% non-GC).

During the focus group sessions at the post-intervention stage a number of participants explained why they believed that chemistry was crucial in the progress achieved by mankind. The aspects of chemistry which were most frequently cited by students as being synonymous with the achievements of chemistry include: a healthier lifestyle (thanks to the progress made in medicine 'supported by chemical research'), the progress made in technology, the discovery of new materials and the progress in chemical and manufacturing industry by better exploitation of resources and less accumulation of waste.

Students were particularly impressed with the impact of chemistry on medical research. They thought that medical research cannot do without chemistry as medicines and other pharmaceutical products are all designed and synthesised as a result of knowledge acquired from chemical research. Typical comments made by students include the following.

> *"Even medicine has improved our quality of life… medicine derives from chemistry… basically it's because of chemistry that we have a better quality of life… Medicine… is a result of progress made by chemistry."*
>
> S-50 (non-GC group E)

There were several instances where students acknowledged that medical research relied on chemistry, citing the discovery of new insights of diseases and the role of newly designed chemicals to fight such diseases. One student recounted how he considered chemistry to be at the centre of cutting edge research such as the creation of the artificial cell.

> *"Yesterday, I was watching the news and saw how the artificial cell divides spontaneously… I mean chemistry must have been involved to create this artificial cell."*
>
> S-25 (GC group B)

Another point made by the students was that the evolution of technology could also be at least partly credited to the achievements of chemical research. They referred to the crucial role of chemistry in the progress made by science and in particular the input and collaboration of chemists to develop new technology, as illustrated in the following statement.

> *"You certainly cannot move on without chemistry. As student [S-26] said, without chemistry man would not have gone to space, we wouldn't have made the first step on the moon and I think that probably we would not even have a computer by now."*
>
> S-24 (GC group B)

The general feeling among students was that progress achieved over the years through chemistry, by far outweighs any negative impact that occurred in the past as a result of chemical activity. The following comment made by a non-GC participant summarises such a favourable attitude held by the majority of students towards societal chemistry.

> *"If man failed to recognise the importance of chemistry, the world would not be as we know it today. Because with all the rights and wrongs that it has done, every sign of progress achieved was made by man and was the result of chemistry research."*
>
> S-63 (non-GC group F)

Participants also referred in particular to the design of new materials by chemists which brought about significant changes in the types of commodities used by man in everyday life. The following remarks were typical of those students holding such a viewpoint on the important contribution by chemistry towards a better quality of life.

> *"Even for instance when you consider plastic material which is used to carry drinking water in it. It's important. Without chemistry we would never have arrived at creating this plastic bottle."*
>
> S-25 (GC group B)

The following student wanted to make the point that the benefits of research activity in chemistry were not only limited to medicine, but in fact go beyond that.

> *"… it' s not only medicine. I was in fact about to mention the creation of new and stronger materials with better functionality… more flexible, for example… In cars, for example, you will find modern carbon fibres, lightweight and hence energy efficient."*
>
> S-44 (GC non-group C)

All this is consistent with numerous studies showing that students recognise the worldwide achievements of science and technology and their important impact on society at large. The same studies show that students show favourable attitudes towards out-of-school science, including chemistry (Haste, 2004; Jenkins & Nelson, 2005; Osborne & Collins, 2001; Sjøberg & Schreiner, 2006).

### 7.2.2 Theme 2: Chemistry is still associated with environmental degradation

In spite of the positive attitudes shown by students towards the impact of chemical activity on the environment, more than half of the participants were also certain that *chemistry (or rather chemical activity) was still responsible for most environmental issues* particularly the large-scale disasters which occurred in different parts of the world since the industrial revolution. Both the survey and the focus group data reveal that such an attitude is manifested by all students even though they knew that it was not the intention of chemists to create such problems. The survey shows that such a negative attitude towards 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.

A Mann-Whitney test on this survey item showed that there was an almost significant difference between the mean attitude of the two groups of students at the post-intervention stage: **z-value = -1.808, p = 0.069** (*appendix 31*). This indicates that the GC respondents were less negative than their counterparts, at the time of the post-test, when associating chemistry (or chemical activity) with commonly mentioned environmental problems. One of the possible reasons of the softer negative attitude taken by the GC group in this case was the fact that the students concerned were more aware of the presence and the potential impact of important measures (including green chemistry) which are being taken to protect the environment and some of them factored this in their judgement.

During the small group discussions, some students explained that the main sources of past problems associated with or attributed to chemistry included environmental degradation from industrial activity and transportation, widely publicised environmental disasters, mass destruction from warfare, crimes and terrorism, as well as large scale experimentation. The following was an argument brought about by one of the students on this matter.

> *"There were a couple of large-scale disasters but this is the cost of improvement… progress. That's how I see it. That is to achieve progress and improve you have to carry out experiments in some way or another. You then learn and improve from past mistakes."*
>
> S-26 (GC group B)

However students also realised that part of the harm done by the use of chemicals was avoidable. For example, they noted that the achievements of chemical research run the risk of being abused to the detriment of humanity. Some of the students went as far as labelling abusive polluters as 'greedy' or 'selfish' businessmen who were only interested in profit making but did not really care about the environment. The chemical industry was particularly blamed for turning a blind eye on pollution as it was primarily focussed on the attitude of 'making money and nothing else'.

### 7.2.3 Theme 3: Chemistry has an overall positive impact on the environment

Although the 'hand' of chemistry was largely blamed for being behind environmental disasters that occurred in the not-so-distant past in different parts of the world, participants were still positive when they considered also the benefits that chemistry brought about as a reaction to past mistakes. This could be noted in students' remarks such as the following.

> *"… first they discovered nuclear fission… by which the Americans created the atom bomb. But then they discovered that they could use the same (scientific) principle to produce a power station."*
>
> S-47 (non-GC group E)

The chemistry survey shows that about two thirds of the students in both groups believed that *chemistry had an overall beneficial effect on the environment*. This implies that most of the students held a favourable attitude towards all activities carried out under the umbrella term of 'chemistry'.

Students also realised that chemical research today is becoming increasingly important to safeguard the environment. If one leaves out direct references to green chemistry, which are treated in other sections of this chapter, one still finds a number of students' references on how chemical research also left its positive mark on environmental issues.

Similar findings from other studies confirm that the majority of school students believe that chemistry plays an important role in solving environmental problems and trying to improve the quality of our lives (Bennett & Hogarth, 2009; Salta & Tzougraki, 2004). Other similar views emerged in a number of other studies cited in the UK State of the Nation Report 2008 (Bennett, 2008).

### 7.2.4 Theme 4: Chemistry can do more for the environment

The general feeling among focus group participants (including non-GC members) was that chemists were doing their utmost to fight pollution and avoid large scale environmental problems.

Some of the students cited green chemistry as being one of the most important reactions of the chemistry community to fight pollution as the strategy shifted from pollution control to pollution prevention. This is how one GC student referred to such a development in chemistry aimed at mitigating the impact of chemicals on the environment.

> *"… in chemistry something concrete is being done… The fact that chemists came up with the idea of green chemistry, it means that there is a serious awareness and a strong will to do something tangible. Even if it may simply be something on a small scale… but there is a significant start."*
>
> S-14 (GC group D)

Students expressed themselves against the idea that chemistry was doing nothing to address the environmental problems it has created in the past. One student reacted as follows to show his disagreement to such a proposal.

> *"I think the term 'nothing' is too strong as a word to use. It could be that they (i.e. chemists) are not doing enough. It could be that we need to work harder, to do more research, to invest more money, rather than on less worthwhile projects, on how to take better care of our environment in order to protect and conserve it for future generations."*
>
> S-36 (non-GC group E)

Another student from the same focus group argued that the growing public awareness on environmental issues was another proof of the efforts by chemists to prioritise such problems and putting them in the limelight in the hope of tangible solutions.

> *"… all those involved, the chemistry experts, are doing their utmost to try and solve the problems related to global warming, pollution, etc. The fact that the media is all the time speaking on these problems… and the documentaries that we watch on TV… So they are informing us on what to do to reduce the harm… They are not keeping everything to themselves."*
>
> S-55 (non-GC group G)

This study also revealed that students reckoned that the potential of chemistry to protect the environment is not yet fully exploited. In fact the chemistry survey found that the majority of students in both groups *rejected the idea that chemistry was doing enough to control the different forms of pollution*. This attitude was more strongly expressed in both classes by the end of the year, with a sharper increase in level of disagreement observed in the GC class by the end of the intervention.

On a similar note, the same survey revealed that while acknowledging the continuous effort by chemists to fight pollution, most students were convinced that *chemistry can do more to protect the environment*. In fact, results show that about 80% of students from both groups held this view at the beginning of the year with hardly any changes occurring by the end of the year. Such an attitude was confirmed even in focus groups with statements such as the following:

> *"The problems are being addressed but this is not enough. More research needs to be done."*
>
> S-48 (non-GC group E)

There were also isolated cases of students hinting an opposite viewpoint, i.e. that they consider that chemistry was doing nothing concrete to solve environmental issues. Some of the GC students argued that it was only thanks to initiatives such as 'green chemistry' that something significant was being done to address pollution problems in the long term.

The fact that students feel emotional on the link between chemistry and the environment confirms evidence from other work that students at this level are very much sensitive to world environmental problems and their initial concern would more likely transform into interest for the scientific aspect of the same problems (Cooper, Elzerman & Lee, 2011; Stearns, 1988).

## 7.3 Cognitive Dimension – Green Chemistry in Society (Dimension 6)

Both groups of participants aired also their views on the impact of the new field of green chemistry on society, even though the non-GC group could only guess or deduce responses from parts of the same chemistry survey or from some information that they might have come across on a personal basis, beyond school. Views on green chemistry were particularly elaborate in the case of the GC students participating in focus group discussions.

### 7.3.1 Theme 1: Green chemistry has a positive impact on human health and the environment

Students forming part of the GC group were convinced that green chemistry had the potential to improve the overall state of human health and the environment. This was evident both in their responses in the chemistry survey as well as in their remarks during the focus group sessions held at the end of the green chemistry intervention.

The chemistry survey showed that almost all participants (from both GC and non-GC classes) agreed that *green chemistry has a positive impact on the quality of human life*. Analysis of data shows that the GC participants were more unanimous on this viewpoint, even though the non-GC group also showed a markedly positive attitude on the possible beneficial effect of their self-concept of green chemistry at the end of the year.

The GC participants acknowledged that green chemistry can make the difference in the quality of their lives as it was aimed towards reducing pollution on a large scale and reducing exposure to dangerous chemicals. They also thought that green chemistry was safer and eliminates or reduces risks to human health. Others realised that green chemistry is not limited to a local situation but is beneficial to all mankind. Most of them agreed that it was an important development as it addresses past mistakes mainly associated with the chemical industry. Students thought it also brought about an improvement by saving energy, raw materials and money. The following was a typical comment made by a GC student on the positive effects of green chemistry in society.

> *"The impact is definitely positive… it must be a great improvement… I'm sure that if these reactions / processes are rendered greener, less toxic products would be produced and this would have a positive effect on the state of the environment. After all, this would leave a positive effect on all of us, too."*
>
> S-26 (GC group B)

The following were some further arguments made by students manifesting some of their positive cognitive views on green chemistry at the post-intervention stage.

> *"But in green chemistry, the emphasis is to avoid any sort of harm. Green chemists are more concerned on the impact a chemical process can have on people."*
>
> S-20 (GC group C)

> *"Green chemistry is now trying to fix the problem and improve the situation from now on… taking extra care of our health and also the environment."*
>
> S-21 (GC group D)

One could easily notice that students forming part of the GC class were very eloquent and at times almost passionate when expressing themselves on green chemistry and none of them ever disputed its potential to boost the positive impact of chemistry on mankind.

### 7.3.2 Theme 2: Green chemistry is environmentally friendly and is synonymous with pollution prevention

Data from part B of the chemistry survey shows that by the end of the year, both sets of students understood that green chemistry was an environmentally friendly approach of practising chemistry which created less pollution. However the statements used by the GC participants at the post-intervention stage to define green chemistry were more complete and focussed with respect to those given by their non-GC counterparts as explained further in chapter 9 dealing with students' understanding of green chemistry ideas.

The survey showed that the majority of non-GC students had a partial understanding of the term ‘green chemistry’ by the end of the year, but this was probably achieved (as indicated earlier) by intuition, by deduction from the type of questions asked in part A of the survey and / or from other possible external sources. In fact very few statements given by the non-GC students covered ideas such as ‘design of safer alternative reagents’, ‘pollution prevention’ or ‘sustainability’ which are all among the key aims of green chemistry.

The sharp contrast that emerged between the two groups on the concept of green chemistry is confirmed from the post-test results of the chemistry survey which show that all GC students declared *they possessed a good understanding of the term ‘green chemistry’* while less than half of their non-GC counterparts were confident about the exact meaning of the term. A Mann-Whitney test confirmed that responses from the two groups were statistically highly significant in the post-test exercise: **z-value = -4.989, p = 0.000** (*appendix 31*).

Analysis of another post-test item shows that more students from the GC group, compared to non-GC participants, viewed green chemistry as a proactive approach to pollution prevention, i.e. an effort to *prevent environmental pollution before it starts* to occur. A Mann-Whitney test on item F6 found a significant difference between the responses from both groups of students: **z-value = -2.944, p = 0.003** *(appendix 31).*

Similar results were obtained in both groups when students were asked whether it was true that *green chemistry principles used a new and more effective approach to address environmental problems*. In fact survey results indicated a substantially higher level of agreement on this idea among GC participants. The Mann-Whitney test on responses to this survey item confirmed another significant difference between the two groups at the post-intervention stage: **z-value = -1.997, p = 0.046** *(appendix 31).*

### 7.3.3 Theme 3: Green chemistry represents a bold effort by chemists to avoid committing past mistakes

Students viewed green chemistry as a reaction by the worldwide chemistry community to avoid committing past mistakes which spelled out into a number of large-scale environmental disasters. This means that students understood the major role of green chemistry as a sort of 'preventive medicine' required by the chemical and related industries in order to ensure that no more human lives are lost by toxic emissions and chemical contamination. This was paraphrased by students in comments such as the following.

> *"Green chemistry has grown in importance after realising the disasters created in the past with traditional chemistry… the harm produced by past experiments and other activity can be prevented by acting now."*
>
> S-22 (GC group D)

All participants held a very high opinion of green chemistry, viewing it as an important development of chemistry 'to make up for past damage'. One participant described it as a 'remedy for the bad things that happened in the past' confirming the general feeling by his colleagues that green chemistry was a concerted effort by a movement of chemists to counteract the failures of some of their predecessors and convert negative into positive experiences of chemistry. Students saw in green chemistry 'a long term investment' by chemists which aims at securing healthier future generations.

Members of the GC group also understood that the success behind such a 'new way of thinking and doing chemistry' depended on the goodwill of many stakeholders and the support of green chemistry education starting at a young age at school.

### 7.3.4 Theme 4: Green chemistry is feasible and sustainable, but not easy to apply

The GC participants were also convinced that green chemistry was not simply theoretical but could in fact be implemented successfully in many ways even though they realised this was not a straightforward task. This was evident in the way they responded to some questionnaire items in the chemistry survey, and confirmed by the way they expressed themselves during the focus group sessions. On the other hand, their non-GC counterparts showed, in the same survey, that they were less convinced about the feasibility of green chemistry.

Another distinct contrast resulted when students were asked whether they agreed or not that *the principles of green chemistry were difficult to apply*. The percentage of GC respondents disagreeing with this was more than double the percentage of non-GC students taking the same stand. This shows that the GC respondents were far more confident than their non-GC schoolmates to express themselves positively about the concept of feasibility of the green chemistry principles. This was confirmed by a Mann-Whitney test on this item which pointed out another significant difference between the responses of the two groups at the post-intervention stage: **z-value = -2.789, p = 0.005** *(appendix 31).*

Despite being so sure about the viability of the green chemistry enterprise, GC students were very much aware that the fundamental principles of green chemistry were not always easy to apply as it involved being extra careful in the planning of chemical processes taking into account many environmental considerations. This notion came out during the focus group discussions with students making frequent reference to phrases such as 'it's not easy being green'. However, students overwhelmingly rejected the idea that *green chemistry consists simply of a set of dreams that can never be realised by the chemical industry*. Once again, the level of disagreement was substantially higher in the GC class, producing a sharper gap between the percentage of agreeing and disagreeing respondents. The Mann-Whitney test conducted on this questionnaire item confirmed that the two groups held a significantly different point of view at the time of the post-test: **z-value = -2.207, p = 0.027** *(appendix 31).*

On the other hand, students were concordant on the idea that *green chemistry is vital in securing a sustainable future for the next generation*. In fact there was a strong voice of approval on this in both groups, with a slight edge by the GC participants. So students in general had no doubt that green chemistry marked an important step towards an improved standard of living.

The two groups participating in the project responded in a completely different manner at the idea that *green chemistry principles are too expensive to be used on a regular basis* implying that green chemistry might not be economically viable. In fact while the GC group disagreed on the statement, the level of agreement was higher in the non-GC class. A Mann-Whitney test conducted on the survey results of this item confirmed a very significant variation between the responses from both: **z-value = -3.194, p = 0.001** *(appendix 31).*

GC participants were more confident that green chemistry was in fact economically viable despite being more stringent on the choice of reagents and synthetic pathways, as the use of hazardous materials includes a number of hidden costs related to the disposal, treatment and regulatory costs. The GC group was convinced that applying green chemistry principles will turn out to be economical even when one factors in the costs of the investment required in the greening of a chemical process. Such reasons were pointed out by a number of students during the focus group discussions at the end of the green chemistry intervention. The following is one example of what the students had to say on this.

> *"Even when we hear, for example that in Europe, if you reach a certain quota of pollution you will have to fork out a hefty fine….. So I think that the industry would stand to gain by investing in greener techniques and new cleaner technology… It would be wiser if you spend money which you know is going to give you a return rather than having to pay excessive fines for nothing."*
>
> S-25 (GC group B)

Results were even more contrasting when students were confronted with the idea that *chemistry can never be rendered 'green' because of higher energy consumption and pollution problems*. About two thirds of the GC respondents disagreed on this compared to about one fifth of the non-GC respondents adopting the same viewpoint. Students agreeing that it was very difficult to implement green chemistry successfully due to energy and pollution considerations, was higher in the non-GC class. A Mann-Whitney test carried out on data generated by this survey item confirmed that, there was a highly significant variation between the groups in the way they responded to this survey item by the end of the year: **z-value = -3.596, p = 0.000** *(appendix 31).* This confirmed that the GC students were more convinced about the applicability of the green chemistry concepts even when one considers the ever increasing demand by the industry for energy and resources.

These results show that students from both classes had a very basic idea of green chemistry by the end of the year and acknowledged the fact that it was beneficial for the well-being of present and future generations. However the GC group adopted more favourable cognitive attitudes towards it and were more optimistic that chemistry can one day be rendered truly 'greener', i.e. harmless, through the use of alternative materials and processes that would in fact be worthwhile doing even on economic grounds.

## 7.4 Students' Convergent and Divergent Views on Chemistry & Green Chemistry

The two groups of students participating in this project were found to share similar cognitive attitudes towards chemistry in society but significantly different attitudes towards the value of green chemistry as a new science.

### 7.4.1 Cognitive Dimension – Chemistry in Society (Dimension 1)

Analysing the students' cognitive attitudes towards chemistry (dimension 1 of the attitude theoretical framework) there was a general consensus among all students (GC and non-GC) that chemistry improves the quality of human life and has a positive impact on the environment. However students thought that chemistry is still associated with environmental degradation and it has the potential to do more to safeguard the well-being of the environment. Students from the GC class were found to be less negative in their outlook towards the responsibility of chemistry for environmental issues. In fact, one of the survey (questionnaire) items showed that the opinions of GC students were almost statistically different from those of the non-GC participants who were more adamant that chemistry is synonymous with environmental degradation. The GC participants regarded the very existence of green chemistry as one of the concrete steps taken by chemists to address pollution problems.

### 7.4.2 Cognitive Dimension – Green Chemistry in Society (Dimension 6)

Another set of attitudinal responses (dimension 6) covered the students' cognitive attitudes towards the value of green chemistry as a science. It is clear that both sets of participants held very favourable attitudes towards green chemistry as a science as they acknowledged almost unanimously, its potential positive impact on human health and the environment. The GC class showed stronger support towards this viewpoint at the end of the intervention.

The two groups were however divergent in some of the fundamental views on green chemistry. For example the GC class held a significantly stronger view that green chemistry represented an effort by chemists to prevent environmental pollution at source. The same applies to their belief that green chemistry principles are effective to address environmental problems. One survey item confirmed also that the GC participants were significantly more confident than their non-GC counterparts that they had a good understanding of green chemistry by the end of the intervention. Another sharp contrast resulted when students from both groups expressed themselves on the applicability of green chemistry. The survey results show that GC respondents were far more convinced than their non-GC colleagues that the principles were also feasible. The same group showed a similar stronger attitude when it rejected the suggestion that green chemistry was a sort of wishful thinking that can never be implemented by the chemical industry. This indicates how determined these students were that green chemistry can truly make the difference in society at large.

Significant differences were also registered in the students' responses on the sustainability of green chemistry from the economic and environmental points of view. In fact the GC group disagreed with the ideas that green chemistry was too expensive to be used on a large scale and also that chemistry can never be rendered truly 'green' on the grounds of high energy consumption and unavoidable pollution problems. The situation was very different in the case of the non-GC class which showed a remarkably higher level of agreement (on this questionnaire item) in both cases.

When the statistical results on this set of questionnaire items analysed in this dimension were compared, students from both classes were found to have an appreciably different general view of green chemistry as a science with the overall means varying from 2.78 (GC) to 2.42 (non-GC). This means that by the end of the classroom / laboratory intervention, the GC class held an overall higher opinion on green chemistry than the control group and showed less scepticism towards its feasibility and benefits to industry and society in general.

## 7.5 Chapter Summary

This chapter treats the main themes emerging from the data analysis describing the students' cognitive attitudes towards chemistry and green chemistry in society before and after a curriculum intervention with one of two groups attending a sixth form institution in Malta. The findings show that the students' attitudes towards chemistry in society in the two groups were more or less the same especially at the pre-intervention stage. However there were some important differences in the way the two groups of participants viewed the contribution of green chemistry to society, particularly at the post-intervention stage.

Both groups of students recognised the achievements of chemistry to improve the quality of human life particularly its significant input in the progress made by medicine, the development of new materials and the evolution of modern technology. This is very concordant with previous research evidence showing that students of the same age usually held favourable attitudes towards science and chemistry in society.

Participants also tended to agree that chemistry was still responsible for most environmental problems but this negative attitude was less pronounced within the GC class by the end of the year. This indicates that the GC participants were more confident on the social responsibility of chemistry with respect to environmental protection.

Participants tended to agree that green chemistry represents an important development of chemistry which would further improve the already positive impact of chemistry on society for a number of reasons particularly related to pollution prevention and the conservation of energy and resources. The GC group showed that it had a significantly better understanding of the role and general principles of green chemistry than the control non-GC group. The same GC participants also had a significantly stronger view that green chemistry was a proactive approach to pollution prevention and that the green chemistry principles were effective tools which may be used to address environmental problems.

Members of the GC group were found to adopt a stronger attitude (compared to non-GC participants) when expressing themselves favourably about important aspects of green chemistry such as the feasibility of the key principles involved, its environmentally friendly credentials and its economic viability especially in an industrial context. Evidence shows that the GC group was generally more convinced about the usefulness of green chemistry and adopted a more favourable attitude towards it when compared to the other group of students involved in the same programme of studies.

# Chapter 8

# THE ATTAINED CURRICULUM – PART 2

# Data Analysis: Students' Attitudes about Learning Chemistry and Green Chemistry

## 8.1 Introduction

This chapter continues to analyse the data generated from various sources to evaluate the impact of the green chemistry intervention on the students' attitudes towards chemistry and green chemistry, especially through their learning experience at school, in a bid to understand the achieved curriculum. The chapter deals mainly with the analysis of attitudinal data generated from the chemistry survey and several focus groups involving two groups of students attending the main sixth form college in Malta during academic year 2009-10. It compares data obtained from the GC class (experiencing the green chemistry classroom / laboratory intervention) with that obtained from the non-GC class (which served as a control group).

The second part of the analysis of students' attitudes from the data generated from the various research instruments was carried out using the same theoretical framework employed in the first part of the analysis (chapter 7). The data analysed in this chapter involves the remaining eight (out of ten) dimensions of the students' attitudes as outlined in the theoretical framework.

## 8.2 Cognitive Dimension – Learning Chemistry at School (Dimension 2)

Students expressed themselves on how they felt about school chemistry at the beginning of the year and then just a few weeks before sitting for their end-of-year exams, half way through their two-year course at the sixth form college. The following were the main cognitive attitudinal responses that emerged from analysis of the survey and focus group discussions.

### 8.2.1 Theme 1: A-level chemistry is a rather difficult science subject

Students considered chemistry to be hard and difficult for a number of reasons such as the presence of abstract concepts, memory work involved, difficult calculations, an overburdened curriculum, irrelevant topics, repetition of material, a perceived gap between O-level and A-level chemistry and the influence from people with a negative perception of the subject.

Students argued that chemistry was more abstract than other sciences and that was one factor that made chemistry harder for them to understand. The following was one of the typical comments made by students to support this viewpoint.

> *"I think more students choose biology than chemistry because (in biology) you are learning on something that you can visualise…. e.g. the human body, plants. On the other hand, in chemistry, you are dealing with atoms… you cannot see them with the naked eye and spot the p-orbital, for example."*
>
> S-8 (GC group A)

Students admitted that some concepts were made harder with the use of chemical formulae and equations and the use of complex models to explain phenomena such as chemical bonding. This is concordant with research showing that science is always perceived by students to be theoretical and harder than other subjects for a number of reasons including the use of unfamiliar terms and complex concepts (Osborne & Collins, 2001; Parkinson et al, 1998; Porter & Parvin, 2008).

The literature review suggested that students find it harder to use and apply the chemical concepts than to understand them. Gabel (1999) argues that the main problem with understanding chemistry is the fact that instruction occurs mostly at the symbolic level which happens to be also the most abstract level of communication.

Students were also concerned that A-level chemistry included a lot of memory work and tricky calculations which made the subject extremely demanding. The following was one of the arguments made one of the students in this regard.

> *"Now I am feeling that I am forced to remember certain details by heart. As I have to reason out so many concepts that for the exam you can make a mess of the reasoning you are expected to explain and end-up in mixing things up. So I find it better to play safe and possibly learn things by heart."*
>
> S-66 (non-GC group F)

This agrees with literature evidence which shows that the two factors which contribute to the students' perception of science as a difficult subject are the need to memorise facts 'for tests and exams', and the mathematical skills required for calculations (Osborne & Collins, 2001; Blenkinsop et al, 2006; Collins, 2011).

One other major difficulty encountered by students was that of having to cope with a vast examination syllabus in a limited time. They agreed in general that they did not have sufficient time to assimilate all the material which they were expected to cover during the course, particularly when one considers the long time they spend at the college every day (sometimes till 5.00 pm) plus other commitments such as private tuition which allows them little space for home study.

One of the problems often cited in attitudes studies is this students' concern that the science curriculum was overloaded with facts, leaving students to struggle to cope with the content whilst they are 'frog-marched across the scientific landscape' (Osborne & Collins, 2001). The general feeling of students in this study was that there was too much content and that material was too crammed, allowing little space for discussion mainly due to examination pressures.

Another factor which according to students made A-level chemistry hard and less interesting was the inclusion of material which they considered to be detached from real life or not directly relevant to their everyday lives and their future career aspirations. The following is an example of how one student felt about 'irrelevant' curriculum material.

> *"Let's take the case of 'chemical equilibria' just to be more specific. To my mind this is useless – you would not need it, you would never use it."*
> S-24, GC group B

The topics of 'periodicity' and 'chemical equilibria' were the ones that were most frequently mentioned and regarded by students as the least relevant with respect to others covered in class during their first part of the A-level course at the college. One student (S-26, GC group B) stood out and went against the grain rebutting the argument by saying that topics / areas of chemistry which students indicated as 'irrelevant' were probably the least fancied ones rather than the least important. There is ample research evidence suggesting that some aspects of science, and chemistry in particular, are viewed by students as being irrelevant and students found it hard to make links between such topics and their everyday lives (Cerini et al, 2003; Osborne & Collins, 2001).

Another point made by students was what they perceived as repetition of material, which was probably a reference to overlapping parts of the subject matter. More than making it harder, this was one possible point of students' disengagement from the subject at this level. The following is a typical comment made in this regard.

> *"They make it like a habit sometimes. Repeating the same thing over and over again. The student would feel bored. And it sounds like a standard procedure."*
>
> S-24, GC group C

This is another finding which can be matched with evidence from other studies showing that repetition of topics is one of the factors which contributes to a 'growing disenchantment' with science (Collins, 2011). Students may perceive such repetition as lack of progression in the subject matter rather than a development or consolidation of basic theory.

Students were particularly concerned about what they considered as an apparent gap separating O-level and A-level chemistry, especially in terms of content and concepts that made the transition from one level to the other harder than expected and far from seamless.

Some participants argued that some chemical concepts are made more difficult (tougher) as they are taught in different stages, spaced out by months if not years of classroom explanation. This made some chemical concepts appear to be fragmented or discontinuous. Some conceptual models explained at secondary level, e.g. atomic structure and electronic configurations, were almost completely discarded or radically transformed into new concepts at sixth form level. The following represents the students' line of reasoning on this perceived interruption between O-level and A-level chemistry subject matter.

> *"At times I have the sensation that I'm starting it (i.e. the subject) all over again here for A-level and I might as well forget all about the O-level stuff. I don't think they are so much related."*
>
> S-44, non-GC group E

There are certainly different factors that contribute to this imaginary gap between secondary and post-secondary chemistry. One of these factors must be the lack of detail given by secondary school chemistry teachers to students asking for extended explanations to specific queries, the main excuse being that the detailed version of the answer would be provided at a later stage. This has been referred to by Osborne & Collins (2001) as an 'act of bad faith' considering that only a small fraction of students usually proceeds with science at a higher level. Another factor is the different structure of the O-level and A-level curricula which gives a general sense of discontinuity of chemistry concepts and topics covered in class, and make it harder for students to obtain a 'seamless picture' of the subject.

Students from both groups shared the general feeling that they were mostly discouraged from choosing chemistry by members of their family and / or friends who had the impression that the subject was harder than the other options. A good number of students felt that they were influenced by this negative viewpoint on chemistry of people close to them, but some decided to simply ignore them. This is what one student had to say on the influence of other people on their decision to choose the subject and how this perspective made the subject appear to be harder than it really was.

> *"… even the influence from the people… When I decided to opt for (A-level) chemistry there were even some relatives who were surprised and who discouraged me with their comments because they believed it was so difficult. But it was my choice…. It appears that people are simply terrified when they hear the term 'chemistry'."*
>
> S-11 (GC group A)

Research confirms that students' attitude towards school science is in fact influenced by peers and friends (Breakwell & Beardsell, 1992; Simpson & Oliver (1985); Talton & Simpson, 1985).

### 8.2.2 <u>Theme 2: Chemistry improves aptitude / achievement in other sciences</u>

The majority of the chemistry survey respondents thought that *studying chemistry improved their aptitudes in other sciences*. In fact students' response on this survey item was overwhelmingly favourable especially in the GC class and there was almost no change in such a student attitudinal response after the intervention. This implies that students strongly believed that studying chemistry at school was an advantage as it helped them to study and perform better in the other sciences.

On the other hand, the same students were less concordant on *whether doing well in chemistry improved their chances to do well (also) in other non-science subjects*. In fact according to the data emerging from the survey, the level of agreement on such a possible link between performance in chemistry and performance in other non-science school subjects was less than 50% in both groups, with no remarkable changes during the period of the intervention.

### 8.2.3 <u>Theme 3: A-Level chemistry lacks relevance and needs updating</u>

One of the points of disengagement of students from the subject seems to be its perceived lack of relevance to everyday life and its apparent detachment from the real world situations. In particular students pointed out that topics that were sub-microscopic such as the atomic structure and bonding, or those that were largely symbolic such as the periodicity of elements and compounds, were not as immediately relevant, as topics that were more tangible such as corrosion of metals and environmental chemistry.

Other participants particularly students belonging to the non-GC group, brought up the issue that the current A-level chemistry programme is almost devoid of any reference to environmental matters. Students viewed this as a major shortcoming as they thought that environmental chemistry concepts and real-world examples would have brought the subject closer to their everyday lives, especially now that the quality and sustainability of the environment feature so prominently in current affairs and political agendas. The following was one of the students' opinions on this matter.

> *"But nothing is being taught here which actually indicates to us or has anything to do with the environment or our future. Even though you may realise what's going on at the molecular level… as far as what happened in the past disasters… nothing is actually enticing us to (continue) studying in the future… nothing at all!"*
>
> S-42 (non-GC group E)

One particular student from the non-GC class made what eventually turned out to be the only direct reference from his group on 'green chemistry' during one of the focus group discussions. He argued that he was disappointed to learn about such an important development in chemistry from another subject rather than from A-level chemistry. The following are his own words on how he discovered the idea of green chemistry.

> *"In fact the only green chemistry that I learnt about I happened to learn it from environmental science and not from chemistry itself… from a completely different subject… and that's really incredible!"*
>
> S-50 (non-GC group E)

The relevance of science to everyday life is an area which has long been of interest to researchers into attitudes to science (Bennett, 2008; Cerini et al, 2003). Research shows that the more relevant the science curriculum the more interest it generates among students

(Jenkins & Nelson, 2005; Murray & Reiss, 2005; Osborne & Collins, 2001). Other evidence indicates that the less relevant school chemistry was the more easily students get disengaged with the subject (Barmby et al, 2008; Cerini et al, 2003; Lyons, 2006; Murray & Reiss, 2005; Osborne & Collins, 2001; Porter & Parvin, 2008; Ware, 2001b). A common finding in such studies was that students could hardly make any connection between the science taught at school and the realities beyond the school precincts.

The students participating in this research study agreed that their chemistry programme needs some changes to illustrate the progress made by chemistry and its impact on contemporary society. This was the outcome of their response to the suggestion that *the chemistry curriculum needs being updated in order to reflect better the present and any possible future contribution of chemistry to society*. The idea could also be confirmed from the various statements made by the participants from different focus groups who argued that one of the important factors leading to students' disengagement in chemistry at this level was this lack of relevance to the real world.

This call by students to update the chemistry curriculum and make it more relevant to life conforms very much with the need, expressed by researchers evaluating the ROSE study, to 'humanise' school science and show that science also forms part of the history of human civilisation, and is a 'corner-stone in our present, modern world view' (Sjøberg & Schreiner, 2010).

## 8.3 Affective Dimension – Chemistry Theory (Dimension 3)

Most of the students' responses regarding learning of chemistry theory, in both the survey and focus group exercises could be regarded as partly affective and partly cognitive. Students explained why they enjoyed the chemistry lessons / lectures and also what made such chemistry theory appear at times to be unappealing. One particular aspect investigated in this section, as it relates to green chemistry, was the students' interest in environmental topics covered during chemistry theory lessons.

### 8.3.1 Theme 1: Chemistry is a subject that appeals to young students.

Despite knowing that it was a challenging subject and at times it may appear to be hard for a number of reasons, students thought that school chemistry still appeals to young people. The main factors which students thought make school chemistry interesting were the joy of discovery of scientific reasons behind common day phenomena, its usefulness and its application in real life situations, and also the students' future career aspirations.

The following student explains why s/he was still interested to study chemistry despite being discouraged to do so by many other people.

> *"… we are part of the younger generation and I find chemistry very interesting… because for instance, I'm interested to know more on the chemistry of fireworks, what they are made of. I'm also interested to know more about chemistry of everyday life. And what I'm consuming… for example, if I'm using a product… everything is based on chemistry… and I'm interested to know what it's made of."*
>
> S-20 (GC group C)

One point often mentioned by students to explain why they considered chemistry to be an appealing subject is the fact that it is related to other subjects (particularly biology) and to everyday life as shown in the following statement.

> *"… when students realise that the two subjects (biology and chemistry) are so much connected… then chemistry would be appealing to the younger generation, perhaps because once you know that things are so much related and make a lot of sense then you would automatically want to learn more. That's what I think!"*
>
> S-37 (non-GC group G)

This study found that students in general enjoyed more learning chemistry at sixth form (post-secondary) level than at their lower secondary education. However several other students from both groups claimed that they found the subject to be alluring mostly at O-level.

The chemistry survey found that students in both groups *always found chemistry to be interesting in their secondary education*. However this positive attitude was less strongly manifested in both groups at the post-intervention stage. A few number of students claimed that they found O-level chemistry more interesting and stimulating than A-level chemistry for a number of factors. These include satisfaction for discovering new scientific knowledge, greater relevance to everyday life situations (citing specifically environmental topics as an example), a shorter examination syllabus, the joy of experiencing for the first time hands-on activities in a school laboratory environment, feeling less pressurised by exams and the fact that concepts and calculations were less complex.

One of the findings of the chemistry survey was that *students did not regret having chosen chemistry as one of their A-level subjects* but there was an observable downward trend in both groups, particularly in the non-GC class, by the end of the students' first year experience at the sixth form college. In fact, the survey found that an overwhelming majority thought they made a good choice at the beginning of the year but numbers dropped with time, the biggest drop occurring in the non-GC. On the other hand, the number of students admitting to have made the wrong choice when opting for A-level chemistry increased more appreciably in the non-GC group. It appears that the GC group were more satisfied with their A-level course with respect to their non-GC counterparts, by the end of their first year at the college.

There is a strong indication that students enjoyed more chemistry at post-secondary level than at secondary level. This was confirmed by students in both groups during their focus group discussions. According to students participating in such focus groups, their interest to study A-level chemistry stemmed from a combination of factors such as the students' higher level of understanding of the subject, their ability to correlate better the different concepts / aspects of chemistry and so form a more complete picture of this area of science, the practical sessions and their realisation that studying chemistry did not rely solely on rote learning. In fact some students claimed that they liked chemistry at O-level mainly out of a sense of curiosity to discover something new, while at A-level they felt more intrigued to discover the 'rest of the story' as by that time, they would have developed higher cognitive skills and a broader scientific background.

One of the non-GC participants described why he felt less of an outsider once he made the grade from O-level to A-level chemistry. He drew the analogy of a curious person making it to the other side of the fence which previously hindered him from accessing to some valuable information (the body of scientific knowledge).

> *"I see O-level chemistry as being in a place waiting behind a closed gate. In O-level chemistry, you're looking in from outside and observe things occurring from the outskirts. Once you're in for A-level you're inside and have to start looking for all details… which you would not even have considered at O-level. I mean if you try to explain the A-level details to a student doing O-level chemistry, he would be overwhelmed."*
>
> S-44, non-GC group E

Some students made reference to the more regular laboratory experience they were gaining at this level, which increased their level of engagement in the subject. The following is a typical comment made by one of the participants on this matter.

> *"… unless you see things in front of your eyes… you would not understand as much as we're doing now. You cannot compare an O-level with an A-level. The A-level is better in many ways. You understand better and in my case, I am putting more of it into practice as I had no proper laboratory experience before."*
>
> S-61 (non-GC group F)

Students from both groups confirmed in the chemistry survey that they liked the subject so much that they did not study it solely in order to pass the exam and join university. In fact the majority of students in both classes rejected the idea that they were only *motivated to study chemistry in order to pass the A-level examination and gain access to a university course,* even though the level of disagreement decreased with time in both groups. However, the exam motivation seemed to gain ground with time with students agreeing with the survey statement increasing in both cases over the same period of time, indicating that the students' intrinsic motivation in the subject shifted to an extrinsic motivation as students approached their end-of-term examination.

There was a minority of participants who admitted they did not like the subject but only chose to study it for other reasons such as career motivation. The following was perhaps the most direct statement representing such an attitude.

*"… to be honest I don't like chemistry very much. I chose it simply because I want to become a doctor. Otherwise I hate it as a subject."*

S-48, non-GC group E

The fact that chemistry students at this level are mainly motivated to study out of their special interest in the subject could be confirmed by research evidence showing that this self-motivation was an important factor, even superior to other factors such as career prospects and teaching methods, which students considered when deciding to pursue science beyond the age of sixteen (Havard, 1996).

### 8.3.2 Theme 2: Students' interest in chemistry is linked to achievement

Achievement was cited by a number of participants as one of the factors that contribute to the student's interest in the subject at school and affect the students' attitude to study chemistry.

Several students from both groups (but mostly from the GC side) explained how they decided to study chemistry post-16 after having discovered they had an aptitude for science in earlier education. One of these students had this to say on how his achievement in science influenced his decision to choose to study the science subjects.

*"… When I used to learn science during my first two years in my secondary school, I used to do well and then I said let me continue studying them (i.e. the science subjects). And then I started getting more interested in science… So I started becoming more intrigued… and I wanted to discover more. That's why I decided to specialise in sciences."*

S-21 (GC group D)

This indicates that students who proved themselves good in science at the secondary level of education stood a better chance of choosing sciences at post-16.

There was a general agreement among all student participants (GC and non-GC) that *chemistry has to be made more interesting in order to help students pass the A-level exam*. In this case, students argued that if they were more engaged with the subject they stood better chances of passing their A-level chemistry exam. This implies that students realised that there was an important link between interest in the school chemistry and academic achievement in the same subject.

The chemistry survey showed that consensus on this viewpoint was stronger in the non-GC group but there was a more remarkable increase in level of agreement in the GC class over a period of the classroom / laboratory. Hence the students' message here was that they would expect themselves to perform better in examinations if they are better engaged with the subject.

### 8.3.3 Theme 3: Learning chemistry is influenced by the teaching approach

Students participating in this study also expressed their views on the influence of teaching on learning of chemistry especially at post-secondary level. Most of the students agreed that the teaching approach determines their level of understanding of the subject while the teacher played an important role in engaging students with the subject during theory lectures and laboratory sessions.

According to students one of the characteristics of an effective teaching approach is the ability of a teacher to dedicate time to explain rather than read or write notes. They also admired a teacher who looks prepared and makes interesting presentations possibly with the use of visual educational resources. Some students strongly believed that they would learn more if the teacher finds how to relate different aspects of chemistry to the real world outside the classroom. Students would also prefer to have the teacher always on their side by being sympathetic and helpful, and also by instilling confidence in them. They also want the teacher to motivate them in the subject rather than coach them to pass the examinations.

The following is an example of how students expressed their positive views on teaching of chemistry.

> *"When I had teachers that showed a great deal of interest… you would surely remember things better… as you would feel that the teacher really wants to give the lesson… that he or she is really motivated… This would certainly leave the mark on you. It motivates you to study."*
>
> S-55 (non-GC group G)

These findings are consistent with a plethora of research evidence that shows clearly that one of the most significant factors determining attitudes towards science and science subjects is the teacher quality variables (Bennett & Hogarth, 2009; Osborne & Collins, 2001; Osborne et al, 2003; Schibeci & Riley, 1986; Simon & Osborne, 2010).

Students also expressed their dislike towards teaching approaches which they regarded as ineffective for science education. These include characteristics of certain teachers such as talking with the board and / or reading from textbooks, the inability to stop and explain, lack of classroom activities, excessive and brisk teacher monologues, poor communication of ideas with students, transmission of facts without relating them to real life situations and putting too much emphasis on examinations. Students agreed that the teacher plays an influential role in their engagement of the subject, so much so that one student remarked that a 'teacher could make or break you'!

The following student's remark exemplifies students' negative views on ineffective teaching approaches, made by participants during focus group sessions.

> *"… if you have a teacher who just talks to the board, reads from the book and does nothing else, you wouldn't be interested in what's going on! You end up 'doodling' and wasting time in class. And you would say: 'We're having chemistry now. How boring!'"*
>
> S-10 (GC group A)

Students from the non-GC group had similar negative views on some ineffective teaching methods which they had to endure in the past, with particular reference to their secondary school teachers of chemistry and other science subjects.

> *"At O-level I studied like a parrot and I had no idea on what I was studying… the teacher was hopeless. And even now that the teachers I have are quite good… but it has affected me so much in the past… I still find chemistry more difficult with respect to other subjects."*
>
> S-34 (non-GC group F)

These findings are similar to students' problems associated with teaching as outlined in a study by Tobias (1990) who reports how students summed up their difficulties they encountered during science lessons with expressions such as 'the tyranny of techniques', 'the isolation of learner' and 'the struggle to attend in a sea of inattentiveness'. This could more or less be reflected in the arguments brought up by participants when discussing the negative influence of some of their science secondary teachers.

One commonly agreed idea among students was that *ways of teaching chemistry have to be flexible and adapt to a changing society*. The chemistry survey shows a considerable strong support from both groups towards the suggestion that teachers must change or update their methods in order to make chemistry more appealing to students living in a modern society. Consensus on this was even higher within the non-GC group by the end of the year.

A Mann-Whitney test performed on the responses to this item showed that the variation between the groups was originally insignificant but almost reached significance by the end of the year: **z-value = -2.103, p = 0.035** *(appendix 31).* This may be interpreted that the non-GC group were keener to see the teacher refer to contemporary developments in chemistry, something which the GC group had just experienced through the green chemistry intervention.

### 8.3.4 Theme 4: The chemistry curriculum is enhanced by environmental topics

Participants were almost unanimous that A-level chemistry programme would be ‘enhanced’ and become more interesting by including more direct references to environmentally related issues. Although the non-GC students did not refer specifically to the term ‘green chemistry’ or ‘pollution prevention’ in their discussions, they still held a strong view on the importance of learning on the environmental aspect of chemistry during their A-level chemistry course.

The students cited a number of reasons supporting their suggestion for a stronger reference to environmental matters in the A-level chemistry curriculum. One of the main reasons was that the subject becomes more concrete and less abstract. Students also thought that an environmental chemistry section would bring A-level chemistry closer to the world outside by treating the chemistry of specific real life situations. They also felt that chemistry students need to be more competent (i.e. more scientifically literate) and conversant in environmental chemistry when dealing with environmental issues even out of school. Another reason was that environmental chemistry has the potential to make chemistry more interesting as it deals with a whole range of different aspects and concepts of chemistry and relates also to other areas of science.

The following argument was brought about by a non-GC student sharing this affective attitude towards school chemistry.

> *"I think that chemistry as it is now is too abstract. The environmental topics are more effective in showing you the reality. We learn a lot about the atoms and so on… things that we cannot see with our eyes and so the concepts are difficult. But if you're talking about environmental topics… basically the environment is full of chemistry…"*
>
> S-63, non-GC group G

Students were aware that there wasn't much reference to environmental topics in their chemistry programme and they were rather eager to have environmental chemistry included along with other topics or replace more abstract aspects of chemistry. They considered that this would bring more of the 'outside world' into the picture and make the subject more relevant to their lives and hence more interesting too.

One recent study confirms that the inclusion of an environmental context to the high school chemistry curriculum, as suggested by the participants of this study, makes it easier for students to connect between chemical concepts and real life problems. In this way, students perceive chemistry as being more relevant to their lives and this increases their motivation to learn the subject (Mandler et al, 2012).

## 8.4 Cognitive / Affective Dimension – Chemistry Practical Work (Dimension 4)

The general feeling among students was that despite being challenging at times, students liked doing chemistry experiments on their own and on a regular basis, in the school laboratory. Many felt that they were more engaged with the subject in the laboratory, though some indicated they experienced difficulties during some of the practical work.

### 8.4.1 Theme 1: Students feel more engaged with chemistry during practical sessions

Students thought that there should be more emphasis and better preparation for the chemistry practical sessions as the laboratory experience provided a golden chance for students to apply theory into practice and learn different laboratory skills and techniques, especially in view of the A-level chemistry practical exam and possible future laboratory-related jobs. Some students even stated that they found A-level chemistry practical sessions highly stimulating, helping them grasp better the theoretical and often abstract concepts learnt during the theory lectures.

However students were not so determined to generalise that *chemistry theory was more interesting and exciting in the laboratory than in the classroom*. In fact the chemistry survey data showed that there were mixed viewpoints on this, but agreement level increased marginally in both groups and prevailed within the GC group, by the end of the year. This means that although students liked practical work, as could be seen from their many comments in the focus groups, they could not be categorical that practical work in the laboratory was always more interesting than what was done in class. The reasons could be that practical sessions are also examination-oriented and at times tend to be hard as explained in section 8.4.3. The GC group expressed a slightly more positive attitude towards practical work than their non-GC counterparts and this affective viewpoint increased marginally by the end of the year.

Students outlined a number of reasons to explain why they still usually preferred doing chemistry practical work than learning theory in class. Students felt that practical work was a captivating experience that allowed students to understand better the theory side of chemistry, to apply what they learnt in class and to help them memorise concepts and theories through experimental observations and results. This is how one of the students expressed this viewpoint during one of the focus group sessions.

> *"I think that laboratory work seems to motivate you to learn the theory because you know that you're going to apply for yourself what you are learning in class. You're not learning something which is detached from you."*
>
> S-18 (non-GC group D)

Practical work also gives students a sense of ownership on the experiments they perform in the lab and allows them to deal with unpredictable situations and the use of hazardous and toxic chemicals. It appears that this is exactly what they like and what they expect in chemistry practical sessions. Some of the students admitted that they invariably enjoy the thrills, emotions, sense of adventure and element of surprise. This was one of their observations on this aspect of the students' participation in school practical sessions.

> *"But when you have to do it yourself you cannot predict exactly what is going to take place… you cannot anticipate whatever will happen when you're mixing chemicals… you can't really say what will happen! And that makes the practical even more exciting!"*
>
> S-4 (GC group C)

Other students observed that the fact that they were allowed to deal with real life chemicals that may be toxic or dangerous makes chemistry even more stimulating. However it should be noted that such contact with toxic and dangerous reagents was also found to keep other students away from the subject.

### 8.4.2 Theme 2: Students acknowledge the importance of chemistry practicals

Students found that apart from being interesting practical work brought chemistry closer to the students' everyday life and this helped them understand better the theory as can be confirmed in the following statement made during one of the focus group discussions.

> *"I think that the practical helps to consolidate the theory… in order to illustrate the theory in a more concrete way and helps you also understand how it is applied in real life."*
>
> S-36 (non-GC group E)

Chemistry practicals allowed students to take a glimpse of possible future scientific careers involving work in scientific laboratories, as suggested by the student who made the following observation:

> *"There should be more emphasis on practical work because in the future we are going to be working on these lines, mainly we are going to work in labs and we want to be hands on with these things."*
>
> S-16 (non-GC group D)

Students could not avoid referring also to the fact that they had to sit for a practical paper as part of their A-level examination. Hence they were further motivated to practise laboratory procedures and techniques for the exam which had a considerable weighting (20%) of the final mark. This is one of the students' references to such a motivation for laboratory work in chemistry.

> *"… Yes you will remember more that way and for the A-level exam, it carries a lot of marks. That's why it is so important for us to do them so frequently at school."*
>
> S-45 (non-GC group E)

Most of the students' observations expressing their emotions towards chemistry practical work were consonant with the outcome of research studies which show that practical work in science helps students develop scientific skills, knowledge and understanding of concepts and theory (Cerini et al., 2003; Collins, 2011; Toplis & Allen 2012).

### 8.4.3 Theme 3: Chemistry practicals at A-level can be hard

Students also recognised the fact that chemistry practicals were not always plain sailing and easygoing and at times provided challenging tasks which made it harder for them to cope on their own without seeking help. Some students even admitted that at times they felt almost lost and helpless half way through an exercise in the chemistry laboratory.

According to students, problems which they commonly encountered during laboratory work ranged from the difficulty to relate the chemistry theory with practice, working out calculations on the spot (particularly those involving volumetric analysis), coming across new situations and applying new techniques without any prior knowledge or training or explanation, and having to interpret observations and results of a particular analysis without having covered the related ground work in class during the theory sessions.

The following argument was made by one of the students to support his/her belief that chemistry practicals were at times demanding and complicated, or out-of-phase with the theory learnt in class.

> *"I think that a greater level of integration is needed between theory and labwork because you cannot simply focus on one aspect only. Like, at school right now, they (i.e. theory and practice) are treated as distinct subjects. We did things in the lab that we shouldn't have done… I mean we didn't even know we had it in theory."*
>
> S-42 (non-GC group E)

There were many references during the focus group sessions to the difficulties which students faced regularly such as when they come across the arduous task of working out calculations as part of the laboratory report in the case of experiments involving physical chemistry. One of the problems commonly cited by students was their inability to deal with simple calculations probably because they are too much focused on doing other tasks such as following the instructions, taking correct readings and / or writing observations. According to students, the real difficulty therefore arises because of the multitasking demands of some of the practical sessions.

Students also felt concerned about the fact that practical work was examinable. Some expressed the view that there were so many possibilities of what could crop up in the practical paper that they were going to play it safe and resort to rote learning even if they knew that the practical examination paper was an open book type of exam.

It is evident that the students' concern to do well in the practical examination affects the element of excitement and fun which students usually experience each time they carry out experimental work in the school laboratory.

The fact that students found A-level chemistry practical work hard and at times problematic is congruent with literature showing that students' participation in practical work may not necessarily improve the learning of scientific concepts (Toplis & Allen, 2012). The effectiveness of practical work in the teaching of science has in fact been challenged by a number of authors such as Abrahams and Millar (2008) and Toplis (2012) who found that students were not always given a fair deal by teachers to develop their own ideas during practical activities.

## 8.5 Behavioural Dimension – Studying Chemistry (Dimension 5)

Several ideas came up in the students' mind when asked about the possibility of present and future actions related to the fact that they were studying chemistry at post-16. The survey and focus groups revealed that students intended to use their background of chemistry to pursue a career track related to medicine, health care and to a lesser extent to the pure sciences.

### 8.5.1 Theme 1: A-level chemistry students aspire for a science-related career

Part of the chemistry survey intended to throw some light on students' future aspirations related to their choice to study chemistry at A-level at the sixth form college. The survey showed that the majority of participants in both groups wished to follow a medical career track upon completion of their two year A-level course of studies. The survey data reveals that the high level of interest in medicine persisted throughout the year with the non-GC class showing a higher inclination than their GC schoolmates. During the focus group sessions some of the students explained that their main motivation to study chemistry at this level was in fact to pass the A-level exam (in chemistry) with a good grade in order to increase their chances of making it for the university course in medicine.

The other students showed that they were more inclined for another science-related course such as a B.Sc. in pure or applied sciences, or B.Sc. in health care studies, with the GC participants showing a greater interest in such options. Very few students were attracted to non-science courses such as Education and Psychology. There were also a minority of students who had no idea about their future career inclinations at the time of the survey questionnaires.

The survey also revealed that the great majority of students in both classes said they *intended to choose a career / profession related to chemistry upon finishing their studies*, even though they were less ready to express such a behavioural attitude by the end of the year. Indeed survey results show that the expressed intention by students to go for a chemistry related job was notably higher in the GC class in the post- intervention survey (**item D2**: 80.0% GC; 63.9% non-GC). The same GC participants were also clearly more confident that studying green chemistry increased their motivation to choose a career in chemistry, with a higher consensus at the post-intervention stage (**item D4**: 46.7% GC; 38.9% non-GC) and a higher surplus of agreement over disagreement on this matter (+26.7% GC; +13.9% non-GC).

Considering the students' strong ambition in medicine expressed in the survey, the fact that the same students showed also that they were highly interested to choose a chemistry job could mean one of two options. It may either mean that students considered medicine as a chemistry-related job or that most students aimed to ply their trade in a chemistry-related profession as an alternative to the MD course at university which required top grades in science subjects.

Most of the students also agreed that their *motivation to choose a chemistry-related job would increase if school chemistry was more related to everyday life*, i.e. if the A-level course is more context oriented and includes more examples of applications of chemistry to the real world. Consensus on this attitude linking student motivation to relevance of the subject remained practically the same in the GC class but decreased appreciably in the non-GC group by the end of the year (**item D3**: 78.8% $\rightarrow$ 76.7% GC; 80.6% $\rightarrow$ 66.7% non-GC). This indicates that the aspect of relevance in A-level chemistry was better valued by the GC group than by the other class and this affected their behavioural tendencies towards the subject.

Another survey item challenged students *whether they found it hard to imagine themselves having a future career involving chemistry*. The number of students disagreeing with this statement and so leaving the doors open to a future job with chemistry was initially high in both groups but decreased by the end of the year most notably in the non-GC class (**item D5**: 72.2% → 60.0% GC; 80.6% → 38.9% non-GC). By the end of the year the GC group was clearly more open to a possible future career in chemistry than the non-GC group.

The strong link between studying chemistry and motivation for a chemistry–related job was evident from many observations made by students during focus group discussions as exemplified by the following comment.

> *"With chemistry and biology there is also an almost certain career. If you do well in them, if you at least pass your exam, whatever (the mark)… I don't think there is anyone… or there are only very few… who actually don't find a job in sciences like biology and chemistry."*
>
> S-42 (non-GC group E)

This is similar to the findings of many surveys which confirm that one of the students' main driving forces to learn science remains the prospect to land a science-related career (Koballa, 1988, Laforgia, 1988; Simon & Osborne, 2010).

Despite their strong interest by the students in medicine as expressed in the chemistry survey, the same exercise revealed that the majority of students still *wanted to pursue further studies in chemistry upon finishing their two year course of studies at the sixth form college*. In fact the chemistry survey data show that this behavioural tendency was very strong in both groups but more pronounced in the GC group towards the end of the first year.

Given that university studies in chemistry mostly lead undergraduates and postgraduates to a science career, such students' interest to continue studying chemistry beyond A-level must be strongly linked with their motivation to choose a science-related occupation.

### 8.5.2 Theme 2: Chemistry research is important but unappealing for students

Students also believed that society needed more people to pursue further studies and research in chemistry, particularly to address urgently the various environmental issues and to support medical research and ongoing progress in science and technology.

The following was a typical student's statement made during one of the focus group discussions, on the need to attract more people to carry out research in chemistry.

> *"… for example in medicine, we are getting new insights on diseases… discovering new diseases or getting to know facts such as a higher incidence of certain types of cancer. All this requires more research in chemistry so that hopefully they would arrive at offering remedies, say."*
>
> S-45 (non-GC group E)

Participants were concerned that very few Maltese students who studied chemistry post-16 decide to proceed with chemistry research at university (local or overseas) or at some other institution.

> *"… many people may have studied chemistry up to our level, but they are not furthering their studies and engage in any research at all."*
>
> S-66 (non-GC group E)

All this shows that more students realised the importance that society, particularly in Malta should invest in more research in chemistry for the common good, but only a few of them indicated that they were ready (or maybe it was still too early for them to decide by then) to take a further step and consider the possibility of being involved in future research activity.

## 8.6 Cognitive Dimension – learning Green Chemistry at School (Dimension 7)

The GC participants of this research investigation made a number of points on the way they viewed green chemistry with respect to the other material forming part of the current A-level curriculum, why they thought it was worth including in future programmes and the most effective way of introducing it in school chemistry curricula.

### 8.6.1 Theme 1: Green Chemistry is Distinct from Mainstream Chemistry

Many GC participants regarded green chemistry to be so different from traditional chemistry studied at an advanced level that it could almost be treated as a separate subject, a new area of science, distinct from the standard chemistry taught in schools till now.

Students gave a number of reasons to justify their claim that green chemistry was different from the chemistry they were being taught at the college. First and foremost they thought that green chemistry proposed fresh radical ideas that were also more relevant and practical than many other concepts of mainstream chemistry. They also thought that unlike the local A-level chemistry, it was related so much with the environment. Students also considered green chemistry as an alternative way of thinking and doing chemistry that was more captivating than other traditional chemistry theory.

The following was one of the relevant considerations made by students to describe the difference between 'ordinary' chemistry and 'green' chemistry.

> *"Now I see that green chemistry is more practical than normal chemistry which has a more traditional approach. I don't think that they influence each other that much. It's more of a separate subject. OK it has to do with chemistry… but even biology includes some chemistry, no?"*
>
> S-30 (GC group B)

During the focus group discussions, students further clarified this point by adding that there was no emphasis in chemistry on studying alternative reagents and reactions in order to choose the 'greener' and more sustainable options. Hence they considered green chemistry to be a more intelligent way of looking at chemistry since it considered the careful choice between different options on producing chemicals and evaluating them right from the very beginning, i.e. from the design stage up to the point of their disposal.

Some items of the chemistry survey sought the participants' view on any important differences between the relatively new term 'green chemistry' and the seemingly synonymous term 'environmental chemistry' which has now been used for a while. The survey found the following points which were relevant to the study.

The GC participants were significantly more confident than their colleagues that *they had a good background of environmental chemistry*. While almost all GC students expressed confidence in this, only about half of the non-GC group declared they had a good understanding of environmental chemistry. A Mann-Whitney test on this item (F1) confirmed that there was a highly statistically significant variation between responses from the two groups: **z-value = -3.202, p = 0.001**, with a higher mean value obtained by the GC group at the post-test stage *(appendix 31).*

Students were unsure that green chemistry was very different from environmental chemistry. However, a higher number of GC participants regarded *green chemistry is a new dimension of environmental chemistry.* A Mann-Whitney test on the responses to this item showed that the difference between the two groups at the post-test stage was appreciable (almost significant) with the GC group expressing stronger support to the idea that green chemistry could be considered as a further development to environmental chemistry: **z-value = -1.669, p = 0.095** *(appendix 31).* The survey confirmed also that the GC group had a clearer picture than their non-GC schoolmates on the preventive role of green chemistry in eliminating pollution, in contrast with environmental chemistry which deals with pollution by 'end-of-pipe' solutions.

Students were aware that studying the principles of green chemistry could be challenging, requiring going deeper in the subject. It is clear that they realised that green chemistry involves more than what they had just experienced in the introductory course. This is what some of the students had to say on this matter:

> *"It seems that each green chemistry principle is the summary of all reactions involved. It is true that the reactions may involve some complicated chemistry and research but each principle puts everything together and makes it easier to understand… even for those who are getting started into this area of chemistry."*
>
> S-26 (GC group B)

The GC students sensed that one would need to understand the properties of unusual reagents and complex chemical reactions and might need to deal with more calculations, complex chemical formulae and unfamiliar chemical equations. Students therefore realised that this would surely make it harder to study the subject to a certain level.

### 8.6.2 <u>Theme 2: Learning green chemistry has become increasingly important</u>

Students agreed also that learning and studying green chemistry has become increasingly important for a number of reasons but mainly to raise the students' awareness that radical scientific decisions need to be taken at an early stage in order to safeguard human health and the environment. The following is a remark passed by one of the students who believed that green chemistry is needed to bring about change.

> *"You will eventually realise that one needs a change in mentality and ways of doing chemistry in order to improve the situation. It's not a question of being important but it's better for us and it's now a necessity."*
>
> S-30 (GC group B)

Results from the chemistry survey show that virtually all participants believed that *if green chemistry were to be included in the school chemistry programme it would help students raise their environmental awareness*. In fact there was a broad consensus on this even within the non-GC class who were not so well informed about this area of green chemistry.

One student referred to the learning of green chemistry as becoming a 'Hobson's choice' as it has become a must that students start studying 'something' in a scientific way to improve the situation of the environment. Another one said that 'we are already feeling the pinch', with reference to environmental degradation, and that it was therefore necessary for students to be started with green chemistry before it would be too late.

Participants from both groups were almost unanimous on *the importance of promoting the green chemistry principles in Maltese education, including secondary schools*. The chemistry survey results show strong consensus on this idea to introduce green chemistry in schools, expressed at the post-intervention stage. This suggestion to introduce green chemistry at an early stage of education was confirmed during the focus group discussions. The general opinions were that it makes chemistry more interesting right from its introduction, and that the earlier students are given the chance to know about green chemistry the more natural will it be for them to be involved in it and to try to apply it in the near future. The following was one of the students' comments on this proposed early introduction of green chemistry in schools.

> *"I believe that the introduction (to green chemistry) has to be done at a young age. If you are to coax more students to choose the subject, you will be helping the scientists who are working on the forefront so that more people would be involved later… which would lead to more opinions and possible new ideas… and (greener) innovations."*
>
> S-26 (GC group B)

Some of the participants even suggested that it would make sense if green chemistry features also in the list of practicals forming part of the coursework component of O-level examination.

Opinions were almost equally divided in both groups of students (when neutral respondents are excluded) on whether *it was more important to study the foundations of chemistry than to introduce green chemistry in secondary school education*. There was only a slight surplus of agreement over disagreement at the end of the year. This data means that towards the end of the year, students valued highly the importance of green chemistry and a good proportion (more than 25%) felt that it was equally important or even more important than studying the fundamental principles of chemistry.

Some of the participants even suggested that a simplified version of the green chemistry concepts could also be presented to younger students attending primary or early secondary (middle) schools. The majority of students were however rather sceptical about this given the basic chemistry background which they considered that is required by young pupils to start understanding and appreciating at least some of the general ideas of green chemistry. This was a valid consideration by students as experts in the field indicate that green chemistry cannot be introduced at such an early stage of education as students would not have sufficient background of science.

### 8.6.3 <u>Theme 3: Green chemistry portrays a more positive picture of chemistry</u>

The chemistry survey results show that students agreed on the point that green chemistry portrays a more positive picture of chemistry and *helps them change the wrong perception of other people that chemistry is the main cause of environmental hazards*. The majority of students agreed on this point but the GC class registered a higher increase in consensus by the end of the intervention.

The following was one of the students' comments explaining why they held such a positive attitude towards learning green chemistry at school.

> *"With green chemistry we would change our perception of chemistry and instead of disadvantages, we might start harping more on the positive impact of green chemicals and chemical processes on the environment."*
>
> S-11, GC group D

Students made several other observations on why they thought that green chemistry was positive and the anti-thesis of 'brown' (polluting) chemistry. They mentioned the fact that it was proactive, supporting the bold effort by chemists to transform all chemistry from a potential source of pollution to an environmentally benign science. They considered that it provided 'positive solutions' rather than emphasizing only the danger and toxicity of certain chemical substances. Students also thought that green chemistry 'throws bright light on chemistry' as it reveals the positive side of chemistry that used to be obscured by the sensational way the past environmental problems were reported, giving the full blame to chemistry and related activities. This is how one student put all this in a nutshell when reflecting to the influence of green chemistry on learning chemistry.

> *"… students would say 'so after all, it's not bad studying chemistry"*
>
> S-8 (GC group A)

The student here is implying that by studying green chemistry students would be in a better position that they would not be associated with a degrading chemistry that can generate pollution on a large scale.

### 8.6.4 Theme 4: Students want green chemistry in the A-level chemistry curriculum

The majority of GC students thought that they were academically prepared to learn the foundations of green chemistry. They also considered that green chemistry is so useful and fundamental that it deserves a place in the A-level chemistry curriculum.

Students who took part in the GC intervention agreed that they didn't find it hard to understand the gist of all the 12 principles which guide chemists to practice green chemistry. They gave a number of reasons to support their claim about their ability to learn about the fundamental principles of green chemistry. They explained that the principles involved are easier to follow than many other abstract chemistry concepts. They also considered the statements describing the principles as being clear and unambiguous, involving the use of simple rather than complicated terms. Students also believed that the same principles could easily be related to real life situations. Moreover, students realised that all ideas involved were coherent and complimentary to each other, focussing primarily on the prevention of hazards and toxic waste during the synthesis of chemical products.

Participants acknowledged however that students need to have the right background science in order to be able to learn the basics of green chemistry. In fact they supported the idea that *students needed to have a good background of chemistry in order to understand (and hence appreciate enough) the true role of green chemistry*. The chemistry survey results show that the majority of students from both groups agreed on this.

The GC students participating in the focus group sessions were mostly against the idea of presenting green chemistry as a separate topic in the A-level programme mainly because it could be perceived as an extra burden to the current material but also because they believed it would be less effective than integrating it in existing material.

One of the points made by students against having green chemistry introduced as a distinct 'stand-alone' topic in the A-level programme is that the curriculum is already crowded and cannot allow being further expanded by adding new material, as this would consequently increase the pressure on teachers and students in view of a corresponding broader examination syllabus.

Another point made by students is that should green chemistry be presented as a single topic, it would be perceived as an isolated unit rather than a set of concepts linking to other key concepts, theories and applications of chemistry. The following was the argument made by one of the participants in this regard.

> *"I personally think that students wouldn't grasp the full concept of it if it's presented as a separate topic… because students would want to relate it to other topics… For example, they would benefit more if you're discussing organic solvents and then refer to how solvents can be 'greener' (with respect to other commonly used solvents)."*
>
> S-26 (GC group B)

The alternative idea of most of the GC students was to introduce green chemistry by integrating it in the existing curriculum rather than presenting it as a separate topic. They were very keen about this and many of them put forward similar suggestions on how they thought this could be done. The students' main suggestion was to introduce the key ideas of green chemistry at some point (during theory or practical sessions) where an immediate link could be made with the other traditional concepts or theories of chemistry. In this way, students felt that green chemistry is not presented as another topic but is embedded in already existing topics without the need to extend the examination syllabus.

The chemistry survey found that the idea of *integrating green chemistry in the A-level curriculum in different stages* was supported by the majority of student participants but the level of agreement was appreciably higher in the GC group by the end of the year.

The final stand by the GC students reflects the view of a number of authors (Braun et al., 2006; Parent et al, 2004) who were against the idea of replacing existing chemistry curriculum material with green chemistry or teaching it as a separate module.

Students thought also that green chemistry could easily be incorporated in the laboratory programme, by replacing some of the repeated exercises (e.g. volumetric and qualitative analyses) by green chemistry experiments. Data generated by the chemistry survey confirms that an overwhelming majority of students agreed that the *best way of* *demonstrating green chemistry principles was through practical sessions*. Support to this viewpoint increased marginally in the GC class but dropped in the non-GC group by the end of the year.

Students showed concern on the fact that *the current chemistry syllabus was already vast and adding new material such as the principles of green chemistry would lower their chances of success in their crucial A-level examination*. The chemistry survey data showed that the level of students' concern increased substantially during the year in the GC group, even though it was still less evident than that expressed by the non-GC respondents. A Mann-Whitney conducted on survey results of both groups confirmed that the difference in mean scores of responses measured at post-test was statistically significant: **z-value = -2.003, p = 0.045** *(appendix 31).*

The possibility of including green chemistry as a non-examination topic was also discussed by the GC participants during the focus group sessions which immediately followed the post-tests. Students explained that they did not like the idea of having green chemistry included in the examinable material as they thought this would turn out to reduce the students' interest in this new component of chemistry precisely because of its association with the exam. Some thought that including green chemistry as an examinable topic might even turn out to be counterproductive as students might get alienated from the 'topic' simply because of its being examination oriented. They preferred having it presented to them as a non-examinable / optional topic / area of chemistry.

Despite the students' concern to the addition of new material to the examination syllabus, the chemistry survey data reveals that students regard *green chemistry as a fundamental area of* *chemistry and so deserved being considered in future A-level chemistry syllabi and exams.* In fact, consensus on this idea was always higher than 50% at the post-intervention stage.

The fact that participants favoured the idea of including green chemistry in future chemistry exams implies that students, once again, viewed green chemistry as a priority and an important component of modern chemistry about which students had to be prepared in the near future.

## 8.7 Affective Dimension – Green Chemistry Theory Lessons (Dimension 8)

The students who were involved in the green chemistry intervention enjoyed learning about the new area of green chemistry for various reasons but mainly because it is very relevant to the students' everyday life, it appealed to students who were already environmentally sensitive and it also generated more interest among students in school chemistry.

### 8.7.1 Theme 1: Green chemistry is relevant to the students' everyday life

Students who were introduced to green chemistry in this project were very categorical that they were pleased to learn about the radical concepts of such a new scientific field which aim for a safer and more environmentally friendly chemistry practice. They sensed that green chemistry imparts positive feelings among students and is also very relevant to contemporary life. This was evident both in the chemistry survey responses and in the way they spoke about their experience of learning about it, during the focus group discussions.

The study found that introducing green chemistry has the potential to bridge the 'gap', referred to by a number of participants, that separated the present curriculum dominated by facts and fundamental principles / theories of chemistry and a more relevant contemporary chemistry that aims to reduce the impact of chemical activity on the students' personal lives and society at large.

The following were some students' observations made during the focus group sessions, explaining why they considered that green chemistry could bring school chemistry closer and more relevant to everyday life.

> *"A lot of material covered in A-level chemistry has nothing to do with the real world and isn't so much useful to us. In contrast, green chemistry is something more concrete that can be applied… for instance, to reduce pollution and protect nature."*
>
> S-19 (GC group D)

Students also considered the relevance of green chemistry as a possible additional point of engagement of students with chemistry. They suggested that if green chemistry was so relevant to the real life context that it would consequently generate more interest in the chemistry classroom.

> *"If you actually relate it to everyday life chemistry would certainly be more interesting… and green chemistry is very much related to everyday life."*
>
> S-6 (GC group C)

This contrasts with the finding from the same study that one of the factors which students found to make chemistry a difficult subject was the presence of many irrelevant topics covered in class during the lectures. So, according to students, green chemistry can make the difference in the chemistry curriculum as it provides an opportunity for the subject to be rendered truly more relevant and hence more appealing to the students.

Students also realised that since green chemistry was virtually ‘harmless’ and relevant, more students might be attracted towards specialising in it, giving also a fresh impetus to research in chemistry. They argued that for the same reason, students might feel more confident to choose careers related to chemistry.

### 8.7.2 Theme 2: Green chemistry generates more interest among chemistry students

Students also liked green chemistry as they thought it was ‘nicer’, ‘less boring’ and ‘more easy going’ than other traditional topics of chemistry, even though others felt it involved challenging concepts too.

Participants thought that green chemistry theory was more interesting as it was not based on learning facts and concepts by heart. They felt that it required higher cognitive skills rather than memory recall as can be noted in the following student observation.

> *“Green chemistry does away with the idea that studying chemistry involves a lot of memory work… Green chemistry involves deeper thinking… more reasoning perhaps, even though you are borrowing basic theory from ordinary chemistry.”*
>
> S-20 (GC group C)

Green chemistry also appealed to students because they saw it more linked to the practical side of chemistry too. They thought that this renders chemistry more enjoyable and ‘more down to earth’ as it is the chemistry that one can come across in everyday life. One particular student remarked that once he started to like green chemistry, he became kind of ‘addicted’ to its ideas and he wanted to learn more about it as it became part of his life. One of his colleagues admitted that she also felt ‘really proud’ that she was learning something which was going to be useful when she grew up.

Some students thought that 'with green chemistry, all chemistry seems to make more sense' as it provided the tools to arrive at better alternative ideas of doing chemistry. For them it also made a lot of sense as it was related to the real world and affected the way of life of present and future generations.

Another general feeling among the GC students was that school chemistry would be rendered more interesting with green chemistry as it adds new and positive ideas about chemistry that are also feasible and related to everyday life.

Many GC participants declared that they *were more interested to learn about green chemistry than some other more traditional topics of chemistry forming part of their A-level programme of studies*. In fact according to the chemistry survey data, by the end of the classroom / laboratory intervention, the number of GC students agreeing on this stand was more than double the number of disagreeing students within the same group. In contrast, a lower number of students in the non-GC class supported the same idea at the same point in time.

One of the reasons given by students which made green chemistry more interesting than other areas of A-level chemistry was that its concepts can be considered as modern and unorthodox ideas in chemistry that made a lot of sense as they concerned sustainability of life on earth and aimed to protect human life and the surrounding environment. They also stressed the point that green chemistry was not just theory as it could easily relate to everyday life. Some of the participants stated that they started appreciating chemistry more when they learnt about the development of green chemistry as it gave them the notion that chemistry was alive and kept evolving too. Others felt that it also generated interest as it was regarded by many as the chemistry of the future since chemistry was gradually moving towards greener techniques and technology.

Students argued that green chemistry was based on creative thinking. According to students, green chemistry also gave them a sense of ‘good feeling’ by knowing that they were learning how to use chemistry in a creative way without harming oneself and the environment.

In order to highlight their enthusiasm towards learning green chemistry, students suggested the need to ‘put more green chemistry in chemistry’ and that one day ‘most of the A-level chemistry is converted to green chemistry’. This is more or less the leitmotiv of promoters of green chemistry education who believe that once green chemistry is fully integrated into the mainstream chemistry instruction, there would not be the need to use the designation ‘green’ any longer as the green chemistry concepts would become part and parcel of all chemistry courses (Ware, 2001a).

One of the findings of the survey was that students believed that *studying green chemistry would raise their interest to study chemistry*. In fact results show that the level of agreement prevailed in the two groups. Although students generally agreed that green chemistry increased their interest to learn chemistry, they also indicated that it may not necessarily affect their motivation to pursue further studies in chemistry. They argued that motivation (particularly of the extrinsic type) depends on a number of factors including the students’ future ambitions and so one can’t really generalise in this case.

## 8.8 Cognitive / Affective Dimension – Green Chemistry Practical Work (Dimension 9)

It is very evident that the green chemistry practical sessions in which the GC students participated proved to be a memorable experience. They agreed that the green chemistry experiments were enjoyable, very different and more stimulating than most of the other experiments forming part of the examination-oriented programme of practicals.

### 8.8.1 Theme 1: Practical work in green chemistry is highly stimulating

Most of the students taking part in the green chemistry laboratory experience thought that a green chemistry practical session instils positive feelings amongst sixth form students. Students gave a number of reasons why they liked doing such practical work in green chemistry.

Students liked the idea of having been able to create their own 'green' product during the green chemistry practical session. This gave them a better sense of ownership on the experiment and a great satisfaction that they were doing something positive, using harmless raw materials to produce a harmless but useful product. This is how one student expressed his/her affective attitude towards the green chemistry practical work.

> *"Even the fact that you can produce biodiesel, for example. The fact that you can do chemistry by doing biodiesel from vegetable oil – that's fantastic and it makes you feel good… It would be different the fact that you are doing something so positive… that you are producing your own 'green' product."*
>
> S-11, GC group A

Students also liked the idea of taking a break from the routine of programmed A-level practicals, with newly designed practicals involving greener reagents and greener synthetic procedures. The following was a typical comment made by students to illustrate such an attitude.

> *"I think that there should be more green chemistry experiments because these are certainly more interesting. Not that the others aren't but, for example, when you consider what we did… converting potato starch into a biodegradable bioplastic. That was certainly more interesting than doing the usual titrations."*
>
> S-24 (GC group B)

Students also realised that laboratory work made it easier for them to grasp the basic concepts involved in green chemistry as it provided a direct hands-on experience. They found this to be a more effective way of learning green chemistry. Students were also fascinated by the fact that they could see green chemistry being applied, thereby proving that it was not only theoretical but truly feasible. The following was a relevant observation made by GC students in this regard.

> *"Even the practicals that we did… of the potato, for example. It was fun and we saw it happening in front of our eyes. It can really happen! You can really produce biodegradable plastic and so better stuff for the environment."*
>
> S-10 (GC group A)

Students also felt that such labwork related to green chemistry brought students closer to the real world outside than the other conventional laboratory exercises. This was another aspect that raised the students' interest in green chemistry experimental work as can be confirmed through student observations such as the following one.

> *"Even when you consider the fact that plastic is a material that we are in continuous contact with… we touch it and use it so frequently… and then you learn how to produce it in a rather simple way… that makes green chemistry extremely interesting."*
>
> S-29 (GC group B)

One could clearly notice that students were extremely satisfied with their first green chemistry laboratory experience, with students viewing it as a new challenge and particularly happy with the results obtained from the experiments. Some of the participants even stated that it was the most unforgettable experience they ever had in a school laboratory and that it made up for the practical sessions which they described as being 'monotonous' and 'repetitive' activities.

### 8.8.2 <u>Theme 2: Green chemistry experiments should be included in A-level chemistry</u>

Students from both groups showed a favourable attitude towards the idea of introducing some practical work related to green chemistry in the school laboratory programme at sixth form level. This attitude was more strongly pronounced by the GC class at the end of the intervention. In fact, following the students' participation in a set of green chemistry laboratory sessions, GC participants expressed themselves very favourably on the importance of experiencing such green chemistry practical work. The chemistry survey data showed that a higher percentage of students in the GC class agreed at this point that *practical work in A-level chemistry would be more useful and interesting if designed to illustrate green chemistry principles*. Agreement level on this concept increased in both groups of students but more appreciably in the GC group by the end of the intervention.

It is clear that GC students were very keen about their new laboratory experience in green chemistry and they strongly supported the idea of replacing some of the standard / classical experiments associated with the A-level exam, with new green chemistry procedures. Their outstanding voluntary participation (an average turnout of 28 out of a class of 30), for the green chemistry practical sessions, as well as the overwhelming enthusiasm of students during both sessions was a further confirmation that students were highly stimulated to participate and be directly involved in this type of laboratory work.

The same GC students explained that they were extremely gratified that they were able to produce with their own hands and then carry out a number of tests on two ‘green’ products starting from renewable raw materials, and in the same time relate their work with a number of important chemistry and green chemistry principles. They remarked several times, in and out of the lab, that these two practical sessions in green chemistry gave them a higher sense of satisfaction and introduced in the college laboratory a touch of modern concepts of chemistry which they regarded as being more contemporary and more relevant to them than most of the other traditional experimental work carried out in a typical sixth form chemistry lab.

The students’ positive attitudes towards learning green chemistry in the laboratory proves right authors such as Parent et al (2004) who suggested the integration of green chemistry concepts in the A-level chemistry curriculum through a number of effective strategies which include the use of green chemistry laboratory experiments.

## 8.9 Behavioural Dimension – Studying Green Chemistry (Dimension 10)

The green chemistry participants thought that learning green chemistry can increase their chances to take a future career in chemistry and it may also help them in other unrelated occupations. The following were some of the concepts developed by students on their ‘action’ attitudes towards studying green chemistry.

### 8.9.1 Theme 1: Green chemistry can motivate students for a chemistry-related career

Students from both groups, but particularly from the GC class, declared that *studying green chemistry would improve student motivation to take up a future job related to chemistry*. This was mostly evident from the data gathered in the chemistry survey which showed that there was a higher proportion of students supporting this idea than others disagreeing with it. Support was substantially higher in the case of GC respondents at the end of the year.

When the idea was brought up in the focus group discussions, there was a general agreement among the GC participants that whoever was interested in choosing a career related to chemistry would soon require some background of green chemistry, given the special attention it is already receiving all over the world and the positive impact it leaves on the chemistry community, industry and society at large. The following were some of the considerations made by a student on the need for more students to study green chemistry for a chemistry-related job.

> *"It's proposing young people to actually realise that it's better to be efficient, it is better to be green than to run normal chemical procedures, even when you consider that you're making more money… as in the long run, it's more profitable anyway. So then, when you actually come to think of it, it's the future generations that count. In their jobs, they would actually need to implement the green chemistry concepts."*
>
> S-6 (GC group C)

One participant even suggested that green chemistry should be even offered as a subject on its own to sixth formers especially for those students who may be already inclined to use it for future work or to specialise in it later on at work or at university level. His point was that it was so distinct from traditional chemistry that it could perhaps be provided as an option on its own, parallel to mainstream chemistry to orientate students earlier to careers related to green chemistry. This is how he expressed himself on this proposal.

> *"But it was just crossing my mind that in the future, someone might want to work in something having to do with green chemistry and you have to study and qualify for it... It may therefore be introduced as a subject on its own… in the same way that there is 'pure maths' and 'applied maths'. Then whoever is interested would have the opportunity of choosing it as a main option."*
>
> S-18 (GC group D)

Students therefore realised that green chemistry was becoming so prominent that all those who wished to pursue further studies or aspired to have a job related with chemistry, would soon discover that they need a sound knowledge of the principles and applications of this area of chemistry.

### 8.9.2 Theme 2: Green chemistry provides students with new opportunities

Students belonging to the GC class thought that learning green chemistry was ideal for those wanting to specialise in it at university level. Few of them however indicated that they would consider taking such an option. The following is an example of a student who already considered the possibility of specialising in green chemistry.

> *"I think that if I were to choose to go deeper in chemistry I would certainly opt for green chemistry. Because honestly speaking, speaking for myself, it's the most interesting part of chemistry that I came across so far."*
>
> S-20 (GC group C)

Others did not share the same inclination but thought about the need for chemistry students to consider committing their future to green chemistry. They suggested that students should be encouraged to specialise further in green chemistry by providing the right courses at university level. Some GC participants showed their concern on lack of opportunities to date to specialise in green chemistry.

> *"It could be that someone gets intrigued with green chemistry and would like to specialise in it… but till now there aren't any openings at all in green chemistry (referring mainly to the local university)… and so it would be a problem."*
>
> S-23 (GC group A)

The chemistry survey confirms that all students regarded *green chemistry research as an important investment to safeguard a healthier future civilisation*. In fact students from both groups were almost unanimous on this with none of them opposing the idea at the post-intervention stage. This implies that the students' attitude towards chemistry research is similar to the 'important-but-not-for-me' syndrome referred to in the literature review chapter to describe some of the students' attitudes to studying science at post-16. It is clear that students are aware of the importance of research work in the various areas of chemistry and particularly in green chemistry but stop short, at least for the time being, from giving it a serious consideration for their personal future academic aspirations.

## 8.10 Points of Convergence and Divergence between the Two Groups

### 8.10.1 Cognitive Dimension – Learning Chemistry at School (Dimension 2)

1. A-level chemistry is a rather difficult science subject

Students from both groups agreed that A-level chemistry was a difficult science subject for a number of reasons such as the need to learn abstract concepts, dependence on memory work and calculations, an overburdened curriculum, irrelevant content, repetition of topics, a perceived gap between O-level and A-level material and the negative influence of relatives and friends.

2. Chemistry improves aptitude / achievement in other sciences

The groups were also in agreement that studying chemistry improved their aptitudes in other sciences, but not necessarily in other non-science subjects. However there was a stronger support from the GC group that studying chemistry improved their chances of success in the other sciences and also in the other subjects.

3. A-level chemistry lacks relevance and needs updating

Students also agreed, in general, that the current local A-level curriculum lacked relevance and needed being updated to reflect better the present and future contribution of chemistry to society. There was an increase in support to this in both groups during the period of intervention but particularly in the non-GC group which therefore perceived A-level chemistry to be less relevant, compared to the GC group.

### 8.10.2 Affective Dimension – Chemistry Theory (Dimension 3)

1. Chemistry is a subject that appeals to young students

Students thought that despite being considered as a hard subject, chemistry still appeals to young people, the main reasons being the joy of discovering scientific phenomena, its usefulness and application in real life and its impact on students' career aspirations. Students agreed that they always found chemistry to be interesting in secondary education but this viewpoint lost some ground by the end of the year. They also did not regret having chosen chemistry as one of their A-level subjects. The GC group was more satisfied with such choice than the non-GC group at the end of the year.

Participants also indicated that they enjoyed more chemistry at post-16 level than at secondary level for a number of factors including better understanding, correlation of different topics, regular laboratory experience and less reliance on rote learning. Students denied that their main motivation was passing the exam to enter university. Disagreement on this was higher in the GC group meaning that the non-GC students were more exam-motivated in chemistry than their GC counterparts by the end of the year.

2. Students' interest in chemistry is linked to achievement

A number of participants thought that students' interest in chemistry is linked to achievement in the subject. They also favoured the idea that chemistry needs to be made more interesting to help students to pass their A-level exam. Support to this idea increased in both groups but more importantly in the GC group, even though the non-GC group showed a stronger support by the end of the intervention.

3. Learning chemistry is influenced by the teaching approach

The teacher was found to play an important role in engaging students with the subject. In fact students from both groups explained what they believed were the factors characterising effective and ineffective teaching and how these shaped their attitudes to chemistry at school. Students admired teachers who dedicated time for explanation, who related different aspects of chemistry to the real world, who were sympathetic and helpful and who motivated them in the subject. In contrast they disliked teaching methods characterised by 'chalk and talk', reading from textbooks, lack of explanation, poor communication of ideas, transmission of facts unrelated to life and exaggerated emphasis on exams. There was a stronger support from the non-GC group that ways of teaching chemistry must be adapted to a changing society.

4. The chemistry curriculum is enhanced by environmental topics

There was also a general agreement by students that the A-level chemistry curriculum would be enhanced and made more interesting by including more direct references to environmentally related topics. Students thought that this would make the subject more tangible and less abstract and increase the students' ability to be conversant in environmental chemistry.

### 8.10.3 Cognitive / Affective Dimension – Chemistry Practical Work (Dimension 4)

1. Students feel more engaged with chemistry during practical sessions

Students from both groups expressed themselves favourably about chemistry practical work in the school laboratory, citing a number of reasons such as the way it helped them apply theory to practice, learn laboratory skills and techniques, memorise concepts through observations, earn a sense of ownership of the experiments and experience positive feelings and emotions. They were however uncertain on whether chemistry was in fact always more interesting and exciting in the laboratory than in the classroom even though the GC group registered a higher number of respondents who preferred practical from theory lessons by the end of the year.

2. Students acknowledge the importance of chemistry practicals

Participants also acknowledged the importance of chemistry practicals as they felt these brought chemistry closer to their everyday life and helped them understand better theory learnt in class. Chemistry practicals were also viewed by students as an opportunity to experience the working environment of possible future laboratory-based jobs.

3. Chemistry practicals at A-level can be hard

Students also recognised the fact that chemistry practicals can be hard at times with problems ranging from difficulties to relate theory with practice, solving complex calculations, dealing with unpredictable situations and facing new techniques / procedures without being suitably prepared. They also felt concerned that practical work was examinable as this added extra pressure on them and reduced the element of excitement and fun usually experienced in a science laboratory.

### 8.10.4 Behavioural Dimension – Studying Chemistry (Dimension 5)

1. <u>A-level chemistry students aspire for a science-related career</u>

Students intended to use their background of chemistry to pursue a career track related to medicine, health care or the pure sciences. Most of the students aspired mainly for medicine with such motivation being slightly higher in the non-GC group. There were more students in the GC group who were interested in other (non-medicine) science careers.

Both groups of students claimed that they intended to choose a science-related career but such an intention was stronger in the GC group by the end of the year. Similarly more GC participants desired a chemistry-related job upon finishing their studies. It is therefore evident that GC students were more open to a possible career involving science or chemistry than the non-GC participants.

Students from both classes also thought that motivation to choose a chemistry-related occupation would increase if school chemistry was more related to their everyday life. Such a viewpoint was also more strongly favoured by the GC class implying that the aspect of relevance in chemistry was better valued in this group. Relevance was also related to career aspiration.

2. <u>Chemistry research is important but unappealing for students</u>

There was a general agreement among students that society needed more people to carry out further studies and research in chemistry. However very few students showed that they were already inclined in research activity at the end of their first year of post-secondary studies.

### 8.10.5 Cognitive Dimension – Learning Green Chemistry at School (Dimension 7)

1. Green chemistry is distinct from mainstream chemistry

Green chemistry was viewed by the GC participants to be very different from traditional A-level chemistry as it proposed fresh radical ideas which render chemistry more relevant and practical in many ways. It was also viewed by participants as environmentally friendly and student friendly. By the end of the intervention, GC students showed that they were significantly more confident in having a good understanding of green chemistry and that they recognised that green chemistry was a new dimension of (but not equivalent to) environmental chemistry. The survey showed also that the GC students had a clearer picture than their non-GC colleagues on the general aims of green chemistry. They also realised that learning chemistry turns out to be challenging especially when one goes deeper in the subject.

2. Learning green chemistry has become increasingly important

The GC participants strongly believed that learning green chemistry has become increasingly important for a number of reasons such as to raise awareness among students of the urgent need to take radical scientific decisions at an early stage to safeguard human health and a sustainable environment. There was a broad consensus among all participants that green chemistry would also help raise students' environmental awareness and that it was important to promote green chemistry even in secondary education. In both cases, the viewpoints were more strongly favoured by the GC group of participants. Students' opinions were divided on whether it was more important to learn the foundations of chemistry than the basics of green chemistry. What was surprising here was that more than 25% of students thought that learning green chemistry was almost more important than learning basics of chemistry at secondary level.

3. Green chemistry portrays a more positive picture of chemistry

Students agreed that green chemistry imparts a positive picture of chemistry and might help in changing the wrong perception that chemistry is the root of all environmental evil. This attitude was more strongly favoured by the GC class than the non-GC group at the end of the year. The reasons given by students to support their claim was that it was proactive, harmless, relevant and provided positive solutions rather than emphasizing only danger and toxicity of chemicals.

4. Students want green chemistry in the A-level chemistry curriculum

The majority of students wanted green chemistry to form part of future A-level chemistry curricula even though they did not agree about the best way to implement such a curriculum development. The GC participants claimed that they did not find any particular problems in learning the basic principles of green chemistry. However students believed that a good background of chemistry is required for anyone to be able to understand and appreciate the true role of green chemistry.

There was a stronger support among non-GC participants for the introduction of green chemistry as a separate topic at the post-intervention stage. In contrast the GC class favoured the idea of integrating green chemistry in the A-level programme in different stages as they thought this would be more effective and puts less pressure on the examination syllabus. Survey data revealed that the majority of students from both sides agreed that the best way of demonstrating green chemistry principles was through practical laboratory sessions with such proposal being more strongly favoured by the GC class. The same survey showed that the groups responded differently to the idea that introducing green chemistry might jeopardise the students' chances to succeed in A-level chemistry. The GC class was in fact less concerned on this. Both groups agreed that green chemistry should even be considered for future exams even though some students preferred to keep it as a non-examinable option.

### 8.10.6 Affective Dimension – Green Chemistry Theory (Dimension 8)

1. Green chemistry is relevant to the students' everyday life

Participants forming part of the GC class thought that green chemistry imparts positive feelings among students and was relevant to the students' everyday life. It also had the potential to bridge the gap between the present curriculum laden with facts and traditional principles and theories of chemistry and a more relevant contemporary chemistry emphasizing the impact of chemistry on society. It was evident that GC students felt more confident to discuss the aspect of relevance in chemistry at the post-intervention stage as they were convinced that green chemistry was more immediately connected to the outside world than mainstream chemistry which for them included several irrelevant topics. They considered that such relevance of green chemistry increased the students' engagement with chemistry.

2. Green chemistry generates more interest among chemistry students

The GC group of students thought that they liked green chemistry for a number of reasons but particularly because it was more enjoyable, less boring, more down to earth and more easy-going than other traditional topics of chemistry, even though the concepts involved were rather challenging. They also liked the fact that it adds new and positive ideas about chemistry and is more related to everyday life experiences. The survey found that GC students expressed a higher interest (with respect to non-GC students) in green chemistry than in other traditional topics of A-level chemistry. At the end of the intervention, GC students thought that green chemistry concepts were more interesting because they were modern and unorthodox ideas which made a lot of scientific sense as they aimed to protect human life and the surrounding environment. Students preferred green chemistry because it gave them a sense of good feeling and was closer to the outside world. They also liked the fact that they could apply it on a small scale in the school laboratory. Some GC participants suggested the need to 'put more green chemistry in chemistry' and wished that one day most of the A-level chemistry would be converted to green chemistry. There was a general agreement among the two groups that studying green chemistry would raise the students' interest to study chemistry.

#### 8.10.7 Affective Dimension – Green Chemistry Practical Work (Dimension 9)

1. Practical work in green chemistry is highly stimulating

Students who experienced the classroom / laboratory intervention thought that green chemistry practicals instilled many positive feelings among students, by giving them a sense of achievement for being able to apply green chemistry, providing fresh ideas for chemistry laboratory sessions and proving that green chemistry is in fact feasible and also relevant to real life situations. Students also realised that laboratory work made it easier for them to grasp the basic ideas of green chemistry.

2. Green chemistry experiments should be included in A-level chemistry

Participants from both groups favoured the idea of introducing green chemistry in the school laboratory programme at sixth form level. The chemistry survey showed that a higher percentage of GC students agreed that practical work in A-level chemistry would be more useful and interesting if it included green chemistry. The best proof that GC students enjoyed doing green chemistry experiments was their active participation in two green chemistry practical sessions which they regarded as a ‘memorable experience’ and a ‘highly stimulating exercise’. Students were particularly overwhelmed that they were able to produce and test a number of useful products by making use of renewable raw materials in place of traditional chemical reagents.

#### 8.10.8 Behavioural Dimension – Studying Green Chemistry (Dimension 10)

1. Green chemistry can motivate students for a chemistry related career

Students agreed also that studying green chemistry would improve their motivation to choose a chemistry related job. This attitude was more strongly pronounced within the GC group, garnering higher consensus and a weaker opposition than the non-GC class. The GC participants argued that in the near future, students would soon be needing green chemistry to carry on with further studies in chemistry or to opt for a chemistry oriented job.

2. Green chemistry provides students with new opportunities

There was general agreement among students that green chemistry research was an important investment for a healthier future civilisation. GC students recognised also the importance of green chemistry research particularly for those wishing to specialise in it but only few of them expressed their inclination to do so by the end of the intervention.

## 8.11 Chapter Summary

This chapter analyses the students’ attitudinal responses towards the learning of chemistry and green chemistry at school. Students’ attitudes are categorised in themes and grouped in eight of the ten dimensions forming part of the theoretical framework of analysis. The findings show that the two groups of students held a number of similar attitudes towards school chemistry and to a certain extent even to green chemistry. However, there were some important differences between the ways the two groups of participants responded towards certain aspects of chemistry theory and particularly towards the learning of green chemistry as a new area of science that does not yet form part of the college (A-level) chemistry curriculum.

The analysis found that GC students regarded A-level chemistry to be more relevant, and that the same students were more satisfied (than non-GC) with having chosen the subject at A-level. They were also more favourable with the idea that chemistry has to be made more interesting to help students pass their exams.

As regards green chemistry, the GC participants had a better picture of this area of science and considered it as a new dimension of environmental chemistry. They felt that it imparts a more positive picture of chemistry and helps to raise environmental awareness among students. They also thought that learning green chemistry has become increasingly important for a number of reasons.

The GC group felt that green chemistry should be integrated in A-level chemistry at different stages of the curriculum and that the best way of demonstrating green chemistry principles was through practical work. The same group saw green chemistry as being more relevant to everyday life than mainstream chemistry and had the potential to bridge the gap between the present curriculum and a more contemporary chemistry. The GC students also expressed a higher interest in green chemistry topics than traditional topics of the A-level programme. The group showed also a stronger view that chemistry as a subject was more interesting and enjoyable in the laboratory but practicals would become even more interesting and useful with green chemistry.

The GC students were also more open (with respect to the other group) to a possible career in chemistry and believed that motivation for such a career would be increased if chemistry was made more relevant. They also thought that green chemistry would also improve their motivation to choose a chemistry-related job.

# Chapter 9

# THE ATTAINED CURRICULUM – PART 3

# Data Analysis: Students' Knowledge and Conceptual Understanding of Green Chemistry

## 9.1 Introduction

This chapter analyses data collected from the second questionnaire of the chemistry survey to determine any changes in students' knowledge and level of conceptual understanding of green chemistry as a result of a classroom / laboratory intervention, and hence evaluate the attained curriculum.

The first section of the questionnaire (pre-test B1 and post-test B2) asked students for personal details similar to those collected in Part A of the first questionnaire (pre-test A1 and post-test A2). This data was processed in the section dealing with student profiles.

The second section of the questionnaire concerned questions on various aspects of green chemistry tackled in class or in the laboratory during the main green chemistry intervention (academic year 2009 – 2010). The first twelve questions were based on each of the 12 principles (general guidelines) which characterise green chemistry while the last three questions tested students on general ideas of green chemistry. Some of the questions were divided in two or three sub-questions, which were all analysed separately, bringing the total number of analysed items (questions or sub-questions) to twenty four.

The pre-test B1 was administered separately to the two samples of students (the non-GC and GC-groups) in the first week of November 2009, while the post-test B2 was applied to the same students in another two separate occasions in the first and second week of May 2010. Each test was completed in about 50 minutes.

## 9.2 Statistical Analysis of Data Collected in Part B of Survey

The questions in part B (pre-test B1 and post-test B2) of the Chemistry Survey were analysed using the scheme included in methodology chapter (see tables 4.12) based on five levels of understanding, from level 0 (no understanding) to 4 (sound understanding). Students were also asked to express how confident or unconfident they were to answer each question, based on a five-point scale from 1 (very unconfident) to 5 (very confident), as described also in methodology chapter (table 4.13). The questionnaire used (pre-test B1 and post-test B2) in the chemistry survey is included as *appendix 21*.

The detailed results of data analysis, including the several statistical tests carried out on this part of the chemistry survey and related to this chapter are displayed in displayed in the tables shown in *appendices 33-41*. The following tables (table 9.1, 9.2 and 9.3) include a summary of the results of the statistical analysis carried out on each of the 24 survey items. Table 9.1 compares data from the two groups during each session of the survey while table 9.2 compares pre-test data with post-test data within each group. On the other hand, table 9.3 summarises the results of a Mann-Whitney test comparing the differences between the individual students' pre- and post-test scores of the two groups.

**Table 9.1**

**Summary of results - comparing data of GC group with non-GC (control) group (using the Mann-Whitney U-test, 2-tailed)**

| ITEM | PRE-TEST DATA Non-GC versus GC | | | POST-TEST DATA Non-GC versus GC | | |
|---|---|---|---|---|---|---|
| | z-value | p-value | Significance | z-value | p-value | Significance |
| 1(a) | - 0.633 | 0.524 | ns | - 3.253 | 0.001 | ** |
| 1(b) | - 1.576 | 0.115 | ns | - 3.976 | 0.000 | *** |
| 2(a) | - 1.562 | 0.118 | ns | - 1.704 | 0.088 | ns |
| 2(b) | - 1.467 | 0.142 | ns | - 5.443 | 0.000 | *** |
| 2(c) | - 2.137 | 0.033 | * | - 4.294 | 0.000 | *** |
| 3 | - 2.236 | 0.025 | * | - 2.076 | 0.038 | * |
| 4 | - 0.102 | 0.919 | ns | - 1.452 | 0.146 | ns |
| 5(a) | 0.000 | 1.000 | ns | - 1.438 | 0.151 | ns |
| 5(b) | - 0.043 | 0.966 | ns | - 2.182 | 0.029 | * |
| 6(a) | - 1.071 | 0.284 | ns | - 3.866 | 0.000 | *** |
| 6(b) | - 2.234 | 0.025 | * | - 3.789 | 0.000 | *** |
| 7(a) | - 0.658 | 0.510 | ns | - 5.152 | 0.000 | *** |
| 7(b) | - 0.787 | 0.431 | ns | - 4.412 | 0.000 | *** |
| 8(a) | - 0.984 | 0.325 | ns | - 2.611 | 0.009 | ** |
| 8(b) | - 1.126 | 0.260 | ns | - 1.587 | 0.112 | ns |
| 9(a) | - 1.463 | 0.143 | ns | - 1.491 | 0.136 | ns |
| 9(b) | - 1.828 | 0.068 | ns | - 2.244 | 0.025 | * |
| 10(a) | - 1.118 | 0.264 | ns | - 2.780 | 0.005 | ** |
| 10(b) | - 0.015 | 0.988 | ns | - 2.130 | 0.033 | * |
| 11 | - 1.194 | 0.232 | ns | - 2.941 | 0.003 | ** |
| 12 | - 0.558 | 0.577 | ns | - 2.277 | 0.023 | * |
| 13 | - 1.722 | 0.085 | ns | - 5.121 | 0.000 | *** |
| 14 | - 1.778 | 0.075 | ns | - 6.376 | 0.000 | *** |
| 15 | - 2.426 | 0.015 | * | - 3.576 | 0.000 | *** |

PRE-TEST: $N_1$ (non-GC) = 35; $N_2$ (GC) = 32; POST-TEST: $N_1$ (non-GC) = 36; $N_2$ (GC) = 30

| *p-values:* | | | |
|---|---|---|---|
| | *>0.050* | *non-significant* | *ns* |
| | *0.010-0.050* | *significant* | * |
| | *0.001-0.010* | *very significant* | ** |
| | *<0.001* | *extremely significant* | *** |

**Table 9.2**

**Summary of results - comparing Pre-test with Post-test data (same group)**
**(using the Wilcoxon Signed-Rank test, 2-tailed)**

| ITEM | NON-GC GROUP Pre-test versus Post-Test | | | GC GROUP Pre-test versus Post-test | | |
|---|---|---|---|---|---|---|
| | z-value | p-value | Significance | z-value | p-value | Significance |
| 1(a) | - 0.834 | 0.404 | ns | - 2.307 | 0.021 | * |
| 1(b) | - 0.038 | 0.970 | ns | - 4.167 | 0.000 | *** |
| 2(a) | - 3.500 | 0.000 | *** | - 2.477 | 0.013 | * |
| 2(b) | - 0.683 | 0.495 | ns | - 4.360 | 0.000 | *** |
| 2(c) | - 1.414 | 0.157 | ns | - 3.630 | 0.000 | *** |
| 3 | - 2.296 | 0.022 | * | - 1.310 | 0.190 | ns |
| 4 | - 0.379 | 0.705 | ns | - 0.881 | 0.378 | ns |
| 5(a) | - 1.710 | 0.087 | ns | - 3.737 | 0.000 | *** |
| 5(b) | - 2.659 | 0.008 | ** | - 3.896 | 0.000 | *** |
| 6(a) | - 3.043 | 0.002 | ** | - 4.066 | 0.000 | *** |
| 6(b) | - 1.588 | 0.112 | ns | - 4.063 | 0.000 | *** |
| 7(a) | - 1.340 | 0.180 | ns | - 4.344 | 0.000 | *** |
| 7(b) | - 0.266 | 0.790 | ns | - 4.408 | 0.000 | *** |
| 8(a) | - 1.976 | 0.048 | * | - 2.355 | 0.019 | * |
| 8(b) | - 0.526 | 0.599 | ns | - 1.399 | 0.162 | ns |
| 9(a) | - 1.005 | 0.315 | ns | - 3.020 | 0.003 | ** |
| 9(b) | - 0.122 | 0.903 | ns | - 3.052 | 0.002 | ** |
| 10(a) | - 1.049 | 0.294 | ns | - 2.288 | 0.022 | * |
| 10(b) | - 0.220 | 0.826 | ns | - 2.066 | 0.039 | * |
| 11 | - 1.521 | 0.128 | ns | - 2.407 | 0.016 | * |
| 12 | - 1.162 | 0.245 | ns | - 2.507 | 0.012 | * |
| 13 | - 1.907 | 0.057 | ns | - 4.013 | 0.000 | *** |
| 14 | 2.698 | 0.007 | ** | - 4.580 | 0.000 | *** |
| 15 | 0.381 | 0.703 | ns | - 1.466 | 0.148 | ns |

$N_1$ (non-GC) = 35; $N_2$ (GC) = 30 (excluding respondents who participated in only one survey)

| | | | |
|---|---|---|---|
| *p-values:* | *>0.050* | *non-significant* | *ns* |
| | *0.010-0.050* | *significant* | * |
| | *0.001-0.010* | *very significant* | ** |
| | *<0.001* | *extremely significant* | *** |

**Table 9.3**

**Mann-Whitney Test using Difference between Pre-test and Post-test Scores (Understanding Data)**

| | Group | Mean | Std. Dev | Std. Error | z-value | p-value | Significance |
|---|---|---|---|---|---|---|---|
| Diff 1(a) | GC | 0.40 | 0.855 | 0.156 | -2.749 | 0.006 | ** |
| | Non-GC | -0.11 | 0.963 | 0.163 | | | |
| Diff 1(b) | GC | 1.97 | 1.650 | 0.301 | -4.262 | 0.000 | *** |
| | Non-GC | 0.00 | 1.475 | 0.249 | | | |
| Diff 2(a) | GC | 0.93 | 1.874 | 0.342 | -0.014 | 0.988 | ns |
| | Non-GC | 1.06 | 1.434 | 0.242 | | | |
| Diff 2(b) | GC | 2.13 | 1.592 | 0.291 | -5.258 | 0.000 | *** |
| | Non-GC | -0.11 | 1.051 | 0.178 | | | |
| Diff 2(c) | GC | 1.10 | 1.470 | 0.268 | -4.708 | 0.000 | *** |
| | Non-GC | -0.14 | 0.601 | 0.102 | | | |
| Diff 3 | GC | 0.20 | 0.805 | 0.147 | -0.874 | 0.382 | ns |
| | Non-GC | 0.31 | 0.758 | 0.128 | | | |
| Diff 4 | GC | 0.13 | 0.819 | 0.150 | -1.294 | 0.196 | ns |
| | Non-GC | -0.06 | 1.235 | 0.209 | | | |
| Diff 5(a) | GC | 0.97 | 1.245 | 0.227 | -1.734 | 0.083 | ns |
| | Non-GC | 0.37 | 1.262 | 0.213 | | | |
| Diff 5(b) | GC | 1.03 | 1.098 | 0.200 | -1.300 | 0.194 | ns |
| | Non-GC | 0.71 | 1.426 | 0.241 | | | |
| Diff 6(a) | GC | 1.97 | 1.586 | 0.290 | -3.323 | 0.001 | ** |
| | Non-GC | 0.66 | 1.136 | 0.192 | | | |
| Diff 6(b) | GC | 2.13 | 1.871 | 0.342 | -3.606 | 0.000 | *** |
| | Non-GC | 0.43 | 1.596 | 0.270 | | | |
| Diff 7(a) | GC | 1.53 | 1.106 | 0.202 | -4.844 | 0.000 | *** |
| | Non-GC | -0.31 | 1.430 | 0.242 | | | |
| Diff 7(b) | GC | 2.03 | 1.377 | 0.251 | -4.616 | 0.000 | *** |
| | Non-GC | -0.06 | 1.748 | 0.295 | | | |
| Diff 8(a) | GC | 0.67 | 1.241 | 0.227 | -1.069 | 0.285 | ns |
| | Non-GC | 0.43 | 1.170 | 0.198 | | | |
| Diff 8(b) | GC | 0.37 | 1.402 | 0.256 | -0.262 | 0.793 | ns |
| | Non-GC | 0.17 | 1.823 | 0.308 | | | |
| Diff 9(a) | GC | 1.07 | 1.639 | 0.299 | -2.035 | 0.042 | * |
| | Non-GC | 0.23 | 1.497 | 0.253 | | | |
| Diff 9(b) | GC | 1.27 | 1.818 | 0.332 | -2.809 | 0.005 | ** |
| | Non-GC | 0.06 | 1.083 | 0.183 | | | |
| Diff 10(a) | GC | 0.50 | 1.137 | 0.208 | -1.070 | 0.284 | ns |
| | Non-GC | 0.23 | 1.140 | 0.193 | | | |
| Diff 10(b) | GC | 0.37 | 0.964 | 0.176 | -1.280 | 0.200 | ns |
| | Non-GC | -0.09 | 1.522 | 0.257 | | | |
| Diff 11 | GC | 0.80 | 1.562 | 0.285 | -3.142 | 0.002 | ** |
| | Non-GC | -0.51 | 1.821 | 0.308 | | | |
| Diff 12 | GC | 0.47 | 0.937 | 0.171 | -0.672 | 0.502 | ns |
| | Non-GC | 0.26 | 1.197 | 0.202 | | | |
| Diff 13 | GC | 0.93 | 1.015 | 0.185 | -2.133 | 0.033 | * |
| | Non-GC | 0.40 | 1.143 | 0.193 | | | |
| Diff 14 | GC | 2.83 | 1.783 | 0.325 | -6.261 | 0.000 | *** |
| | Non-GC | -0.66 | 1.305 | 0.221 | | | |
| Diff 15 | GC | 0.37 | 1.245 | 0.227 | -1.096 | 0.273 | ns |
| | Non-GC | -0.06 | 1.434 | 0.242 | | | |

*p-values:* *>0.050* *non-significant* *ns* *0.001-0.010* *very significant* ****
*0.010-0.050* *significant* *** *<0.001* *extremely significant* *****

## 9.3 Ideas on Waste Prevention

**Question 1** of part B of the chemistry survey concerned the green chemistry principle emphasising pollution prevention by **'waste minimisation'**. It is the approach which is frequently described as 'prevention is better than cure'. In this question, students were asked:

(a) to suggest three possible measures in order to minimise or prevent environmental pollution;

(b) to explain what they understood when they read the phrase 'pollution prevention at the molecular level'.

Baseline analysis of this question showed that students already had a good idea of what is meant by 'pollution prevention' but could not relate it to the planning stage of a chemical reaction or process which occurs on a large scale in a chemical industry. A Mann-Whitney test showed there was no significant difference between the ways the two groups answered question 1 at the pre-intervention stage *(table 9.1, appendix 38).*

Both groups of students gave reasonable responses to question 1(a) at the post-intervention stage, with frequent references to the use of alternative cleaner sources of energy, recycling and using 3Rs for waste management, the use of catalytic converter and treatment of flue gas emissions. Other responses referred to an increased use of public transport, using biodegradable materials and treatment of waste prior to disposal. Post-test data analysis showed that there was a significant increase in the number of GC students showing sound understanding in this question.

In part (b), non-GC students almost showed no change in the understanding level of the concept involved. Although these non-GC respondents tried to give rather detailed explanations of the phrase in question, none of them referred clearly to the idea of ‘designing’ a tailor-made chemical with a specific set of properties including low toxicity and ‘planning’ a chemical process to ensure that all reactants and products are safe to human health and the environment. A few of them thought that the phrase referred to some extreme measure to prevent pollution but then failed to elaborate on this. In many cases responses were rather vague or generalised and did not refer to any specific technique used to achieve pollution prevention.

By the end of the year, some GC students were able to explain in their own words the essence of the principle of waste minimisation by referring to the importance of the concept of ‘molecular design’ in the planning of chemical reactions / processes. The following are some examples comparing GC students’ responses to question 1(b) before and after the green chemistry intervention.

**Table 9.4**

**Comparing responses of GC participants to question 1(b)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-5 | “I have no idea.” | “Preventing pollution by studying and making sure that the chemicals used and those produced do not cause any harm to the environment.” |
| S-13 | “Preventing pollution at the level that it can be prevented. Above this level it is natural.” | “Making sure that most of the atoms of the reactants are transferred to the desired product rather than in a side product or waste product.” |

One could note that the GC responses were more focussed at the post-test stage proving that students were able by then to associate pollution prevention with a careful evaluation by chemists of the consequences of chemical synthesis at the planning stage. Students also understood the need of the intended action of the chemist to intervene during the planning of a reaction, a feature which was completely absent in the non-GC responses in the same post-test.

A Mann-Whitney test confirmed that the two groups of students responded to both parts of question 1 in a significantly different manner at the post-intervention stage *(tables 9.1 & 9.3, appendix 39).* This was mostly due to a better interpretation of the spirit behind the green chemistry principle of waste minimisation.

## 9.4 The Principle of Atom Economy

**Question 2** of the chemistry survey (part B) tested the students on their knowledge of percentage yield and the fundamental green chemistry principle of **'atom economy'**. Students were given an equation representing the esterification reaction between ethanol and ethanoic acid and they were then asked:

(a) to calculate the 'percentage yield' of the reaction from data provided;

(b) to explain the term 'atom economy';

(c) to calculate the 'atom economy' of the same reaction.

The GC group showed an initial higher level of knowledge / understanding of the term 'percentage yield' than their non-GC counterparts. However, the level of understanding of the principle of 'atom economy' was very low in both groups at the start of the year with none of the students being able to define the term and work out correctly the given calculation.

By the end of the year, there were more students in both groups who could work out the percentage yield problem in part (a). This could be explained by the fact that students were exposed to such calculations in due course through the curricular topic dealing with moles and stoichiometry. In parts (b) and (c) concerning the concept of ‘atom economy’ the non-GC group fared rather badly and showed they still had no idea on what it was all about, achieving very low mean scores (less than 1.0) in this survey, both in the pre-test and in the post-test.

The GC participants performed better in the post-test when answering question 2 even though they still found themselves more confident calculating percentage yield than calculating atom economy. In fact GC respondents achieved a higher mean level of understanding in the three sub-questions by the end of the year.

When analysing the students’ explanations of the term ‘atom economy’ it was clear that none of the students were able to recall the exact definition as given in class during the intervention and so responses varied considerably as shown in the following examples.

**Table 9.5**

**Comparing responses of GC participants to question 2(b)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-1 | “Never heard of it.” | “Atom economy is the mass of atoms of desired products on the mass of atoms in reactants.” |
| S-10 | “Never heard of this term before.” | “It is the amount (number) of molecules of reactants which form the products. It is the planning / designing processes in which as much of the reactants are converted to the products as possible.” |

In the above cases, students still managed to underline in their own words the principle of atom economy without actually memorising any specific expression to define the term. Other students used simpler alternative phrases which although did not qualify the term, were acceptable and confirmed how the students concerned still grasped the idea behind the green chemistry principle involved.

The Mann-Whitney tests confirmed that the two groups of students also responded in a significantly different way when asked to explain and calculate the atom economy of the reaction *(tables 9.1 & 9.3, appendix 39).* None of the non-GC respondents were in fact able to do this and some of them even declared that they never came across the term before. As for the GC group, more than half (56.6%) attempted to solve the problem (compared to 13.3% in the pre-test) but only 16.6% arrived at the correct answer.

The fact that GC students struggled to carry out simple calculations explains why the overall level of understanding of the group in question 2 was lower than that achieved in other questions of the same survey. It also confirms that students in general find it hard to deal with chemistry calculations as indicated by a number of researchers in chemistry education, cited earlier in the literature review.

## 9.5 Planning Less Hazardous Chemical Syntheses

**Question 3** of part B of the chemistry survey concerned the green chemistry principle that aims to design **'less hazardous chemical syntheses'** in order to produce substances that are less toxic or non-toxic to human health and the environment. In this question students were asked to choose between three different ways (A, B or C) of producing a given amount of pure substance X and then justify their choice. The techniques were described as follows:

- Technique A – involving small amounts of expensive and hazardous reagents and water;
- Technique B – involving large amounts of cheap and non-hazardous reagents and water;
- Technique C – using small amounts of expensive and hazardous reagents and large amounts of an inexpensive but highly inflammable solvent.

Students were almost unanimous in their decision to favour option B both in the pre-test and in post-test. In most cases students realised that the benefits of using safer reagents in the synthesis of chemical products, would outweigh any other considerations on the method. However there was little reference to the properties and / or use of solvents.

When one looks at the reasons given by students for choosing between the three proposed techniques, one could note that the emphasis on the economical aspect was more pronounced in the non-GC group responses while the priority of the majority of GC respondents was safety to human health or the environment. Moreover only students from the GC group referred to the fact that the technique was also chosen because it made use of water which is considered as the commonest green solvent. The following table shows some of the GC students' responses to question 3, before and after the intervention.

**Table 9.6**

**Comparing responses of GC participants to question 3**

| **Student** | **Pre-test Response** | **Post-test Response** |
|---|---|---|
| S-1 | "Technique B.<br>It needs a minimum amount of expenses on substances and none of the substances are dangerous to handle." | "Technique B.<br>Because it uses reactants that are cheap and non-hazardous, and water as a solvent, all being environmentally-friendly as they don't pollute." |
| S-25 | "Technique B.<br>It is the most economical and non-hazardous." | "Technique B.<br>The substances are non-hazardous and cheap as well and the solvent is distilled water which is also non-hazardous." |

Although the responses are similar there is more reference to the fact that the solvent (the main resource) used is water which is also more environmentally friendly compared to other solvents traditionally used in industry, which are often toxic / hazardous / polluting.

The Mann-Whitney test confirmed that there was a significant difference between the way the two groups responded to question 3 at the end of the intervention *(appendix 39)* and this was mainly due to the more complete reasoning made by students to defend their choice on the basis of the data provided and the chemical principles involved. There were several GC students who referred also to the fact that the solvent used (i.e. water) was recyclable unless heavily contaminated. Some of the GC participants noted that the question did not make any reference to the cost-effectiveness of the techniques which should also be factored in to decide about the most sustainable method of production.

## 9.6 Designing Safer Chemicals

**Question 4** addressed the green chemistry principle proposing the **'design of safer chemicals'** having desired properties but low toxicity. Students were invited to choose the best out of five different combinations of properties for a newly designed chemical substance. The properties considered were toxicity, specificity (i.e. how effective it was to its target application) and the overall cost of production. Students were expected to base their evaluation on safety of product, but also on its efficacy and the cost-effectiveness to produce it, in other words on the basis of all important aspects of sustainability.

The majority of students from both groups favoured option A both in pre-test and post-test, i.e. low toxicity and high specificity but no indication on cost of production. There were few respondents who preferred option E which meant that the new material was highly specific and cheaper but had unknown (or unproven) toxicity. The number of students choosing an alternative option (i.e. B, C, D or E) in the post-test was higher in the non-GC group with the set of properties E being the second most favoured option. The fact that there were more non-GC students who chose this option (E) is further proof that some students from the non-GC class regarded the economical aspect more importantly than environmental considerations when evaluating properties of new chemicals, showing also a greater detachment from the principle involved in this question. One of these students defended his / her choice (i.e. option E) by explaining that the chemical industry would only be looking at the economic side in the use / production of chemicals….

> "….even if this produces a lot of toxic waste."
>
> (S-64, non-GC, post-test).

This however contrasts with statements made by other (GC) students who declared that they ruled out option E precisely because of its unknown toxicity which was a risky and hence an unacceptable alternative. The following are examples of how some GC students responded differently before and after the intervention.

**Table 9.7**
**Comparing responses of a GC participant to question 4**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-14 | Option E<br>"Because even though 'A' has the best features to prevent pollution, the price is important as an expensive substance would be useless." | Option A<br>"Even though 'A' might be more expensive than 'E', option 'A' is the safest choice since future generations might suffer if it has a high toxicity… and it is not worth the risk." |
| S-23 | Option A<br>It is best for use in a lab, as it is accurate and not too toxic." | Option A<br>"Low toxicity is important so it proves to be less hazardous, and its high specificity ensures that it only serves its function to the full (generating less waste)." |

The first example shows how the student had a change of heart, in the interval between the two tests, giving more weight to the human health and safety aspect in the sustainability of a newly designed chemical, thereby adopting a green chemistry viewpoint. In the second example the student realised that specificity of reagents was an important requirement in the design of chemicals in order to avoid waste / by-products.

Even though there was a slight improvement in level of understanding of both groups, results of the chemistry survey showed that this was one of the few cases whereby there was no significant difference between the pre-test and post-test responses of the two groups of participants *(tables 9.1 & 9.3; appendix 39).* It should however be pointed out that the

GC group, once again, had the edge on the non-GC group registering a higher mean level of understanding in the post-test mainly due to the fact that reasoning was once again more closely associated with the green chemistry perspective, with a higher emphasis, for example to features such as specificity and low toxicity of the newly designed substance.

## 9.7 Using Benign Solvents & Safer Conditions

**Question 5** tested students on the properties and types of solvents used during chemical reactions and processes. It was based on the green chemistry principle which emphasised the importance of **‘using safer solvents and reaction conditions'**. Question 5 was divided in two parts:

- ♦ Part (a) asked students to name any TWO hazardous or toxic solvents.
- ♦ Part (b) then asked them to explain the term ‘green solvent’ and give one example.

Most of the students in both groups showed an initial lack of basic scientific knowledge in answering question 5(a) at the beginning of the year, by naming commonly used toxic or hazardous *‘reagents’* such as hydrochloric acid, sulphuric acid or ammonia rather than toxic / hazardous *‘solvents’*, particularly at the pre-intervention stage. Only 14% of non-GC respondents and none of the GC students managed to give a partially correct answer to the same question in the pre-test. The survey showed that most of the non-GC students repeated the same mistake in the post-test by citing concentrated inorganic acids as examples of hazardous / toxic solvents, with only few referring to correct examples such as benzene, ether, aromatic or chlorinated organic solvents.

The GC students quoted better examples of toxic / hazardous solvents in the post-test indicating they were more knowledgeable by the end of the year on the use of such substances (mostly organic) as solvents in great quantities in many laboratory / analytical techniques and some industries. There were also fewer wrong references to substances such as acids and alkalis. The most popular example of toxic / hazardous solvents given by this class in the post-test were benzene, propanone and perchloroethylene (PERC).

Students fared better in answering question 5(b) with many of them knowing or deducing that a ‘green solvent’ was non-toxic or non-hazardous or environmentally friendly. However there were some students who declared they had never heard about the term at the pre-intervention stage.

There was an improvement in the quality of responses to question 5(b) in both groups in the post-test survey. There were less students stating that they did not know about green solvents in the non-GC group. As in the case of the original pre-test, the most frequently mentioned example of a green solvent among non-GC students was water (cited by 25% of students in pre-test; 42% in post-test).

The GC students gave more complete descriptions of the term ‘green solvent’ with the following table comparing responses given by members of this group just before and after the intervention.

**Table 9.8**

**Comparing responses of GC participants to question 5(b)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-15 | "It is a solvent that doesn't pollute the atmosphere." | "This is a solvent that is non-toxic and non-hazardous. It does not harm the environment. E.g. bioethanol. |
| S-26 | "It means that the solvent used is neither hazardous nor toxic, but still carries out and performs the act of a solvent efficiently." | "Green solvent refers to chemicals in which reactions occur, which aren't hazardous and toxic to the environment. An example of such solvent is supercritical carbon dioxide which replaces PERC." |
| S-30 | "An organic solvent. Example: ethanoic acid. | "A solvent that does not produce toxicity. E.g. water." |

Once again one can note how GC responses developed with time to the point that students were confident enough to include an example of a green solvent in their post-test explanation. It must be noted that most of the students in both groups could figure out the meaning of 'green solvent' in the post-test even if they had never encountered the term in chemistry at school. However, while non-GC students limited their example to water (cited by 14 students) and a couple of incorrect responses, the examples given by the GC students included a wider range of solvents, indicating that GC students had a better understanding of the term and knew by that time of more examples of solvents regarded as 'greener' options by chemists with respect to traditional organic solvents. It could be added that all GC students gave a reasonably correct definition of 'green solvent' but some of them failed (or forgot) to include an example in their response.

A Wilcoxon Signed-Rank test confirmed that there was a highly significant improvement of the GC post-test responses to both parts of question 5, over the ones given earlier in the pre-test *(appendix 41).* Furthermore, a Mann-Whitney test indicated that there was a significant difference between the ways the two groups of students responded to question 5(b) at the end of the year with the GC group gaining a higher mean level of understanding of the concept involved *(appendix 39).*

## 9.8 Designing for Energy Efficiency

**Question 6** concerned the use of 'fuel cells' as a cleaner alternative source of energy. The question was linked to another principle of green chemistry stressing the importance to **'increase energy efficiency'** by minimising energy requirements and possibly carrying out chemical processes at ambient temperature and pressure. This question was divided into two sections and asked students:

(a) to explain the chemistry involved in the fuel cell, and

(b) to name two advantages of fuel cells over other traditional sources of energy.

Only very few students had a faint idea of 'fuel cells' prior to the intervention and only one GC student showed that s/he knew that it involved an electrochemical reaction between elemental hydrogen and oxygen to form water and produce electricity. Both groups had a very low mean level of knowledge / understanding at the pre-intervention stage with many students declaring that they had never heard about the term (fuel cell) before or that they did not know anything about it or how it works. Students who attempted to answer question 6(a) gave incorrect explanations showing that they had a misconception. There was only a minor improvement in the way non-GC students answered this question at the post-intervention stage but the quality of responses given by the GC group to both parts of the question at the same point in time was significantly better.

The following table shows how GC participants improved their response to question 6(a) over the period of the classroom intervention when asked to explain the operation of a fuel cell.

**Table 9.9**

**Comparing responses of GC participants to question 6(a)**

| **Student** | **Pre-test Response** | **Post-test Response** |
|---|---|---|
| S-3 | "Don't know what a fuel cell is." | "Fuel cells convert chemical energy into electrical energy and use hydrogen as their source of fuel. Hydrogen passes over a catalyst, and then joins with oxygen, forming water as a by-product." |
| S-9 | BLANK (no response) | "Fuel cells work via an electrochemical reaction that converts the chemical energy stored in a fuel directly into electricity. Fuel is oxidised at the anode, electrons flow through an external circuit to do electrical work and the oxygen is reduced at the cathode." |

One can note how detailed and clear were the post-test descriptions provided by the three students involved to explain the chemistry of the fuel cell. In both cases, the GC students expressed themselves confidently in the post-test on the mode of operation of the fuel cell even though descriptions were not necessarily complete. It was evident that students understood well that it was an efficient method of converting chemical into electrical energy which did not result in any form of pollution as these were the advantages most frequently cited by GC respondents in answering part (b) of the question.

The Mann-Whitney tests conducted on the data generated by question 6 (both parts) confirmed the significant difference between the two groups of students at the post-intervention stage, with the GC group showing again a higher level of knowledge and understanding of the green chemistry principle involved *(table 9.3, appendix 39).*

## 9.9 Using Renewable Feedstock

**Question 7** concerned the use of biofuels as another alternative source of energy and was meant to reflect the spirit behind the green chemistry principle supporting the **'use of renewable resources'**. In this question, students were asked:

(a) to explain what they meant by 'renewable feedstock', giving also an example; and

(b) to give an example of a biofuel and name another advantage (other than renewability) of biofuels over other traditional fuels.

Baseline analysis of this question showed that students in both groups did not have a clear idea of the term 'renewable feedstock' and found it hard to give a suitable example. Non-GC respondents did slightly better in part (b) of this question, at the pre-intervention stage, mainly by quoting more correct examples of biofuels and / or by describing better some advantages of the use of biofuels over other fuels.

There was no marked improvement in the quality of responses to question 7 by non-GC students, by the end of the year. It appears that some of the students in this group did not differentiate between raw materials required for the production of biofuels and the biofuel itself. In fact some of the students even included 'animal waste' as a possible biofuel!

In the case of the GC class, the situation changed significantly with most of the students being able to relate better on the subject of biofuels and alternative sources of energy, by the end of the intervention. The following table shows how the concept of renewable feedstock developed in GC students over the period of the intervention.

**Table 9.10**

**Comparing responses of GC participants to question 7(a)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-6 | "Type of energy that can be used over and over again. Example: wind." | "Renewable feedstocks are sources of fuel which are replenished over a short period of time and thus they will not run out. E.g. vegetable oil." |
| S-9 | "Sources of energy which can be renewed and used over and over again. E.g. sunlight." | "A renewable feedstock is a material that isn't depleted after use but which is continuously available; one can obtain chemicals / energy from it. Example: starch." |

It is clear that students realised during the post-test that the term 'renewable feedstock' referred to a raw material supplied from non-depleting resources that is used to produce energy (and chemicals) correcting their earlier idea that it could refer to other 'renewable' forms of energy.

The number of GC students who were able to mention at least one correct example of a 'renewable feedstock' for energy production during the post-test, was 76.6%. This contrasts sharply with the lower percentage of non-GC participants, 19.4%, who also succeeded to identify correct examples of alternative renewable sources of energy in the same exercise.

The most common examples of biofuels given by the GC group in the post-test were 'bioethanol / ethanol' and 'biodiesel'. On the other hand the most frequently mentioned advantages of biofuels in the same post-intervention exercise were 'less polluting source' and 'relatively cheaper to produce'.

The GC students' level of understanding of the concept in question 7 changed significantly in due course indicating that students in the GC class moved from a low level to a very high level of understanding of the green chemistry concept on the use of renewable energy resources, by the end of the year.

A Wilcoxon Signed-Rank test carried out on the data generated by question 7 showed that unlike the case of the non-GC class *(appendix 40)*, there was a significant change in the type of responses given by GC students before and after the intervention *(appendix 41)*. On the other hand a Mann-Whitney test confirmed that the GC students' post-test responses to the same questions were significantly better than those of their non-GC counterparts, with students showing higher confidence in explaining features of the green chemistry principle on the use of renewable energy resources *(appendix 39).*

## 9.10 Reducing Derivatives

**Question 8** focussed on the green chemistry principle emphasizing the need to **'avoid chemical derivatives'** through unnecessary conversions during the industrial production of chemical products. The question invited students to evaluate between two different synthetic procedures - the 'old' method A and the 'new' method B, requiring a different number of steps, reagents and solvents, which both produce the same type of drug. Students were invited:

(a) to name two possible benefits of using method B, which involved less steps (chemical transformations) and hence the formation of less chemical intermediates (derivatives);

(b) to name two other important considerations they would make before deciding on which is the better method for the industrial production of the chemical product (i.e. the drug).

Students from both groups performed fairly well in this question during the pre-test with most of them reaching at least a partial understanding level (level 3). One wrong assumption frequently cited by students in this question was that method B was better as it would be a faster synthetic route. This was considered as a misconception as the question did not indicate anything about the kinetics of the reactions involved in each step of the methods under consideration.

Amongst other factors that students thought one needs to consider before deciding on the better or greener method, students mentioned safety to human health, cost-effectiveness of process, pollution problems and percentage yield of product.

There was a notable improvement in the non-GC responses to this question in the post-test. The same cannot be said of question 8(b) were the change was minimal. The GC respondents showed a higher level of understanding in both sections of this question but particularly in question 8(a) during the post-test exercise, with students reaching level 4 increasing from 31% (pre-test) to 73% (post-test).

The GC students referred more or less to the same categories of benefits (cited in pre-test) of the new method B over the traditional method A, i.e. greater economic viability, being less polluting and requiring less resources / reagents / solvents. The same applies to part (b) of the question regarding alternative considerations made before choosing the better method. Frequent responses by GC students included economic feasibility of methods, toxicity of reagents / solvents / by-products, health hazards and pollution-related problems. Other aspects which according to GC students ought to be factored in before taking a decision included the yield of the product, atom economy of reaction, overall time required to complete the process, the efficiency and volumes of solvents used, the cost of production (including energy consumption) the conditions used (whether mild or drastic), renewability of reagents, the presence of any safety hazards, recyclability of any by-products and eco-friendliness of entire process. Very few of these additional 'green' considerations were pointed out by the non-GC group at the same post-intervention phase. This means that the GC respondents regarded the term 'better' to be synonymous with 'greener' and hence responded from a green chemistry perspective. Responses given by non-GC students were again taken from a business point of view even though they included also some economical / safety considerations.

The following table shows how GC responses changed with time when students were asked about the benefits of the process which involved less chemical transformations.

**Table 9.11**

**Comparing responses of GC participants to question 8(a)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-10 | "1. Less money spent (less expenses).<br>2. Less time taken. It is also less complicated." | "1. A shorter process with a fewer different reagents reduces the risk of unwanted fumes or toxic chemicals.<br>2. Less reagents / solvents are used and wasted." |
| S-28 | "1. The method found is faster and also…<br>2. It involves less reactants leading to an economy of substances." | "1. There will be less waste of chemicals.<br>2. It will minimise side products (pollution), some of the extra reagents of method A might have been harmful, so it will be better if they are not used." |

The key terms used by the GC students to explain the benefits were 'less reagents', 'less solvents', 'less waste' and 'less pollution'. This confirms again that students remained focussed on the main aims of green chemistry.

Considering the GC and non-GC data generated from the survey (part B) one can infer that there was a significant difference between the responses provided by the two groups of students to question 8(a) at the post-intervention stage *(appendix 39).* The difference in responses to 8(b) was non-significant but still remarkable considering the difference in the mean level of understanding shown by the two groups in answering this sub-question in the post-test.

## 9.11 Preferring Catalysts from Stoichiometric Reagents

**Question 9** dealt with the green chemistry idea that encourages the **'use catalysts rather than stoichiometric reagents'** in an effort to reduce energy requirements and reduce the use of excessive reagents. Students were asked:

(a) to explain why catalysts are considered as more environmentally friendly than other (i.e. stoichiometric) reagents involved in the reactions;

(b) to give an example of a catalysed reaction that could replace the traditional synthesis of ethanol from ethene (which involves the use of another catalyst but requires more drastic conditions).

Baseline analysis of question 9 showed that more than half of the students in both groups did well in answering part(a) of question 9 (involving basic knowledge of chemistry), but only one student from both groups gave a correct response to part (b). Many students from both groups did not even attempt part (b) indicating that although students were surely familiar with the biochemistry of fermentation, a topic covered even in O-level biology, they were unable to relate it as a possible way of producing ethanol on a commercial scale.

There was hardly any improvement in the quality of responses given by the non-GC students to question 9 at the post-intervention stage. Environmental benefits of catalysts which were frequently cited by non-GC students were the fact they are recyclable and that they do not produce any harmful products. In part (b), only two non-GC respondents referred in the post-test to fermentation of sugars as a possible greener alternative method of production of ethanol.

Post-test responses by GC participants to part (a) of question 9 were very similar to the ones given in the pre-test. However there was a stronger reference to the fact that using catalysts would bring down the demand and hence consumption of energy during a chemical process, producing less harm to the environment.

The following table compares some responses to question 9(a) made by GC students before and after the intervention.

**Table 9.12**
**Comparing responses of GC participants to question 9(a)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-7 | "They are less harmful because they aren't consumed completely. They help speeding up the reaction, thus emitting less waste." | "They do not produce toxic waste during chemical reactions. They reduce the time for the reaction to occur and also reduce energy needed for this reaction." |
| S-9 | "They are renewable. Reagents can be polluting." | "Because they can be used all over again and never be used up; so they would be less polluting and would be cheaper than buying substances again every time. They do not give off or produce other substances which can be hazardous." |

Once again one can easily note the difference in the type of response of the GC students in the post-test, which included important green chemistry concepts such as using less energy, saving on resources and being less polluting. A Wilcoxon Signed-Rank test showed that unlike the use of the non-GC group, there were significant changes in the way GC students responded to both parts of question 9 *(appendices 40, 41)*. The fact that the mean level of knowledge / understanding in part (b) was low even in the post-test indicates that most of the GC students still found it hard to recall (knowledge) that ethanol can also be produced on a large scale with fermentation of sugar which produces 'bioethanol'. The problem here was not the understanding of the principle involved. In fact other data collected during the green chemistry intervention suggests that the GC students did not find any particular problem in understanding the green chemistry principles involved in this alternative 'greener' synthesis of ethanol.

## 9.12 Designing Materials for Degradation

**Question 10** dealt with the green chemistry principle which inspires chemists to try and **'design (new chemicals) for degradation'** in order not to persist in the environment and create waste.

The question was divided into two parts:

- ♦ Part (a) asked students to explain what was meant by 'biodegradable' plastics;
- ♦ Part (b) asked them to explain how the production of biopolymers would help in safeguarding a healthier environment.

Baseline analysis to this question showed that students seemed quite familiar with the concept of biodegradable plastics with the majority of them showing that they had sound / partial understanding on this aspect of green chemistry. Most of the participants were able to give a partial or complete meaning of the term 'biodegradable plastic'. They also referred to several ways they thought such plastics could help protecting the environment.

Post-test responses by the non-GC group to this question showed a similar pattern to the ones in the pre-test and gave similar results. Once again, students forming part of the GC class showed they had developed a higher level of understanding in the interval between the two surveys. Another Wilcoxon Signed-Rank test confirmed that unlike the non-GC responses there was a significant difference between the pre-test and post-test responses given by the GC students to both parts of question 10 *(appendices 40, 41)*.

It could be noted, for example, that the descriptions given by GC students to explain the term 'biodegradable plastic' were more complete at the post-intervention stage, with many of them describing how biodegradation of such polymers is brought about. Table 9.13 shows some examples of how GC students' descriptions changed from the pre-test to the post-test survey.

**Table 9.13**

**Comparing responses of GC participants to question 10(a)**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-18 | "After they are used up, they can be broken down to simple molecules. Then they are re-formed and can be used again." | "These are organic plastics derived from renewable resources such as starch. When they are disposed of, they disintegrate into harmless species without polluting the environment." |
| S-21 | "Plastics that eventually decompose." | "Plastics that can break down by the effect of light, water or other conditions such as acidic / alkaline media, without producing harmful by-products. Degradation usually takes place by the action of microorganisms such as bacteria, fungi and yeasts." |

One can note that certain important features about biodegradability such as the conditions required for degradation and products formed were omitted in the GC pre-test responses. The same could be said of descriptions given by most of the non-GC students before and after the intervention.

The GC students' responses to part (b) were also more elaborate even though they covered more or less the same ideas referred to by the non-GC participants in their responses. These include reduced pollution of the environment (with reference to all forms of pollution including visual), saving wildlife, reduced need for incineration of plastic waste, reduced volume of waste in landfills. A Mann-Whitney test on relevant data revealed a significant difference between the post-test responses of the two groups in both sections of question 10 *(appendix 39)*.

## 9.13 Real-Time Analysis for Pollution Prevention

**Question 11** referred to the green chemistry principle recommending **'real-time analysis for pollution prevention'**. This principle emphasizes the need to monitor closely all reactions occurring during a chemical process in order to anticipate and avoid the formation of toxic and hazardous products. The question asked students to suggest measures which need to be taken in order to avoid the production of high amounts of hazardous by-products during a chemical process which may involve a series of large-scale chemical reactions.

Students in general did not fare very well in this question at the pre-intervention phase but this was mainly due to the notable number of students who were unable to give some kind of response. The non-GC group registered a slightly higher mean level of understanding on this question at the time of the pre-test, but a Mann-Whitney test established that such a difference between the groups was not significant *(appendix 38)*. The same non-GC class however fared worse in the post-test (with mean value falling from 1.74 to 1.24) when answering the same question with many students resorting to irrelevant or unacceptable responses.

A Wilcoxon Signed-Rank test comparing responses by the non-GC students before and after the intervention showed that any difference was minor and non-significant *(appendix 40).* In contrast there was a clear improvement in the quality of responses given by the GC students in the post-test *(appendix 41).*

Several proposals made by GC students in the post-test to answer question 11 included direct references to green chemistry principles such as the use of alternative, less toxic / less hazardous reagents, use of greener solvents, continuous monitoring of reaction conditions and choosing more efficient reactions (with higher atom economy & yield). There were a few GC students who came up with the idea of installing control measures at various points of the chemical process and carry out a real-time analysis to minimise waste and prevent pollution as suggested by one of the principles of green chemistry. Table 9.14 illustrates how responses to question 11 changed in some of the GC participants from pre-test to post-test, with students, once again showing how they their arguments (at the post-intervention stage) were influenced by an increasing understanding and knowledge of green chemistry concepts.

**Table 9.14**

**Comparing responses of GC participants to question 11**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-6 | "One must try to reduce the amount of the reactants which produce the hazardous products but still keep the reaction working properly." | "Use of green solvents.<br>Use of non-toxic reagents.<br>Controlling the process at every stage of the reaction." |
| S-21 | "Do not use excessive reagents. Always take precautions." | "Check continuously whether conditions under which the reaction is made are correct. See whether any catalysts may be used. Make sure that the proper solvents, temperature conditions, etc. are employed." |

So the GC students understood that if one were to avoid any pollution from an industrial process, one has to monitor closely and continuously all steps and reactions involved in order to be able to correct in time any faulty situations leading to an eventual accumulation of waste material. The fact that students were able to arrive at using such logic at the post-intervention stage indicates that GC students had adopted the green chemistry viewpoint, leaving no stone unturned in order to prevent pollution at every possible source during a chemical process.

A Wilcoxon Signed-Rank analysis on pre-test and post-test data from question 11 confirmed a significant difference in responses given by the GC participants on the two occasions *(appendix 41).* Furthermore a Mann-Whitney test established a significant difference in the quality of responses given by the two groups of students to the same question at the post-intervention stage *(table 9.3, appendix 39).*

## 9.14 Inherently Safer Chemistry for Accident Prevention

**Question 12** was the last of the series of questions based on the twelve principles of green chemistry, and emphasized the importance of taking necessary measures in order **'to minimise the potential for accidents'** during the production of chemicals. In this question, students were asked to choose between five different sets of precautions which could be taken by the industrial chemists to prevent the possibility of fires, explosions and large-scale environmental disasters.

Baseline analysis showed that, generally speaking, students in both groups arrived at the correct choices. However most of the students adhered only to one of the options and then went on to explain the relevant precaution. The total number of references made by students to the three correct options C, D and E was almost the same in both groups and even justifications were similar, typically consisting of a short phrase or sentence. Option C was by far the favourite choice as students regarded it to be the safest / most important measure to be taken. However the reasoning was not always scientifically logical. There was no significant difference between the responses given by the two groups in the pre-test where they showed similar level of understanding.

Analysis of the post-test data shows that the quality of responses improved slightly in the non-GC group, but more appreciably in the GC group in the period between pre-test and post-test. The Wilcoxon Signed-Rank tests conducted separately on the data from both groups confirmed that there was no major development in responses of non-GC group *(appendix 40)* but a significant change in the GC responses *(appendix 41).* In fact the GC respondents showed a significantly higher level of understanding of the concept referred to in question 12 with an increase in number of students referring to options C, D and E and improved quality of arguments supporting their choices.

The following are some examples illustrating how reasoning evolved in the GC students' responses to question 12.

**Table 9.15**

**Comparing responses of GC participants to question 12**

| **Student** | **Pre-test Response** | **Post-test Response** |
|---|---|---|
| S-6 | "Option C<br>They should try to use catalysts, for example, instead of toxic substances, because it would do the same job at a cheaper environmental cost." | "Options C, D, E<br>Non-toxic and non-hazardous chemicals are safer for the workers. By using renewable sources of energy, pollution at the source is reduced. High temperatures and pressures may cause river pollution if warm water or solvents are released there." |
| S-21 | "Option C<br>To be safer." | "Options C, E<br>They shouldn't use toxic reagents because these might not only harm the environment but also the people living in it. Also such high temperatures and pressures should not be used due a higher probability of explosions and thermal pollution." |

One could notice that GC students showed greater considerations in their post-test responses, referring to more than one possible consequence if the precaution is not followed. Furthermore, in both cases, students considered both the safety of workers and of the environment when discussing the different precautions, which once again, overlaps with the spirit and aims of green chemistry.

As in the case of the pre-test, the most popular choice by both groups of students in the post-test was option C. There were fewer references by the GC respondents to option A and option B which do not necessarily prevent pollution and environmental accidents, and were the least options that could be associated with green chemistry.

A Mann-Whitney test carried out on post-test data showed that once again, a significant difference was registered between the responses given by the two groups of participants by the end of the intervention *(appendix 39)*.

## 9.15 Thoughts about Green Chemistry

**Question 13** simply invited students to explain in their own words what they thought was the meaning of the term 'green chemistry'. Students were not expected to recall the definition of the term by heart but only to suggest a statement summarising the main aims or role of green chemistry, including reference to important features such as:

- ♦ pollution prevention (and not pollution control / remediation);
- ♦ the design / use of environmentally friendly reagents / solvents;
- ♦ the design / use of safer chemical reactions / processes.

Analysis of pre-test data showed that both groups already had a hint that green chemistry was associated with the environmental aspect of chemistry even though some of them declared that they had never heard about the term before at school or elsewhere. Most of the answers made a direct or indirect reference to environmental protection and / or pollution prevention. In fact the concept of pollution prevention was referred to by about 50% of students (16 non-GC and 18 GC participants) on this occasion.

The following is a sample of non-GC students' pre-test responses throwing light on the students' early perception of green chemistry after having been asked on various aspects of the subject in the rest of the survey.

> "I am not informed on this term. But I think that it has to do with chemistry about the environment"
>
> S-43, non-GC, pre-test

> "The branch of chemistry which takes into consideration the consequences a chemical reaction can have on the environment."
>
> S-61, non-GC, pre-test

In most cases, students associated green chemistry with environmental chemistry and thought that it was more or less the same 'branch' of chemistry that was interested in discovering, understanding and containing environmental problems. The GC pre-test statements on green chemistry weren't so different and made similar references to an 'environmentally friendly chemistry' that was particularly interested in the chemistry of the environment and in solving pollution problems by chemical means.

The mean level of understanding in this question measured at the pre-intervention stage showed that both groups already possessed a partial understanding of the term 'green chemistry', with some degree of alternative conception. This was probably achieved by deduction from the content of the rest of the questions or from the connotation of the term 'green' which usually evokes environmental friendliness. A Mann-Whitney test confirmed that there were no important differences between the statements given by the two sets of students to answer question 13, in the pre-test exercise *(appendix 38)*.

There was a slight improvement in the quality of responses given by the non-GC group to question 13 by the end of the year. However none of the responses in the test could be regarded as a full definition of the term ‘green chemistry’, in the sense that there was little or no reference to important concepts such as ‘design’ and ‘manufacture’ of safer chemicals to achieve pollution prevention.

The GC participants showed an even more evident improvement from their original perception of green chemistry and confirmed they were able to produce a more complete statement to describe it. In fact the mean level of understanding of this group increased to a point that it approached a sound understanding level. A Wilcoxon Signed-Rank test comparing the statements related to question 13 found a significant difference in the responses made by GC participants before and after the intervention *(appendix 41)*. This contrasts with the insignificant change observed in the non-GC group over the same period of time *(appendix 40)*.

In their post-test responses, 80% of the GC students included a direct reference to pollution elimination or minimisation, which is the essence of green chemistry, and one student even referred to green chemistry as ‘sustainable chemistry’, which is the second most frequently used alternative designation to green chemistry. Although there were similar references in the non-GC responses, such a feature was not as prominent and frequent as in the case of the GC class post-test data.

The following statement summarises the contrast between the overall idea of green chemistry generated by the two groups. The non-GC group thought of an environmentally friendly science that aimed primarily towards safety in the use of chemicals.

> "Chemistry designed to be beneficial or at least non-harmful to the environment."
>
> S-48, non-GC, post-test

In contrast the following table shows how GC respondents developed their idea of green chemistry over the period of the intervention, with more refined statements / descriptions which included most of the features which are included in the aims and definition of green chemistry.

**Table 9.16**

**Comparing responses of GC participants to question 13**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-9 | "Using chemicals which are good for the environment and do not pollute." | "Green chemistry is a new philosophy of chemical research and engineering that encourages the design of products and methods to minimise the use of toxic and / or hazardous substances, thus polluting less the environment." |
| S-10 | "Chemistry which concerns the environment and is done in favour of the environment." | "Green chemistry is studying ways and means to design processes which include less harmful reagents or produce less harmful products. It involves designing safer processes which will not harm the environment and which will prevent pollution. It can also be called sustainable chemistry." |
| S-21 | "Don't know!" | "Green chemistry is a revolutionary way of looking at and treating today's environmental crisis. It devises chemical methods to reduce pollution, take care of the environment, reduce costs of production, etc., in a conscious effort to reduce harm to the environment." |

In their statements students referred to green chemistry in different ways, describing it as a 'new philosophy of chemical research', 'designing safer processes' and 'a revolutionary way of looking at and treating today's environmental crisis'. Another student referred to this new area of chemistry in a rather 'poetic' way describing it as follows:

> "Green chemistry is the 'bandage' by which scientists are trying to heal the wound they inflicted on the environment in the past. It consists of a set of rules that help people to take care of the environment for the good of future generations."
>
> S-44, GC, post-test

All this indicates that the aims and role of green chemistry managed to captivate the students' imagination and this is what led to their high level of understanding.

A Mann-Whitney analysis on post-test data confirmed a significant difference between the two groups even with respect to question 13 *(table 9.3, appendix 39)*.

## 9.16 Explaining the Principles of Green Chemistry

**Question 14** was highly specific as it challenged students to explain briefly any three of the 12 fundamental principles upon which green chemistry was based. Students were expected to make statements which matched as closely as possible with any three of the 12 different concepts that served as guidelines to whoever wanted to study or practice green chemistry.

Baseline analysis showed that the majority of students in each group claimed that they never heard anything about green chemistry principles and / or failed to make any suggestions at the pre-intervention stage. The rest came up with a number of ideas which they thought could form part of the list. These included suggestions such as reducing / eliminating pollution or hazardous chemicals, reducing the use of toxic reagents and using non-toxic / less toxic / less hazardous chemicals. The mean level of understanding at the beginning of the year was very low in both groups with the non-GC class doing better due to a higher number of suggested concepts. A Mann-Whitney test however established that there was no significant difference between the two groups in the pre-test with respect to this survey item *(appendix 38)*.

Post-test responses showed that the non-GC fared worse than the pre-test with a higher number of students choosing not to answer the question. This indicates that students were still not confident enough to write about concepts related to green chemistry by the end of the year. One of the non-GC students made it clear that s/he was not yet conversant on green chemistry and cited ‘acid rain’ as the only ‘green’ topic s/he was familiar with. The types of suggestions given by the rest of the students in this group were very similar to the ones made earlier by the same participants in the pre-test. Some of these respondents made it very clear that green chemistry was never discussed in class as it did not form part of the examination syllabus. Other suggested that ‘greater publicity’ is required if these principles were truly regarded as fundamental ideas of chemistry.

Responses to this question resulted in the most significant change in level of knowledge and understanding experienced by GC students during the post-test with the mean score increasingly sharply from 0.67 (pre-test) to 3.50 (post-test). In fact, on this occasion, the GC respondents gave a good account of some of the green principles of green chemistry, with 80% of the group being able to recall and explain well three of these principles and hence reaching level 4 of the understanding scale. There were three students who, for some reason, failed to answer this question by the end of the exercise.

Analysing the students’ responses to question 14, one finds that the most popular principles quoted by students were waste minimisation (16 references), designing safer chemical procedures (16), maximising atom economy (11), minimising energy requirements (9) and using renewable raw materials (8). The following is a sample of responses to question 14, made up of statements describing the three principles of green chemistry:

- "Designing safer chemicals: chemical products should be designed to affect their desired function while minimising toxicity.
- Prevention: it is better to prevent waste than to treat or clean up waste after it has been created.
- Reduce derivatives: unnecessary derivatisation should be minimised or avoided if possible because such steps require additional reagents and generate waste."

S-8, GC, post-test

- "Use safer solvents. This encourages us to opt for the use of solvents which are non-hazardous and non-toxic.
- Use renewable sources of energy: use energy sources such as light energy, biomass and wind to produce energy. Such resources do not produce / produce very little harmful waste.
- Maximise atom economy. This encourages scientists to carry out reactions that do not waste chemicals."

S-28, GC, post-test

The quality of the statements provided by the GC respondents to explain some of the principles of green chemistry confirm that the group was very knowledgeable about the fundamental ideas which define green chemistry at the end of the green chemistry programme. Most of the GC respondents did not simply memorise and recall a list of terms or phrases from their notes but were also able to rephrase them using simple language which shows again that they were confident to do so. In fact there were no repetition of statements and students expressed themselves in a different way to describe the same principle of green chemistry, sometimes adding also concrete examples. This is, for example the way two different students chose to explain the green chemistry principle of atom economy in the post-intervention questionnaire.

> "Maximising atom economy when we will make sure that we use substances that don't produce a lot of waste at the end of the reaction."
>
> S-5, GC, post-test

"Atom economy – as much of the reagents used is converted into the product."
S-25, GC, post-test

Students were able to explain in a rather different way that the principle of atom economy was all about finding ways of converting reactants into products without creating waste or by-products. Once again this showed a high level of understanding of the concept involved.

The responses given by the GC group covered a total of eleven out of the twelve principles of green chemistry, proving that students had a good overview of the basics of this new area of chemistry by the end of the programme. The Mann-Whitney test carried out on post-test responses confirmed that there was an extremely highly significant difference between the ways the two groups expressed themselves in this question *(table 9.3, appendix 39).*

## 9.17 Benefits of Green Chemistry

The last question (**number 15**) of part B of the chemistry survey asked students to give one practical example of how they thought human civilisation could benefit from green chemistry. Students were expected to give a concrete example of how society can benefit directly or indirectly from the practice of green chemistry. Any general statements made by students on the usefulness of green chemistry, which however lacked specific examples, were accepted as a form of partial understanding of this question.

Despite the fact that practically all students in both groups had claimed at some point in the pre-intervention stage, that they knew nothing in particular about green chemistry, the majority of students still chose to answer this question giving their view on the matter.

It could be noted that in their pre-test responses, most students made a correct guess of what some positive effects of green chemistry would be but then failed to elaborate on how the environment and human health could be better safeguarded through its application.

The post-test responses by the non-GC participants to question 15 were more or less the same in term of quality as those given in the pre-test. This implies that by the end of the year, the non-GC students did not develop the originally vague idea they had about how green chemistry could be useful to society at large. Examples of ideas by non-GC respondents showing lack of knowledge of green chemistry included references in the post-test questionnaire to 'separation of rubbish', 're-use of materials', producing 'less expensive chemicals', 'recycling' materials derived from nature, and simply 'becoming more aware of the environment'. Some of these ideas are more closely linked to environmental science or environmental chemistry than to green chemistry.

The GC participants performed better in question 15 at the post-intervention stage with a higher number of students achieving sound understanding (level 4). The most popular responses by GC participants included: a cleaner / less polluted environment, a healthier lifestyle, reduced global and more efficient use of earth resources. Analysis showed there was an improved quality of statements (by the GC class) describing the ways (examples) green chemistry could be of benefit to mankind. Table 9.17 illustrates some changes in GC students' responses to this question before and after the classroom intervention.

**Table 9.17**

**Comparing responses of GC participants to question 15**

| Student | Pre-test Response | Post-test Response |
|---|---|---|
| S-19 | "Having less pollution thus preserving life for future generations." | "It can benefit from new ways of doing the same things, but doing them without producing pollution, like driving a car on biofuels and using biodegradable plastics. And also helping to avoid disasters which could effect and kill a lot of people, making industries safer." |
| S-29 | "Healthier environment." | "By adopting such methods as (those involving) biofuels and greener solvents, we are cleaning the air we breathe. We are eliminating diseases such as asthma and also cancer. The cleaner the air, the better our lifestyle is for us and for our generation." |

The emphasis of most of the GC respondents was on a better quality of the environment (less toxic / hazardous waste) and a healthier life (lower incidence of diseases and living longer) as a result of reduced pollution, particularly that originating from the chemical industry. One factor which was frequently cited by students was the exploitation of renewable energy resources with particular reference to the use of biofuels. One of the students referred to green chemistry using the phrase 'a life-saving methodology', thereby realising the preventive approach of green chemistry, primarily aimed to save human lives.

There was a noticeable improvement in the expressed knowledge of green chemistry within the GC class from the pre-intervention to the post-intervention stage, indicating that the average student attained a partial understanding on the real benefits of green chemistry by the time of the post-test. This was approximately one level higher than that achieved by the non-GC participants in the post-test showing a highly significant difference between the two groups as confirmed by a Mann-Whitney test on relevant post-test survey data *(appendix 39).*

## 9.18 Conclusions

Data analysis of the second part of the chemistry survey reveals that there was no major difference in the initial (pre-intervention) knowledge and understanding of green chemistry possessed by the two groups of students participating in this project. The situation changed at the end of the intervention where the GC group was found to have gained a sound understanding of the basic principles of green chemistry and became conversant with some aspects of it. This contrasts with the non-GC group of students who did not show any progress in their conceptual understanding of the same aspects of chemistry despite having been minimally exposed to green chemistry through their participation in the chemistry survey and their attendance to an educational poster exhibition organised by other students in the same college during the period of the intervention.

The following were the main findings of the analysis of data generated by the students' responses in questionnaire B forming part of the chemistry survey.

### The Pre-Intervention Stage

Students had no idea about green chemistry before the classroom and laboratory intervention and they perceived it, at this point in time, as being more or less equivalent to environmental chemistry which aims to identify, understand and quantify rather than solve problems related to the earth's environment. A series of Mann-Whitney tests conducted on the responses given by the two groups of students showed that there was no significant statistical difference in the way students expressed themselves on the majority of aspects of green chemistry which featured in part B of the chemistry survey at the pre-intervention stage.

## The Post-Intervention Stage

The situation changed radically by the end of the intervention where evidence shows that there was a significant disparity between the way GC students responded to questions regarding concepts related to green chemistry, compared to the way the non-GC students answered to the same set of questions. In fact, when the Mann-Whitney test was carried out on data generated by part B of the chemistry survey at the post-intervention stage, it emerged that there was a statistically significant difference between the two groups on the majority (19 out of 24) of survey items in the post-test exercise *(table 9.1, appendix 39).* Analysis of the post-intervention data from the same survey showed that the GC group attained a higher level of knowledge / understanding in all aspects of chemistry / green chemistry tested by the same exercise. In fact the mean level of understanding of the GC group was consistently higher than that of the non-GC group at the post-intervention stage. This includes the five items where no statistically significant change was detected using the Mann-Whitney test.

## How the Groups changed with Intervention

When one compares the pre-test data with post-test data obtained from the same group of students, one finds that the responses given by the GC group changed more evidently with respect to those of the control (non-GC) group. The change did not simply consist of a build-up of knowledge of green chemistry which students acquired as a result of the classroom and laboratory intervention. Neither was it a question of understanding and dishing out terms and vocabulary related to green chemistry. The change was even more radical as it involved clarifying vague ideas and correcting some misconceptions on environmental aspects of chemistry through the actual understanding of a set of chemical principles which fall under the umbrella term of green chemistry.

In fact students from both groups could already relate, at the beginning of the year, to the environmental side of chemistry giving their views on features such as sources of energy, toxicity of reagents and solvents, use of catalysts, safety considerations and pollution from the production and use of chemicals. However the way which GC students dealt with such concepts at the end of the year was found to be significantly different as ideas developed, reasoning was more profound and students gained confidence in their arguments or explanations forming part of the survey responses.

The survey found that the average sixth form chemistry student is usually able to deal superficially with environmental terms such as biofuels, pollution prevention and renewable sources of energy. However the same student would not necessarily be knowledgeable and sufficiently prepared to be conversant in this relatively new area of chemistry now referred to as green chemistry. So the classroom intervention was instrumental in changing the students' outlook towards chemistry providing them with a new green chemistry perspective which allows them to evaluate better any future achievements of science and particularly chemistry.

## 9.19 Chapter Summary

This chapter analyses the students' responses in part of the chemistry survey concerning the students' knowledge and conceptual understanding of green chemistry, by making use of a number of criteria as described in the methodology chapter. The results of this analysis were tabulated and a number of nonparametric statistical tests were carried out to measure any significant differences between the two groups of students (GC vs non-GC) at the pre-test and post-test stages (Mann-Whitney test), and also to detect any significant changes in responses occurring within the same group following the period of the classroom intervention (Wilcoxon Signed-Rank test).

Part B of the chemistry survey consisted of a set of questions concerning various aspects of green chemistry, with most of them related directly to the twelve fundamental principles which characterise green chemistry. The students' responses to each of these questions were analysed by comparing statements and other data provided at the pre- and post-intervention and highlighting important changes made in the way students' answered the same questions. Reference was also made to statistical analysis mainly by referring to the outcome of the nonparametric Mann-Whitney tests comparing the two sets of participants and the Wilcoxon Signed-Rank tests to compare the performance of each group before and after the intervention.

The main finding of this exercise was that the two groups of students taking part in the survey started the year with very limited knowledge and understanding of green chemistry but one of the groups ended the year with a different baggage of ideas on this new development of chemistry. In fact it was found that contrary to the non-GC group, members of the GC class were evidently more knowledgeable and held a better understanding of many of the facets of green chemistry as presented in the chemistry survey, by the end of the intervention. More than that the green chemistry intervention served to equip students with a new frame of mind which enables them to interpret and discuss more thoroughly some important aspects of science, particularly those related to chemistry for a sustainable environment.

# Chapter 10

# CONCLUSIONS

## 10.1 Introduction

This research investigation sets out to address the main research question:

***"How do Maltese sixth form students respond to the incorporation of green chemistry in the A-level chemistry curriculum?"***

In an attempt to answer this question the author tried to address the following relevant sub-questions:

*1. In what ways do students' attitudes change by including aspects of green chemistry in the core A-level curriculum?*

*2. What understanding of green chemistry ideas is developed by students who do or do not experience the green chemistry intervention?*

*3. What are the effects of the green chemistry intervention on the students' views of studying chemistry beyond A-level?*

In order to resolve such a research inquiry, the author collected data from two groups of Maltese sixth form students (forming part of the same cohort) prior to the classroom / laboratory intervention and then upon completion of the same intervention. The green chemistry intervention package was applied only to one of the groups (the GC class) while the second group (the non-GC class) acted as a control. A theoretical framework was developed to facilitate the analysis of pre-intervention and post-intervention data related to the students' attitudes. The twelve principles of green chemistry, originated by Anastas and Warner (1998) were then applied together with a set of criteria (adapted from Çalik and Ayas, 2005) to analyse the data collected related to the students' understanding of green chemistry concepts.

This chapter discusses the main research findings and how these helped in answering the research questions. It then discusses the main contribution of this work to knowledge. The chapter also reflects on some methodological issues of the study including some limitations of the method used. It also considers some reflections on the intervention package and on the research instruments used, and discusses some of the implications of the study for policy and practice. The chapter concludes with some general comments on the overall project.

## 10.2 Main Research Findings

This section attempts to answer the research questions in the light of the main findings of the study. It refers to the results of the analysis of the data gathered from participants through the use of various instruments including the chemistry survey (questionnaires), focus groups, research diary and other documents.

### 10.2.1 The Main Research Question

*How do Maltese sixth form students respond to the incorporation of green chemistry in the A-level chemistry curriculum?*

The study found that Maltese sixth form students reacted very positively to the introduction of green chemistry and showed a great deal of interest through their voluntary participation in all activities that formed part of the classroom / laboratory intervention. In fact, even though they knew that green chemistry was not included in their A-level programme of studies, students honoured their commitment to attend regularly for a number of weekly seminars which discussed basic theory and concepts of this new area of science. They also accepted to take part in a number of learning activities through which they showed that they were able to understand the different aspects of green chemistry that were presented to them in class. The students 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 (e.g. **item C1**: 69.7% $\rightarrow$ 83.3%) and even towards school chemistry (**item E2**: 63.6% $\rightarrow$ 80.0%). 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. For example GC participants still felt, by the end of the year, that despite all worldwide efforts, chemistry was still not doing enough to control pollution (**item C3**: 39.4 $\rightarrow$ 53.3%). They also showed a significantly stronger positive attitude (with respect to the control group) towards the applicability of green chemistry as could be confirmed by statistical tests on items F6, F10, F13, F14, F15 and F16 of part A of the chemistry survey, with p-values lower than 0.05 in all cases (appendix 31). This higher sensitivity of the GC students towards the environment could also be confirmed in the way they spoke about the various environmental world problems and the way they perceived the impact of green chemistry on society during focus group discussions (as explained in chapter 7). GC students also showed a sharper critical mind both in the way they tackled certain questions in part B of the chemistry survey (e.g. questions 11 and 12) 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 much 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 realised 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 practical work in the school laboratory.

### 10.2.2 Sub-question 1

*In what ways do students' attitudes change by including aspects of green chemistry in the core A-level curriculum?*

One of the main findings of this study was that green chemistry managed to change the students' attitudes towards societal chemistry. The survey showed, for example, that their initial negative attitude towards social responsibility of chemistry with respect to the environment became less pronounced amongst the GC respondents but more meaningful within the non-GC group (**item C5:** 57.6% → 53.3% GC; 55.6 → 66.7% non-GC) over the same period of time. The green chemistry intervention also succeeded to bring about new ideas and considerations among students about the true value of chemistry in society and this was very evident in the way GC students expressed themselves during the focus group discussions, which gave stronger indications on this than the survey findings. The intervention therefore helped students reflect on the unique contribution of green chemistry to human civilisation. It is evident that students recognised, 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 past mistakes which claimed thousands of human lives throughout the years and ended up in environmental nightmares in different parts of the world. Hence students realised also that green chemistry had the potential to correct the public perception that chemistry is a dirty scientific discipline which ends up generating toxins and pollution. This is due to the fact that according to the same students, green chemistry was proactive, harmless and provided positive solutions. This is what students meant to say when stating that 'green chemistry throws bright light on chemistry' and that 'after all, it is not bad studying chemistry'.

In contrast, the control (non-GC) 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. The typical sixth form students thought that green chemistry was more or less the same as environmental chemistry and they felt sceptical about its aims and applicability. They agreed, for example, that a chemistry that claims to be 'green' may be too expensive to be used 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 and waste produced by the chemical industry. It is clear that by the end of the intervention, unlike the GC participants, the non-GC students did not change their original perception on the value of chemistry in society and did not revise their views on its overall impact on mankind.

The study confirmed findings of other studies indicating that students found A-level chemistry to be a difficult subject for a number of reasons such as the learning of abstract concepts, emphasis on memory work, the mathematical skills needed to solve calculations, an overburdened curriculum, the negative influence from family and friends, and also because of the inclusion of irrelevant material. Students also perceived a significant gap separating the content covered at O-level and that presented at A-level, to the extent that some thought that it was as if they were starting everything afresh. Students were also particularly concerned that A-level chemistry lacked relevance to everyday life and agreed that the local curriculum needs to be revamped to reflect better the ongoing contribution of chemistry to the progress achieved by mankind.

One important finding of the study was that 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 space 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 easygoing with respect to the other topics and areas of chemistry. In fact 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. They also liked the idea that green chemistry could also be applied on a small scale in the school laboratory where they could see it in action at a close range.

The general feeling among students who experienced the green chemistry intervention was that the inclusion of green chemistry would raise the students' interest and motivation to learn and study chemistry. This explains why the same students saw the need 'to put more green chemistry in chemistry' and why they wished that one day, 'most of the A-level chemistry would be transformed to green chemistry'.

There is abundant evidence showing that students were enthusiastic and felt stimulated doing practical work in green chemistry. The study found that 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 practicals 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 practice, proving also that they were feasible and not just theoretical. The green chemistry experiments 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 the green chemistry laboratory experience that they strongly favoured the idea of including it in future A-level chemistry programmes. The 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.

### 10.2.3 <u>Sub-question 2</u>

*<u>What understanding of green chemistry ideas is developed by students who do or do not experience the green chemistry intervention?</u>*

This research investigation showed clearly that the students who were exposed to green chemistry were able to master the key ideas which characterise this newly emerging area of science. In fact there is sufficient evidence showing that students found no particular difficulties in absorbing 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, and discuss some related concepts in class.

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 found to be able to deal confidently with questions related to different aspects of green chemistry including waste minimisation, 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 chemistry survey showed clearly that the GC students were more prepared 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. In most cases, the responses given by the two groups of students were found to be significantly different, with the GC students showing a significant improvement in the way they addressed the same questions at the pre-intervention stage.

Evidence shows that the GC group did not learn any of the new green chemistry principles by heart but their frame of mind evolved with time in such a way that they gradually adopted a new green chemistry perspective which helped them answer the questions more confidently at the post-intervention stage. 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, the survey responses given at that point in time lacked any reference to features which define sustainability, this being the overarching 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 fact that GC students were able to grasp the basics of green chemistry, was already indicated throughout the different phases of the intervention, but particularly during the learning activities, laboratory experience and poster presentations during the students' research seminars. Further evidence of the GC students' understanding of green chemistry concepts was their ability to discuss with confidence, with the use of related terminology, the different aspects of green chemistry in class 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 also 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. Evidence shows that other students at the same level of education and following the same course of studies, but who did not experience the same intervention, did not develop the same level of critical thinking on the environmental side of chemistry, over the same period of time.

This is consistent with other studies showing that students who are exposed to green chemistry would improve their critical thinking and communication skills which are required in order to understand better the contexts of sustainable development (Parrish, 2007). 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 (Haack et al, 2005).

### 10.2.4 Sub-question 3

*What are the effects of the green chemistry intervention on the students' views of studying chemistry beyond A-level?*

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 but were mainly interested in medicine, followed by health sciences, with only few showing interest in the pure sciences. For many students, the prime motivation to study chemistry was to follow a medical career track for which they wanted good grades in their A-level sciences. The survey showed that the GC participants had a stronger inclination (by the end of the year) than other students, to choose a science-related career and also a stronger ambition for a chemistry-related job. Evidence shows that despite the general motivation for a medical career, this group of students was more open to a possible future career in chemistry than the rest of the students, by the end of the intervention. The study indicated, in fact, that studying green chemistry improved the students' motivation to choose a chemistry-related job. The green chemistry participants also felt that students wishing to pursue further studies in chemistry or those aspiring for a chemistry-related job would soon be requiring a good background of green chemistry. This explains why the same students believed that more students need to be enticed to study and specialise in this area of chemistry.

The students also thought that research in green chemistry was an important investment for a healthier future civilisation while a few of them (a minority) declared that if they were to specialise in chemistry they would seriously consider the area of green chemistry, getting the approval of the other members of the focus group, in one of the sessions held at the end of the intervention. This proves that the intervention also had a positive effect on students' behavioural attitudes towards studying chemistry.

## 10.3 What the Thesis has Contributed to Knowledge

The study has contributed to knowledge in at least two different ways. The first consists of the development of a structure which provided the appropriate mechanism to process data gathered from the students participating in this study. The second original contribution to knowledge consists of the main findings of this case study on the first group of sixth form students from Malta to have been introduced to the principles of green chemistry.

The structure which helped in the systematic analysis of data was based on two frameworks. The first theoretical framework provided the platform that allowed the students' responses to be mapped against ten attitudinal dimensions which reflect the students' attitudes towards chemistry in general and green chemistry in particular. This conceptual framework is based on the latent process viewpoint of attitudes and has the potential to be adapted and used in future attitudinal studies particularly those related to the introduction of other curriculum innovations in science subjects at the different levels of education. The second framework used to extract and analyse students' data on the understanding of green chemistry is the established set of 12 principles which characterise the same field. In fact part of the chemistry survey (questionnaires) used in this study was designed to ask students questions related to the statements defining these basic principles of green chemistry. The students' responses to this part of the survey were then analysed adapting a set of assessment criteria used by other researchers to gauge the level of understanding in similar studies.

This work can be considered as an original case study of the first ever group of students to be taught green chemistry in a Maltese pre-university institution. It includes rich information on the students' voices expressing their reaction to the possible introduction of one of the most important recent developments in chemistry, in the A-level curriculum. The study indicated that students reacted positively and were predisposed and sufficiently prepared to learn about this new area of chemistry. The students felt that green chemistry provided an important missing link that existed between the current curriculum which was loaded with facts and theories of chemistry and had little reference to the environmental context, and a curriculum which would reflect better the contribution of chemistry to society including its pivotal role to secure a sustainable environment. The study also found that with green chemistry students raised their environmental awareness, their interest to study chemistry and their motivation to follow a chemistry-related career. Evidence suggests also that students were particularly intrigued with the practical side of green chemistry. Further evidence shows that apart from gaining knowledge and understanding of green chemistry, students who experienced the classroom / laboratory intervention also developed a more positive perspective of chemistry as a science as well as a critical mind that allowed them to be familiar with aspects of green chemistry. Further evidence of the positive impact of the intervention package was the fact that one of the students who had participated in this project and who is currently reading for a degree in pharmaceutical sciences has chosen green chemistry as an area of specialisation for his undergraduate dissertation. This suggests that the first green chemistry experience in Malta generated sufficient interest and motivation among students to the extent that participants involved considered it for future studies and career.

This case study therefore sheds light on some of students' aspirations for curricular changes and may be referred to by other researchers in science education to evaluate the impact of prospective changes in the teaching of science subjects at post-16.

## 10.4 Reflections on Research Methodology

The main strategy adopted in this research investigation was the case study approach. Yin (1994) suggested that in order to carry out a case study, the researcher must possess or develop a number of skills such as being able to ask relevant questions and interpret the responses, being a good listener, and being able to adapt and be flexible in order to react to different situations. The researcher is also expected to be knowledgeable on the issues being studied and be as unbiased as possible to any preconceived ideas. The author of this study did his utmost to achieve all this throughout the entire investigation.

The methodology used in this study attempted to interpret the students' reaction to the introduction of the new area of green / sustainable chemistry in the A-level chemistry curriculum. The author recognises that there were some limitations in the design and application of this methodology even though he tried his best to minimise their effect in the various phases of the project. Part of these limitations derive from the use of the case study approach itself while others arise from the other design features adopted in the same study.

One of the main disadvantages of a case study is the extent to which the findings can be generalised to other similar situations. However, rather than emphasizing on generalisability, the study attempts to promote 'relatability' by allowing readers to recognise, through the rich description of events, a number of similarities to their very own situation, thereby establishing the basis for the so called 'naturalistic generalisation' (Stake, 1978). Although this investigation was a case study carried out in a unique sixth form institution in Malta, the intervention package designed for this study could certainly be applied in other institutions and similar techniques could be adopted or adapted to extract and analyse data from other students embedded in similar educational settings.

Specific limitations of the study include the use of two randomly chosen different groups belonging to the same cohort of sixth form students and the fact that research evidence was mainly based on data collected from questionnaires and focus groups, which both have their own disadvantages.

As regards the samples of students participating in this study, it was assumed that the groups were comparable as both included students with a similar mixture of family and cultural backgrounds and with similar academic qualifications. The only important disparity was in gender ratio as one of the groups (the GC class) was predominantly composed of female students, while the other was more balanced. No major gender-related issues emerged from the results obtained in the study. However, one cannot exclude the possibility that some of the differences noted between the GC (experimental) group and non-GC (control) group could have partly derived from such a different gender make up rather than because of the green chemistry intervention.

In the case of the main research instruments, the questionnaire method (applied in the chemistry survey) is limited in the amount of information that can be elicited from the respondents while the focus group is more difficult to analyse and is prone to lack reliability. The measures taken to safeguard the validity and reliability of the research instruments used were discussed in section 4.11 of the methodology chapter.

One of the potential risks linked to a teacher researcher is his / her influence on the type of data collected. The author was very much aware of such a risk that he made it a point to remain as detached as possible during data collection, with as minimum interference as possible from his side. This included adopting as neutral a position as possible especially during the focus group discussions and refraining from interacting with respondents during the pre-test and post-test chemistry surveys.

Another point worth mentioning is the fact that the teacher-researcher had no direct contact with the non-GC group, except for his role in the pre- and post-intervention data collection stages. In fact, the author was only assigned one first year chemistry A-level class (the GC group) at the time of the project, with the rest of the teaching load mainly involving contact (lectures / practicals / tutorials) with second year students. This inability of the author to establish regular teaching contact with the non-GC group throughout the intervention may have had an effect on some of the conclusions as some of the differences between the groups could have resulted from the different teaching experienced by the students rather than the curriculum intervention itself.

There is also the possibility that the additional teaching hours received by the GC group (but not by the control group) could have played an important role in some of the findings of this research investigation. This is due to the fact that students' knowledge and attitudes are likely to change to some extent with every new learning opportunity given to them including this type of classroom / laboratory intervention.

Another possible danger in this type of study carried out by an individual researcher is the possibility of researcher bias in the collection, analysis and interpretation of data. Bell (2006) refers to bias as 'the old enemy' which tends to invade research, almost inevitably, because of the human nature of researchers. Bias can occur in a number of ways and may be deliberate or unintentional. Miles and Huberman (1994) warn that one has to be extremely cautious especially in what appear to be 'moments of illumination', that is, when things seem to 'come together', as the researcher may still be wrong by basing evidence on 'overweighted facts' whilst ignoring or forgetting other important, and maybe more obvious, situations or facts. In order to minimise the risk of such bias, the author was constantly vigilant, gave a detailed description of data with frequent use of verbatim quotes from participants and triangulated as much as possible by referring to data from multiple sources to put more weight to claims made during the interpretation of data.

In the case of the interviews (which include focus groups), it has been suggested that the researcher may find it hard to be objective and in the same time put the interviewees at ease. The author counteracted this by always manifesting honesty in the purpose of the research and by showing integrity when conducting all focus group sessions.

## 10.5 Some Reflections on the Intervention Package & Research Instruments

One of the early stages of the research project was dedicated to the planning of an intervention package aimed at introducing, in an effective way, the fundamental principles of a newly emerging area of chemistry to students studying A-level chemistry. At the time when the project was started, green chemistry was still making its way in university curricula and was about to make its debut in the lower levels of education. It had not yet been proposed to Maltese students at the secondary or post-secondary levels of education. Hence, creating the intervention package from the limited resources available was a challenging task especially when one considers that the material to be presented had to link to the current local chemistry curriculum which clearly lacked references to environmental matters.

With the benefit of hindsight and considering the main objectives of the intervention package, the author believes that the intervention package could have been more effective if more emphasis was placed on the choice of material at the planning stage of the intervention. This could have involved proposing a wider range of areas of focus as the basis for the pilot intervention package. This would have allowed a longer programme of activities for the pilot intervention and a deeper evaluation resulting in a more refined programme for the main study, possibly covering a wider or a more representative section of green chemistry.

There is also plenty of room for improvement of the resources used in the intervention. The animated slide shows and frequent use of short video clips were certainly effective from the pedagogical point of view to make the seminar topics more interesting for students, but the content was extensive and could have been kept more concise to allow more space for the subsequent student-teacher interaction and the learning activities planned for the same session. This was in fact commented upon by students in the focus group discussions of the main study but was unfortunately not highlighted earlier by students in the pilot study.

The learning activities, especially those linked to the seminars, could also have been varied and not limited to written assignments which were perceived by some students as an 'extra classwork / homework'. The slogan competition, poster presentations and laboratory exercises turned out to be more challenging but certainly more inspiring for students than the written activities.

The organisation of the green chemistry laboratory experience (consisting of two two-hour practical sessions and a follow up session) provided another tough challenge for the author and participants. In fact, time-table restrictions and the limited availability of the chemistry laboratories created logistic problems, which translated into insufficient space and time for students to complete the entire procedures and write the laboratory report in the same session. The situation could have been rectified with students (within the same group) being concurrently assigned different tasks, cutting down on procedures and writing tasks, and allocating more time for students to reflect on observations and results… and to enjoy more the session. Alternatively, the ‘rush’ could have been avoided by extending the same material and techniques over more sessions to allow students to carry out procedures at their own pace and devote more time for observations to be made and results to be compared and interpreted. Having been so important in stimulating students to learn the subject, one could also have considered adding at least another two laboratory sessions in order for the researcher to be able to evaluate better the impact of the practical side of green chemistry in the students’ understanding of the subject.

The research instruments used could also have been improved further. The first part of the chemistry survey (questionnaire A) could have been designed in a way to elicit responses which were more directly linked to the ten dimensions of the conceptual framework of analysis of attitudinal data. This would have saved a lot of time in data analysis and ensured that there was a more balanced distribution of data on the ten dimensions of attitudes proposed in the framework. The second part of the survey (questionnaire B) could have included more open-ended questions allowing respondents to express themselves at more length on some aspects of green chemistry without necessarily covering the whole set of twelve principles involved. This could have allowed better assessment of the type of knowledge and understanding gained by students at that point in time.

The focus groups could also have been organised to draw data in a more effective way. Different focus groups could have been assigned with different sets of stimulus statements covering a wider range of aspects of learning chemistry / green chemistry. In fact, using a limited pool of statements led to a lot of overlap in the data collected from the different groups of students. Besides this a longer list of statements would have ensured that discussions returned data covering all dimensions of the theoretical framework.

Another instrument which could have been better exploited was the research diary. Some of the journals could in fact have been more detailed to capture more usable data through a richer description of the situations unfolding in the class or in the lab, during and after the activities forming part of the intervention.

It should however be noted that the programme of activities involving the students' participation in this study was carried out according to plan, with only minor changes from the original schedule. Students appeared always at ease and overall satisfied with their first experience of learning green chemistry. They were equally satisfied with the contribution and feedback they were able to give throughout the project, particularly through their input in the focus group sessions at the end of the intervention.

## 10.6 Implications of this Work 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. In fact young students studying science subjects at A-level are usually well-informed and rather sensitive on environmental topics and that is why green chemistry was so well received by the participants of this project.

When one considers that the local O-level chemistry curriculum dedicates a whole section to the impact of chemistry on the environment, it is difficult to explain why the (local) A-level curriculum is still limited in its references to environmental issues. One of the findings of this study was that sixth form students strongly believe that the chemistry curriculum would be enhanced by including environmental topics as these would make the subject more relevant to their everyday life, making it also more appealing too.

This study 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 the sustainability of the earth. Green chemistry, which has now been around for more than twenty 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 of this study 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.

The study showed that sixth form (A-level) students had sufficient background of chemistry to be able to understand the main concepts and theory of green chemistry. However the same students prefer having such concepts infused into the regular chemistry programme rather than having green chemistry presented to them as an extra separate topic. These students' 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 (Braun et al, 2006; Parent et al, 2004). The project found that green chemistry would also be taught effectively through the use of laboratory experiments.

The study also showed 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. It would also possibly attract more students to pursue further studies in chemistry and eventually aspire for a chemistry-related career.

Finally, chemistry educators involved in such a fundamental curriculum change would need to be trained accordingly to be able to adapt to the new challenge. They need to be well-supported not only through the availability of updated teaching resources but also by being given the chance to attend professional development (in-service) courses run by the university or by an alternative competent institution.

## 10.7 Conclusions

This research investigation collected and analysed data from a group of students attending a Maltese sixth form institution in an effort to provide evidence to describe how they responded to the introduction of green chemistry in the mainstream A-level curriculum.

The study shows how the author designed an intervention package aimed at helping students understand the fundamental principles involved in the theory and practice of green chemistry. The data generated by the application of a number of research tools at different points of the intervention were then analysed using a theoretical framework and the 12 principles of green chemistry together with a complementary assessment scheme developed from other sources encountered in the literature review. The effectiveness of the intervention package was tested by applying a model used in other research projects related to curriculum evaluation.

The analysis of data found that students reacted very positively to the introduction of green chemistry as this raised significantly their interest in the subject. Green chemistry allowed them to view chemistry with a new frame of mind allowing them to think more critically on the effects of chemical products and chemical changes on human health and the environment. The green chemistry intervention also helped in improving the chances of students to further their studies in chemistry and to choose a chemistry-related career. Perhaps the best proof of this is the fact that one of the students who had been involved in the main intervention has chosen green chemistry to assess the quality and safety of solvents used in the pharmaceutical industry as part of his undergraduate research project (leading to a degree in pharmaceutical sciences). This is just one concrete example of the impact the green chemistry intervention had on students' participating in this project.

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 2005-2014 which had been declared by the United Nations as the 'decade of education for sustainable development'.

**Appendix 1**

# Pilot Intervention

## Record of Activities (Year 2008-2009)

| Session | Date & Time | Theme | Activities & Attendance |
|---|---|---|---|
| Seminar 1 | Thu 06.11.08 (11.00) | Students' Attitudes towards Learning Chemistry & Green Chemistry | Pre-test A *(40 students)* |
| Seminar 2 | Fri 07.11.08 (09.00) | Students' Understanding of Green Chemistry Concepts | Pre-test B *(40 students)* |
| Seminar 3 | Wed 26.11.08 (13.00) | SEMINAR: **A General Introduction to Green Chemistry** | Students divided in 12 groups: teams A to L.<br>Two PowerPoint Presentations<br>• Introduction to Green Chemistry<br>• The 12 Principles of Green Chemistry<br>Slogan Competition<br>*(38 students)* |
| Seminar 4 | Wed 03.12.08 (13.00) | SEMINAR: **Green Chemistry and Atom Economy** | PowerPoint Presentation<br>Worksheet 1<br>*(39 students)* |
| Seminar 5 | Wed 10.12.08 (13.00) | SEMINAR: **Green Chemistry and Fuel Cells** | PowerPoint Presentation<br>Worksheet 2<br>*(35 students)* |
| Seminar 6 | Wed 17.12.08 (13.00) | Follow up to Seminars 3, 4 and 5. | Green Chemistry: Innovations for a Cleaner World (22-min video produced by the Education & International Activities Division, American Chemical Society, 2000).<br>Feedback + results of Slogan Competition.<br>Presentation of information/token pack to students donated by Green Chemistry Centre (York), Green Chemistry Institute (USA) and Agenda bookshop (Junior College, Malta).<br>Launching of Students' Seminars.<br>*(35 students)* |

| Session | Date & Time | Theme | Activities & Attendance |
|---|---|---|---|
| Seminar 7 | Wed 04.03.09<br>(13.00) | SEMINAR:<br>**Green Chemistry and Liquid Carbon Dioxide** | PowerPoint Presentation<br>Worksheet 3<br>*(32 students)* |
| Seminar 8 | Wed 11.03.09<br>(13.00) | SEMINAR:<br>**Green Chemistry and Degradable Plastics** | PowerPoint Presentation<br>Worksheet 4<br>*(39 students)* |
| Seminar 9 | Wed 18.03.09<br>(13.00) | Students' Research Seminar A | Presentations by teams B, E, I, K.<br>*(39 students)* |
| Seminar 10 | Tue 24.03.09<br>(10.00) | Students' Research Seminar B | Presentations by teams A, G, J, L.<br>*(38 students)* |
| Seminar 11 | Wed 25.03.09<br>(13.00) | Students' Research Seminar C | Presentations by teams D, F, H, (C).<br>*(34 students)* |
| Seminar 12 | Wed 22.04.09<br>(13.00) | SEMINAR:<br>**Green Chemistry and Biofuels** | Two PowerPoint Presentations<br>• Introducing Bio fuels<br>• Producing / Using Bioethanol<br>• Producing / Using Biodiesel<br>Worksheet 5<br>*(35 students)* |
| Seminar 13 | Wed 29.04.09<br>(13.00) | A Green Chemistry Experiment (1): Synthesis and Analysis of Biodiesel | Two hour Practical Session for half the class: teams A, B, C, D, E, F<br>Laboratory Report<br>*(20 students)* |
| Seminar 14 | Wed 06.05.09<br>(13.00) | A Green Chemistry Experiment (2): Synthesis and Analysis of Biodiesel | Two hour Practical Session for half the class: teams G, H, I, J, K, L<br>Laboratory Report<br>*(18 students)* |
| Seminar 15 | Fri.08.05.09<br>(09.00) | Students' Attitudes on Learning Chemistry & Green Chemistry | Post-test A<br>*(37 students)* |
| Seminar 16 | Tue 12.05.09<br>(10.00) | Students' Understanding | Post-test B<br>*(37 students)* |
| Seminar 17 | Wed 13.05.09<br>(13.00) | Follow up to Practical Sessions (Seminars 13 & 14).<br>Review of Results, Calculations & Conclusions. | Short (22 minute) video on 'Climate Change and Biofuels', produced by the National Non-Food Crops Centre (NNFCC), York, UK.<br>Results of Students' Seminar Presentations.<br>*(35 students)* |

| Session | Date & Time | Theme | Activities & Attendance |
|---|---|---|---|
| Session 18 | Tue 12.05.09 (09.00) | Focus Discussion Group X | Discussion based on a number of issues related to Green Chemistry and Education. *(9 students)* |
| Session 19 | Fri 15.05.09 (08.00) | Focus Discussion Group Y | Discussion based on a number of issues related to Green Chemistry and Education. *(7 students)* |
| Session 20 | Fri 15.05.09 (09.00) | Focus Discussion Group Z | Discussion based on a number of issues related to Green Chemistry and Education. *(8 students)* |
| Session 21 | Fri 15.05.09 (16.00) | Celebration marking end of Pilot Study. | Pizza party attended by the Maltese sixth form college Head of Chemistry Department (Subject Coordinator) *(36 students)* |
| Session 22 | Tue 19.05.09 (09.00) | Conclusion | Presentation of 'Token of Participation' to all students of Group 6A. *(38 students)* |

## Appendix 2

# Main Intervention

## Record of Activities (Year 2009-2010)

| Session | Date | Time | Theme | Activities (& Attendance) |
|---|---|---|---|---|
| 1. | Wed 28-10-09 | 09:00 | Students' Attitudes on Learning Chemistry & Green Chemistry | Survey: Pre-test A1 for GC class. *(33 students)* |
| 2. | Tue 03-11-09 | 13:00 | Students' Attitudes on Learning Chemistry & Green Chemistry | Survey: Pre-test A1 for non-GC class. *(36 students)* |
| 3. | Wed 04-11-09 | 09:00 | Students' Understanding of Chemistry / Green Chemistry | Survey: Pre-test B1 for GC class. *(32 students)* |
| 4. | Thu 05-11-09 | 12:00 | Students' Understanding of Chemistry / Green Chemistry | Survey: Pre-test B1 for non-GC class. *(35 students)* |
| 5. | Wed 11-11-09 | 09:00 | CLASS SEMINAR: **A General Introduction to Green Chemistry** | Students divided in 12 teams: H to Mg. PowerPoint Presentation Worksheet 1A *(32 students)* |
| 6. | Wed 18-11-09 | 09:00 | CLASS SEMINAR: **The Twelve Principles of Green Chemistry** | PowerPoint Presentation + Video Clips Slogan Competition *(29 students)* |
| 7. | Wed 25-11-09 | 09:00 | CLASS SEMINAR: **Green Chemistry and Atom Economy** | PowerPoint Presentation Worksheet 2A *(24 students)* |
| 8. | Wed 02-12-09 | 09:00 | CLASS SEMINAR: **Green Chemistry and Fuel Cells** | PowerPoint Presentation Worksheet 3A *(31 students)* |
| 9. | Wed 16-12-09 | 11:00 | CHRISTMAS SEMINAR: **End of Phase One** | Video Clips (Fuel Cells) Slogan Competition (Voting & Results) Launching of Student Seminars *(29 students)* |
| **CHRISTMAS RECESS 19-12-2009 – 03-01-2010** | | | | |

| Session | Date | Time | Theme | Activities (& Attendance) |
|---|---|---|---|---|
| 10. | Wed 13-01-10 | 11:00 | CLASS SEMINAR:<br>**Green Chemistry and Liquid Carbon Dioxide** | PowerPoint Presentation + Video Clips<br>Worksheet 4A<br>*(29 students)* |
| 11. | Wed 20-01-10 | 11:00 | CLASS SEMINAR:<br>**Green Chemistry and Degradable Plastics** | PowerPoint Presentation + Video Clips<br>Worksheet 5A<br>*(31 students)* |
| 12. | Wed 24-02-10 | 11:00 | CLASS SEMINAR:<br>**Green Chemistry and (Introduction to) Biofuels** | PowerPoint Presentation + Video Clips<br>Worksheet 6A<br>*(30 students)* |
| 13. | Wed 03-03-10 | 11:00 | STUDENTS' RESEARCH SEMINAR<br>**Poster Presentation 1** | Presentation by first six teams<br>Evaluation Sheet<br>*(25 students)* |
| 14. | Wed 10-03-10 | 11:00 | STUDENTS' RESEARCH SEMINAR<br>**Poster Presentation 2** | Presentation by second six teams<br>Evaluation Sheet<br>*(29 students)* |
| **GREEN CHEMISTRY FOR A SUSTAINABLE FUTURE**<br>**Poster Exhibition held at the College Chemistry Department**<br>**Tue 16 March - Thur 15 April 2010** | | | | |
| 15. | Wed 17-03-10 | 11:00 | CLASS SEMINAR:<br>**Green Chemistry and Biodiesel** | PowerPoint Presentation + Video Clips<br>Worksheet 7A<br>*(30 students)* |
| 16. | Wed 24-03-10 | 11:00 | CLASS SEMINAR:<br>**Green Chemistry and Biosynthesis of Ethanol** | PowerPoint Presentation + Video Clips<br>Worksheet 8A<br>*(30 students)* |
| **EASTER RECESS**<br>**27-03-2010 – 11-04-2010** | | | | |
| 17. | Tue 20-04-10 | 12:00 | GREEN CHEMISTRY LABORATORY EXPERIENCE 1<br>**Producing & Analysing Biodiesel** | A two hour practical session for GC class. Students working in 12 teams<br>Laboratory Report<br>*(30 students)* |
| 18. | Tue 27-04-10 | 12:00 | GREEN CHEMISTRY LABORATORY EXPERIENCE 2<br>**Producing a Biodegradable Bioplastic** | A two hour practical session for GC class. Students working in 10 teams<br>Laboratory Report<br>*(26 students)* |
| 19. | Tue 04-05-10 | 12:00 | Follow up to GC practical sessions | Discussion on results, calculations & conclusions.<br>*(27 students)* |

| Session | Date | Time | Theme | Activities (& Attendance) |
|---|---|---|---|---|
| 20. | Tue 04-05-10 | 13:00 | Students' Attitudes on Learning Chemistry & Green Chemistry | Survey: Post-test A2 for GC class . *(30 students)* |
| 21. | Thu 06-05-10 | 09:00 | Students' Attitudes on Learning Chemistry & Green Chemistry | Survey: Post-test A2 for non-GC class. *(36 students)* |
| 22. | Thu 06-05-10 | 12:00 | Students' Understanding of Chemistry / Green Chemistry | Survey: Post-test B2 for non-GC class. *(36 students)* |
| 23. | Tue 11-05-10 | 12:00 | Students' Understanding of Chemistry / Green Chemistry | Survey: Post-test B2 for GC class. *(30 students)* |
| 24. | Fri 07-05-10 | 08:00 | Focus Discussion Group A (GC class) | Discussion based on a number of issues related to learning and understanding chemistry and green chemistry. *(7 students)* |
| 25. | Fri 07-05-10 | 09:00 | Focus Discussion Group B (GC class) | Discussion based on a number of issues related to learning and understanding chemistry and green chemistry. *(7 students)* |
| 26. | Mon 10-05-10 | 14:00 | Focus Discussion Group E (non-GC class) | Discussion based on a number of issues related to learning & understanding chemistry. *(10 students)* |
| 27. | Fri 14-05-10 | 08:00 | Focus Discussion Group C (GC class) | Discussion based on a number of issues related to learning and understanding chemistry and green chemistry. *(9 students)* |
| 28. | Fri 14-05-10 | 09:00 | Focus Discussion Group D (GC class) | Discussion based on a number of issues related to learning and understanding chemistry and green chemistry. *(7 students)* |
| 29. | Fri 14-05-10 | 12:00 | Focus Discussion Group F (non-GC class) | Discussion based on a number of issues related to learning & understanding chemistry. *(7 students)* |
| 30. | Fri 14-05-10 | 14:00 | Focus Discussion Group G (non-GC class) | Discussion based on a number of issues related to learning & understanding chemistry. *(7 students)* |
| 31. | Mon 24-05-10 | 09.00 | Conclusion | Presentation of 'Token of Participation' + book tokens to all students of GC class. *(30 students)* |

## Appendix 3

# The Green Chemistry Intervention Package
# (Main Study)

| Session | Date | Title | Type of Activity |
|---|---|---|---|
| 1 | Wed 11-11-09 | A General Introduction to Green Chemistry | Classroom Seminar |
| 2. | Wed 18-11-09 | The Twelve Principles of Green Chemistry | Classroom Seminar |
| 3. | Wed 25-11-09 | Green Chemistry and Atom Economy<br>• avoiding waste by applying the green chemistry principle of atom economy | Classroom Seminar |
| 4. | Wed 02-12-09 | Green Chemistry and Fuel Cells<br>• providing cleaner energy from renewable resources instead of fossil fuels | Classroom Seminar |
| 5. | Wed 16-12-09 | Christmas Seminar: Conclusion to Phase 1<br>• launching of student seminars<br>• green chemistry slogan competition | Classroom Seminar |
| 6. | Wed 13-01-10 | Green Chemistry & Liquid Carbon Dioxide<br>• using safer solvents for chemical processes | Classroom Seminar |
| 7. | Wed 20-01-10 | Green Chemistry and Degradable Plastics<br>• design for degradation | Classroom Seminar |
| 8. | Wed 24-02-10 | Introduction to Biofuels<br>• using renewable rather than depleting resources | Classroom Seminar |
| 9. | Wed 03-03-10 | Students' Poster Presentations – Part 1 | Student Seminar |
| 10. | Wed 10-03-10 | Students' Poster Presentations – Part 2 | Student Seminar |
| 11. | Wed 17-03-10 | Green Chemistry and Biodiesel<br>• synthesis of biodiesel from renewable resources | Classroom Seminar |
| 12. | Wed 24-03-10 | Green Chemistry and Bioethanol<br>• biosynthesis of ethanol from sugar & other carbohydrates | Classroom Seminar |
| 13. | Tue 20-04-10 | Green Chemistry Laboratory Experience 1<br>• producing and analysing biodiesel from cooking oil | Laboratory Session |
| 14. | Tue 27-04-10 | Green Chemistry Laboratory Experience 2<br>• producing a biodegradable bioplastic from potatoes | Laboratory Session |
| 15. | Tue 04-05-10 | Conclusion<br>• including follow-up to practical sessions | Classroom Seminar |

**Appendix 4**

# Seminar 1: General Introduction to Green Chemistry

## Aims

- To launch the concept of green chemistry, presenting it as a novel way of doing chemistry rather than a new branch of chemistry.
- To introduce the definition of green chemistry and link the goals of green chemistry with the goals of sustainability.
- To introduce some real life applications of green chemistry.
- To make students aware that green chemistry is now being taught and practised all over the world.

## Content of Presentation

The presentation starts with a reference to some of the many products and benefits of the chemical industry but also to some environmental pollution problems resulting from the activity of the same chemical industry. Students will then be shown some short video clips (less than 5 minutes each) to illustrate some large scale historical environmental disasters which are often cited and tarnish the public perception of chemistry.

Green chemistry is presented as one of the possible solutions to address pollution problems originating from the chemical industry. It is here that the definition of green chemistry is launched. The tutor explains how the aims of green chemistry overlap with those of sustainability, and describes how green chemistry is a powerful tool to achieve sustainability of the world. The tutor then gives some concrete examples of real world application of green chemistry and concludes by listing a number of benefits on practising green chemistry.

This presentation does not refer to any of the 12 key principles of green chemistry but a simplified version of the set of concepts is included in the first information handout supplied to the students at the beginning of the seminar. The information sheet also makes reference to some national / international organisations and research centres working in green chemistry, and gives examples of publications on green chemistry. It also includes a list of websites related to green chemistry activity such as research and education.

## Student Activity

The first activity for students involves a short exercise whereby each group has to write a suitable alternative term to describe green chemistry and then write also short phrases summarising the main aims of green chemistry. Students are also asked to indicate the part of the presentation that the liked most in the introduction to green chemistry.

## Learning Outcomes

By the end of this introductory session, students should be able:

- to have a general idea about the aims of green chemistry and sustainability;
- to relate green chemistry with a new and safer way of doing chemistry which prevents hazards and pollution;
- to realise that green chemistry encourages critical thinking and careful planning of chemical reactions and processes;
- to understand that green chemistry is not only theoretical but is also practical.

**Appendix 5**

# Seminar 2: The 12 Principles of Green Chemistry

## Aims

- To introduce and explain the theory behind each of the 12 universally accepted principles of green chemistry.
- To emphasise that these principles are to be regarded as guidelines that need to be observed by all chemists in order to ensure that all chemical processes and products are clean and safe to human health and the environment.

## Content of Presentation

The presentation starts with a reminder of the definition and aims of green chemistry and then proceeds with an introduction to the 12 principles of chemistry which characterise green and sustainable chemistry. The principles are explained one by one, using both the original text used by Anastas and Warner in their reference text 'Green Chemistry: Theory & Practice' (Anastas & Warner, 1998) and a simplified version in order to make it easier for students to grasp the main concepts involved.

Students are then provided also with two acronyms to serve them as mnemonics and also to help them visualise in a simpler way the main ideas behind the principles of green chemistry. The presentation concludes by describing green chemistry as a sort of 'reducing agent' (borrowing the term used when dealing with the traditional concept of oxidation and reduction) as the principles suggest that green chemistry aims to reduce a number of factors involved in the production of chemicals such as: raw materials, energy requirements, the use of hazardous and toxic reagents, pollutants and waste products.

Following the main presentation, the students are also shown selected parts of a video 'Green chemistry: innovation for a cleaner world', published by the American Chemical Society, and short video clips featuring students and professors of chemistry sharing some ideas and their own experience of green chemistry. The information sheet to be handed out to students during this seminar includes both the original version, a simplified version and a summary of the 12 principles of green chemistry, as well as references for further reading.

## Student Activity

At the end of the seminar, students are invited to take part in a competition for the best 'slogan' for green chemistry. Each of the 12 groups of participating students will be assigned one of the principles of green chemistry and will be invited to create a short phrase (slogan) representing the key message of the principle involved. In this exercise, students will be encouraged to use simple language that can be understood even by non-chemists. The same students will later be asked to vote and choose the most favourite message after being shown the 12 submitted slogans.

## Learning Outcomes

By the end of this session, students should be able:

- to realise that green chemistry is inspired by a set of guidelines referred to as the 'the twelve principles of green chemistry';
- to understand that the principles of green chemistry aim to reduce energy, material resources, risks, waste and pollution;
- to realise that green chemistry is a smarter way of doing chemistry which is however not always easy to achieve.

**Appendix 6**

# Seminar 3: Green Chemistry & Atom Economy

## Aims

- To focus on the green chemistry principle of 'atom economy' which is a way of measuring the extent by which a chemical reaction or process is considered to be 'green'.
- To show students how careful planning of a chemical reaction / process can be rendered greener by creating less waste products.
- To relate the relatively new concept of 'atom economy' with 'percentage yield', explaining that both need to be factored in to evaluate the efficiency of a chemical reaction / process.

## Content of Presentation

The seminar starts with an introduction of the green chemistry principle of 'atom economy', first proposed by Prof Barry Trost in 1991, which earned him the US Presidential Green Chemistry Challenge Award in 1998. Students are reminded that not all chemical reactions are equally efficient; many of them are indeed highly inefficient with a large proportion of reactants ending up as waste products and contributing to pollution. They are also told that the objective of every chemical synthesis is to convert the maximum amount of raw material to the final product. Students are then reminded that one way of measuring the success of a chemical process was by calculating the percentage yield. Students are told that by calculating the atom economy, one would measure how much of the reactant atoms would be converted into the desirable product. It is pointed out that a reaction with a high percentage yield may still produce a lot of waste. Hence students learn that reaction efficiency is a product of percentage yield and atom economy and that the higher the overall efficiency the greener will the chemical reaction / process be. They are also told of other considerations which need to be taken in order to evaluate the 'greenness' of a chemical reaction or process.

The information handout to be given to students includes the definition of related terms such as reaction selectivity, yield, atom economy and reaction efficiency. It emphasizes the importance of the application of such concepts in certain chemical industries dealing with large volumes of chemicals which can therefore potentially produce a lot of waste.

## Student Activity

The activity planned for the end of this seminar consists of a set of 12 different problems, each comparing two separate reactions which produce the same chemical product. Each group of students is assigned one of the problems in which they have to calculate the percentage yield, atom economy and reaction efficiency for each of the two synthetic routes indicated. The group has then to decide on the greener (i.e. most efficient and environmentally friendly) method of synthesizing the particular target product.

## Learning Outcomes

By the end of this seminar, students should be able:

- to understand the concept of atom economy and its importance to prevent pollution at the molecular level (i.e. the planning stage of every chemical reaction);
- to calculate the atom economy of a given reaction and use it, together with percentage yield, to calculate reaction efficiency and compare the greenness of different reactions;
- to recognise the importance of applying atom economy in the chemical industry in order to make better use of resources and generate less waste and pollution.

**Appendix 7**

# Seminar 4: Green Chemistry & Fuel Cells

## Aims

- To explain how the operation of the fuel cell involves a number of green chemistry principles.
- To explain the electrochemical process of the fuel cell which generates electrical power makes use of renewable raw materials without producing any waste.
- To explain the current limitations in the application of fuel cell technology.

## Content of Presentation

The presentation starts with a reference to three green chemistry principles, namely 'waste minimisation', 'use of renewable resources' and 'increasing energy efficiency'. Students are reminded that energy is traditionally produced by combustion of fossil fuels but this creates pollution and contributes to global warming apart from making use of non-renewable resources. The fuel cell is then presented as a green alternative source of energy which is safer, renewable and non-polluting.

The tutor then goes into the detailed electrochemistry of the fuel cell and refers to different types of fuel cells that have been produced so far. Students learn that the overall redox reaction of the fuel cell is similar to the combustion of hydrogen which produces water as the only product and heat energy. In fact the only chemical product of fuel cells is warm water. Students are also shown several applications of the fuel cell (e.g. to power transport vehicles, cellular phones and remote devices such as spacecraft and weather stations). They will also discuss some of the advantages and the main difficulties in the use of fuel cells such as the storage and continuous supply of hydrogen. The presentation concludes that the fuel cell is one example of the use of renewable sources of energy which do not pollute, which also represents one of the missions of green chemistry. During the seminar, students are also shown video clips of the fuel cell in operation, and the use of the hydrogen fuel cell in cars.

The information handout gives further details and diagrams of fuel cells and makes specific reference to their use in public transport and space shuttles. The information also refers to different types of fuel cells, comparing their applications, advantages and disadvantages. The sheet also includes a list of references for further reading.

## Student Activity

At the end of the seminar students are assigned with a worksheet asking them to recall important features of a fuel cell such as chemical reactions involved, the use of electrolytes and classification. They are also asked about some of the applications of fuel cells and to write a list of advantages and limitations in the use of fuel cells.

## Learning Outcomes

By the end of this session, students should be able:

- to understand the green chemistry principles involved in the operation of the fuel cell;
- to recognise that the electrochemical process involved is greener compared to combustion of fossil fuels;
- to realise the sustainability of producing clean energy from renewable resources with fuel cells providing one feasible option for future power generation and transport;
- to know that fuel cells are already in use;
- to recognise that there are still some limitations in the wider use of fuel cells.

**Appendix 8**

# Seminar 5: Green Chemistry & Liquid Carbon Dioxide

## Aims

- To explain how carbon dioxide can be converted to the liquid phase or to a supercritical fluid under special conditions.
- To explain how liquid or supercritical carbon dioxide can be used by the industry in place of other toxic solvents.
- To explain how the properties of liquid or supercritical carbon dioxide make it an ideal 'green solvent' in various industrial processes.

## Content of Presentation

The presentation starts by highlighting the important green chemistry principle concerning the use of safer solvents. It makes reference to the importance of solvents in the production and purification of chemicals by the chemical industry. Students learn how many of the solvents used are toxic and/or hazardous and most of them are volatile and end up being lost to the atmosphere. Reference is made to a list of commonly used volatile organic solvents indicating also those that are toxic or dangerous. Then, students are asked to consider whether chemical processes can still take place in the absence of solvents or by replacing toxic ones with harmless alternatives. They are told that this is possible and that one such harmless solvent which was recently found to be an ideal candidate to replace toxic organic solvents is in fact liquid or supercritical carbon dioxide.

Students could then compare the properties of liquid carbon dioxide with those of a toxic organic solvent such as PERC (perchloroethylene or 1,1,2,2-tetrachloroethene) which is used in dry cleaning operations. The tutor then refers to the phase diagram of carbon dioxide to explain the conditions required for carbon dioxide gas (or solid – dry ice) to be converted to the liquid state or to a supercritical fluid. Reference is also made to the chemistry of detergency to explain how a special surface active agent was developed in order to be able to switch from the toxic solvent PERC to non-toxic carbon dioxide in the dry cleaning process.

During the presentation, students could view some short videos showing how liquid carbon dioxide can be produced from dry ice and how the same liquid carbon dioxide is used in different industrial processes such as extraction of limonene from orange peel and in dry cleaning.

The information handout prepared for students refers to the phase diagram (which forms part of the A-level chemistry curriculum) to explain how liquid or supercritical carbon dioxide can be obtained from gaseous or solid state. It also explains the new role of liquid carbon dioxide as a green solvent and in modern dry cleaning operations, as well as in other applications such as decaffeination of coffee. Reference is also made to other green solvents, particularly water and ionic liquids on which research is still ongoing.

## Student Activity

The student activity linked to this seminar consists of another exercise where students are asked to answer several questions on the chemistry of commonly used organic solvents and the safer alternatives referred to in the presentation. They are also asked to explain the conditions required to convert dry ice to carbon dioxide and to explain terms used such as surface active agent and green solvent. Students are also asked to list a number of advantages and disadvantages of using liquid / supercritical carbon dioxide over other traditional solvents used in the chemical industry.

## Learning Outcomes

By the end of this session, students should be able:

- to be familiar with the use of the term 'green solvent' and recognise the properties which distinguish a green solvent from other commonly used solvents;
- to interpret a phase diagram and use it to understand how carbon dioxide can be converted from a gas (or solid) to the liquid or supercritical fluid state;
- to know what makes carbon dioxide an ideal solvent in industry;
- to appreciate the important role of green solvents to minimise waste and safeguard human health and the environment.

**Appendix 9**

# Seminar 6: Green Chemistry & Degradable Plastics

## Aims

- To underline the green chemistry principle 'design for degradation'.
- To explain that plastic is usually made from non-renewable raw materials.
- To highlight the special properties of plastic which make it widely used in everyday life.
- To highlight the problems associated with plastic waste disposal.
- To introduce the chemistry involved in degradation of plastic.

## Content of Presentation

The green chemistry principle 'design for degradation' is introduced at the beginning of the presentation, stressing that one of the important aims of green chemistry is to eliminate the accumulation of waste in the environment.

Students will first look into different types, properties and uses of plastics and then discuss some important advantages and disadvantages of their use with respect to other materials. They will then refer to the chemistry of polymerisation reaction which produces different types of polymers which are usually difficult to degrade after being used. Reference is made to official statistics showing the amount of plastic waste generated locally and the amount collected for recycling purposes. Students learn that biodegradability could help to solve the problem of plastic waste disposal. A distinction is then made between the composition and disposal of biodegradable and photodegradable plastics. The presentation concludes with a comparison between the several advantages and some disadvantages of using degradable plastics with respect to the use of non-degradable plastic material.

During the seminar students are shown a short video clip concerning recycling of plastic and another one on the production of biodegradable plastic made from corn flour.

The information sheet provided to students includes references to problems associated with plastic waste disposal and explains how, over the years, researchers tried to address this problem by developing different degradable plastic materials. It also refers to the difference between photodegradation and biodegradation. The handout also compares recycling of plastic with biodegradability as two 'green' solutions to address disposal of plastic waste.

## Student Activity

At the end of the seminar, students are asked to answer several questions on plastics related to their use, chemical composition, classification and waste disposal. They are also asked what chemical features make certain plastics non-biodegradable and those making others biodegradable. Students are also invited to compare advantages and disadvantages of using biodegradable plastic and explain why green chemistry supports research into the use of such degradable material.

## Learning Outcomes

By the end of this session, students should be able:

- to understand how green chemistry addresses problems associated with plastic waste;
- to know the chemical features that distinguish between degradable and non-biodegradable plastic;
- to recognise that biodegradation is a greener option with respect to other methods of plastic waste disposal;
- to distinguish between advantages and disadvantages in use of biodegradable plastic.

**Appendix 10**

# Seminar 5: An Introduction to Biofuels

## Aims

- To give an overview of the expanding area of green chemistry which concerns research on the use of alternative sources of energy in order to reduce reliance on fossil fuels and minimise pollution.
- To distinguish between the different types of biofuels.
- To compare properties of biofuels with those of traditional fossil fuels.

## Content of Presentation

The tutor presentation starts with a reference to the green chemistry principle concerning the use of renewable resources. The tutor then defines the term 'biofuel' and mentions different raw materials which can be used to produce such biofuels. The tutor explains why biofuels are considered as carbon dioxide neutral. Students are then introduced to the classification of biofuels, giving some examples to distinguish between first generation, second generation and third generation biofuels. This presentation ends by making reference to some examples of biofuels used for transport following by a discussion on the general advantages and disadvantages of using biofuels over the traditional petroleum based fuels.

The information handout given to students in this seminar refers to several examples of organic materials that are useful for the production of biofuels. It also outlines the main differences between the different classes of biofuels. It also highlights some important advantages and disadvantages in the use of biofuels.

## Student Activity

The student activity linked to this seminar involves an exercise with a set of questions directly related to the classroom presentation and subsequent discussion on biofuels. Students are asked to give a definition of 'biofuel', list a number of commonly used biofuels and raw material that could be converted to biofuels. One question refers specifically to one of the green chemistry principle which concerns the use of non-renewable resources. Students are also asked to differentiate between biofuels and fossil fuels, and also to distinguish between first and second generation biofuels. They are asked to describe what a third generation biofuel is and compare advantages with disadvantages of using biofuels.

Students are also shown selected parts of a video 'Biofuels and Climate Change' produced by the UK National Non-Food Crop Centre.

## Learning Outcomes

By the end of this session, students should be able:

- to recognise that biofuel production uses renewable rather than depleting resources;
- to realise that biofuels are generally less polluting than fossil fuels;
- to distinguish between the different types of biofuels depending on the raw materials used for their production;
- to follow the ongoing debate on the pros and cons of producing and using biofuels.

## Appendix 11

# Seminar 8: Green Chemistry & Biodiesel

## Aims

- To explain composition, properties and production of biodiesel as one of the most important biofuels in use to date.
- To differentiate between the chemical composition of petrodiesel and biodiesel.
- To explain the process involved that converts the raw material (oils / fats) into biodiesel.
- To show students how the use of biodiesel contributes towards a healthier and more sustainable environment.

## Content of Presentation

The presentation starts with a comparison between the chemical composition of petrodiesel (a typical fossil fuel) and biodiesel (a renewable fuel). It refers to the raw material required for its production and then explains the chemistry involved in the transesterification reaction which converts vegetable oil (or animal fat) into a mixture of methyl esters which make up biodiesel. Reference is made to the nature of reactants, catalyst, main product and by-product involved in this reaction, comparing it to a similar reaction (of which students are familiar) known as esterification. Students are then shown two short video clips, one showing the laboratory conversion of vegetable into biodiesel, the other reviewing the chemistry of the transesterification reaction. Students are also allowed to take part in the discussion with tutor on some of the benefits and limitations in the use of biodiesel, compared to petrodiesel.

The information handout provides students with the highlights of the presentation including differences between properties of diesel and biodiesel, and the conditions, reactants and products of the transesterification process. It also reminds students of some advantages and disadvantages in the use of biodiesel.

## Student Activity

At the end of the seminar students are asked a number of questions such as the basic difference between the chemical composition of petrodiesel and biodiesel, raw materials required for biodiesel production, the type of reaction involved, conditions of reaction and the type of product and by-product formed. Students are also asked how 'used cooking oil' can also be recycled to produce this biofuel. They are also invited to list a number of advantages and disadvantages of using biodiesel with respect to petrodiesel.

## Learning Outcomes

By the end of this session, students should be able:

- to realise that biodiesel is a green fuel made from renewable resources;
- to know that it is significantly different in chemical composition from ordinary diesel;
- to know that it is produced by a reaction known as 'transesterification' involving a change from one type of ester into another;
- to recognise that producing and using biodiesel is beneficial to the environment but there are also some disadvantages (e.g. cost of production and being unsuitable in cold weather).

Appendix 12

# Seminar 5: Green Chemistry & Bioethanol

## Aims

- To compare synthesis of ethanol from ethene (derived from petroleum) with the biosynthesis of ethanol from sugar.
- To explain how production of bioethanol underlines a number of principles of green chemistry.
- To explain why the biosynthesis of ethanol is considered as a greener process compared to the catalytic hydration of ethane.
- To compare benefits with limitations in the production and use of bioethanol, compared to petrol.

## Content of Presentation

The presentation starts by an overview of the principles of green chemistry which are involved in the production and use of bioethanol. The tutor explains that bioethanol is the most commonly used biofuel in the world and is used either as a fuel in its pure form (E100) or as a petrol additive for a smoother combustion (higher octane rating) and to reduce toxic emissions.

Students learn that ethanol can be manufactured on a large scale in one of three ways: by hydration of ethane, by fermentation of sugars or by fermentation from waste biomass. Reference is made to the fact that worldwide production of ethanol is largely based on fermentation of crop biomass (93%) with Brazil and USA being the major producers of bioethanol. The tutor then compares the two main techniques used to produce ethanol.

Students learn how ethanol is usually produced from catalytic hydration of ethene, the raw material being obtained by the process of cracking of petroleum (fossil fuel). On the other hand they are also shown how bioethanol can be produced on a large scale by the process of fermentation of sugar from various energy crops. The tutor refers to the conditions, reagents, and chemical reactions involved in both processes. Reference is also made to statistics showing an upward trend in the production of bioethanol across Europe over the period 2004-2006. The tutor also explains how bioethanol could be alternatively be produced from other biomass and waste material. Students will learn that the production of bioethanol from such material involves the hydrolysis of polysaccharides (such as cellulose) and separation of sugars (by ion exchange) as two extra steps before the fermentation step. They are also told how development in biotechnology has made it possible to use genetically modified bacteria to convert sugars obtained from biomass and waste into ethanol. The presentation concludes by comparing several advantages with some disadvantages in the use of bioethanol, compared to petrol.

During this seminar students will also be given the chance to view two short video clips, one concerning the conversion of corn into fuel, the other showing production of bioethanol from other organic matter (biowaste).

The information handout prepared for this seminar explains why bioethanol is regarded as a green fuel. It refers to the different raw materials required and techniques used in the manufacture of ethanol and bioethanol. It explains how bioethanol is the main biofuel produced in America and used in the whole world. Reference is also make to a number of advantages and disadvantages in the production and use of bioethanol, compared to petrol.

## Student Activity

The worksheet which students are given at the end of the seminar asks a number of questions related to the presentation. Students have to explain what features makes bioethanol a 'green fuel'. They are asked to write chemical equations to represent the synthesis of ethanol from ethene and the fermentation of glucose to produce bioethanol, naming also the catalyst used for each reaction. They are also asked about the raw material used in the preparation of bioethanol and to explain terms such as 'energy crop'. Students are also required to calculate the volume of carbon dioxide produced (measured at s.t.p.) upon burning in air one litre of alcohol. They are then asked to name two alternative raw materials that may be used to produce bioethanol and the two extra steps required for their conversion to ethanol, compared to the conventional fermentation of sugar from plants. They also have to outline the advantages and disadvantages of using bioethanol as a petrol substitute in cars.

## Learning Outcomes

By the end of this session, students should be able:

- to know that ethanol can be synthesized in the industry both from renewable and non-renewable resources;
- to recognise that fermentation of sugars is a greener process when compared to synthesis from ethene (obtained from petroleum), as it involves milder conditions and the use of renewable raw material;
- to realise that bioethanol is a greener fuel compared to petrol, and can be used to transport vehicles;
- to appreciate that there are benefits but also some drawbacks in the replacement of petrol by bioethanol.

Appendix 13

# Green Chemistry Experiment 1
# Producing and Analysing Biodiesel

## Aims

- To demonstrate the application of the green chemistry principle ‘using renewable resources’.
- To give an opportunity to the students to practise green chemistry in the laboratory making use of relatively harmless raw materials / reagents to produce biodiesel.
- To allow students evaluate the efficiency of the transesterification reaction by calculating the atom economy and percentage yield.
- To enable students to compare some of the properties of biodiesel with those of other fuels.

## Laboratory Procedure

The practical session is divided in two parts, the first involving the synthesis of biodiesel and the second part dedicated to the analysis of the product obtained in part A and of a number of fuel samples provided.

In part A, students are required to prepare a sample of the biofuel making use of the sample of cooking oil provided together with methanol and potassium hydroxide, and following a simple procedure involving heating the mixture to a temperature of 50$^{o}$C. On allowing to stand, the product separates into two layers, one of which is crude biodiesel. This is then separated by means of separating funnel and washed several times with distilled water to remove any soap formed by a side reaction (alkaline hydrolysis of ester). The freshly prepared biodiesel is then transferred to a flask and weighed.

In part B, students have to carry out a number of tests on their product (B1) and compare observations and results with those obtained when the same tests are carried out on samples of petrodiesel (D), commercial biodiesel (B2) and petrol (P). The tests involve determination of density, pH, freezing point, combustion and solubility in methanol.

## Reporting Results & Calculations

In part A, students are required to calculate the density of the vegetable oil provided and that of the biodiesel produced, both measured at room temperature. Then from the results obtained, students will calculate also the percentage yield of biodiesel. They are also required to calculate the atom economy of the transesterification and comment on reaction efficiency.

The students then have to answer a number of questions related with the synthesis of biodiesel such as whether they observed any changes between the physical appearance of the raw material and main product, how did they notice that a reaction had taken place and why did biodiesel need to be washed with distilled water. They are also asked to calculate the percentage yield of a typical commercial production of biodiesel (using data provided). They also have to state why biodiesel is considered a ‘greener’ fuel with respect to petrodiesel and one disadvantage of diesel over petrodiesel (or mineral diesel).

In part B, students had to complete a table of results comparing a number of properties of the product obtained with those of the samples of fuels provided. They are also expected to make some inferences on the results obtained from the various samples.

## Learning Outcomes

By the end of this session, students should be able:

- to be familiar with the chemistry and conditions of 'transesterification' which converts vegetable oil to biodiesel;
- to work out the atom economy and percentage yield of a reaction;
- to compare some of the properties of biodiesel with those of other fuels;
- to recognise that biodiesel is produced from a renewable resource and is a greener fuel with respect to mineral diesel.

**Appendix 14**

## Green Chemistry Experiment 2
# Producing a Biodegradable Bioplastic

## Aims

- To demonstrate the application of two green chemistry principles: 'using renewable resources' and 'designing for degradation'.
- To give an opportunity to the students to practise green chemistry in the laboratory by producing a biodegradable plastic from a renewable resource (potato tubers).
- To allow students to carry out simple tests on the product and comment upon its biodegradability.

## Laboratory Procedure

The experiment was divided into three parts, the first consisting of the extraction of starch from potatoes, the second part involving conversion of potato starch into a polymer (bioplastic) and the last part concerning the analysis of the product.

In the first part, students have to extract starch from the potatoes provided using a very simple technique requiring grating and grinding of potatoes, adding water, mixing, allowing mixture to stand, separating the starch by decanting and drying it by gentle heating. In the second part, students are required to produce two types of bioplastic, one including glycerol as a plasticizer and the other excluding this plasticizer. They have to boil two separate mixtures of starch, water and dilute acid for a few minutes, adding glycerol to one of the mixtures and making sure that the resulting solution has a neutral pH. The mixtures are then coloured differently, using green food colour for the mixture including glycerol and red colouring matter for the second mixture. The mixtures are then poured onto separate petri dishes and allowed to dry out for a few days at room temperature.

## Reporting Observations & Results

The analysis part will be carried out in a week's time to allow enough time for drying. The samples will then be inspected for hardness and consistency, and for their reactivity with water, dilute acid / alkali and concentrated acid / alkali. Then students have to determine whether there were any differences between the properties of the green coloured plastic (which included glycerol) and the red plastic product (which had no glycerol). Students also have to explain why they thought that the product was biodegradable and how could they carry out a test to prove biodegradability.

The students will also have to answer a number of supplementary questions concerning the raw material and the polymerisation reactions required to produce plastics. They are also asked to explain terms such as 'biodegradable' and 'bioplastic'. Students will have to write a list of advantages and at least one disadvantage of using such material. They also have to name some uses of biodegradable plastics.

## Learning Outcomes

By the end of this session, students should be able:

- to distinguish between petroleum derived plastic and bioplastics;
- to understand the green chemistry principle of biodegradability;
- to realise that biodegradable plastic can be produced in a safe way and disposed of safely too;
- to relate some advantages and limitations in the use of biodegradable plastics.

**Appendix 15**

## List of computer slide shows used in main seminars

1. Introduction to green chemistry: pollution prevention and sustainability. (31 slides)
2. The twelve principles of green chemistry. (41 slides)
3. Green chemistry and atom economy. (40 slides)
4. Green chemistry and fuel cells. (45 slides)
5. Green chemistry and liquid carbon dioxide. (32 slides)
6. Green chemistry and degradable plastics. (39 slides)
7. Green chemistry and biofuels. (37 slides)
8. Producing and using biodiesel. (25 slides)
9. Producing and using bioethanol. (26 slides)

## Appendix 16

### List of video clips used during main seminars

| | SEMINAR: Introduction to Green Chemistry | Time (min:sec) |
|---|---|---|
| 1. | Cuyohoga river fire, 1969 | 00:54 |
| 2. | Seveso disaster, 1976 | 03:53 |
| 3. | Bhopal gas tragedy, 1984 | 02:27 |
| 4. | Challenger disaster, 1986 | 04:33 |
| | **SEMINAR: The 12 Principles of Green Chemistry** | |
| 5. | Green chemistry: innovations for a cleaner world | 20:00 (edited) |
| 6. | Going green in chemistry: undergraduate, Univ of Oregon, USA | 01:36 |
| 7. | Professor Martyn Poliakoff, Univ of Nottingham, UK | 02:30 |
| 8. | Professor Terry Collins, Carnegie-Mellon Univ, USA | 01:28 |
| 9. | Professor Guy Bertrand, Univ of California Riverside, USA | 02:44 |
| | **SEMINAR: Green Chemistry and Fuel Cells** | |
| 10. | How fuel cells work | 03:17 |
| 11. | Demonstration on the hydrogen fuel cell car | 05:10 |
| 12. | Hydrogen fuel cell and fuel cell powered cars | 03:42 |
| 13. | Hydrogen fuel cell electric bike | 04:34 |
| | **SEMINAR: Green Chemistry and Liquid Carbon Dioxide** | |
| 14. | How to produce liquid carbon dioxide from dry ice | 01:39 |
| 15. | How dry cleaning works | 01:38 |
| 16. | Extracting limonene from orange peel using liquid carbon dioxide | 02:52 |
| 17. | Using liquid carbon dioxide in dry cleaning operations | 01:44 |
| | **SEMINAR: Green Chemistry and Degradable Plastics** | |
| 18. | Producing biodegradable plastics from corn flour (Jiang Univ, Taiwan) | 01:23 |
| 19. | Recycling of plastic (North Carolina, USA) | 01:51 |
| | **SEMINAR: Green Chemistry and Biofuels** | |
| 20. | Biofuels and climate change (National Non-Food Crop Centre, UK) | 22:33 (edited) |
| | **SEMINAR: Green Chemistry and Biodiesel** | |
| 21. | The chemistry of the transesterification reaction | 01:56 |
| 22. | Converting vegetable oil to biodiesel | 04:03 |
| | **SEMINAR: Green Chemistry and Bioethanol** | |
| 23. | Converting corn into fuel | 01:59 |
| 24. | Producing bioethanol from cellulosic material | 03:50 |
| 25. | Producing bioethanol from biowaste | 02:41 |
| 26. | Ethanol: the hidden panacea (National Corn-to-ethanol Research Centre, USA) | 14:47 |

Appendix 17

# Student Seminar Presentations

**(Main Study)**

**Green Chemistry Educational Project**
**Chemistry Department**
**Maltese Sixth Form College**

## Guidelines for Presentations

1. All work has to be related to the principles of Green Chemistry discussed during seminars.

2. Each presentation may be delivered by one or more students (per team) and should not exceed 10 minutes.

3. Each team is encouraged to produce and present:

   (a) a POSTER (size of standard chart, portrait format), with appropriate captions and labelled illustrations, or
   (b) a short PowerPoint (or alternative computer) PRESENTATION, including not more than 12 slides (maximum 75 words per slide), on the researched topic.

4. A hard copy (on A4-size paper) of poster / material used has to be submitted to tutor before each presentation.

5. All material has to include:
   - the title of the presentation;
   - the name of all participants (team members);
   - any sources of reference (websites, books, other literature).

6. Dateline for submission of material: Monday 16$^{th}$ February 2010.

7. All material will be presented by teams during the student research seminar sessions starting in the first week of March 2010.

**mfc - 12/09**

**Appendix 18**

# Students' Seminar Presentations 2010

**Green Chemistry Educational Project 2009-10**
**Chemistry Department**
**Maltese Sixth Form College**

## Poster Presentation - Evaluation Sheet

Assign a mark next to each presentation by choosing one of the following score:

**5 = excellent; 4 = very good; 3 = good; 2 = fairly good; 1 = fair**

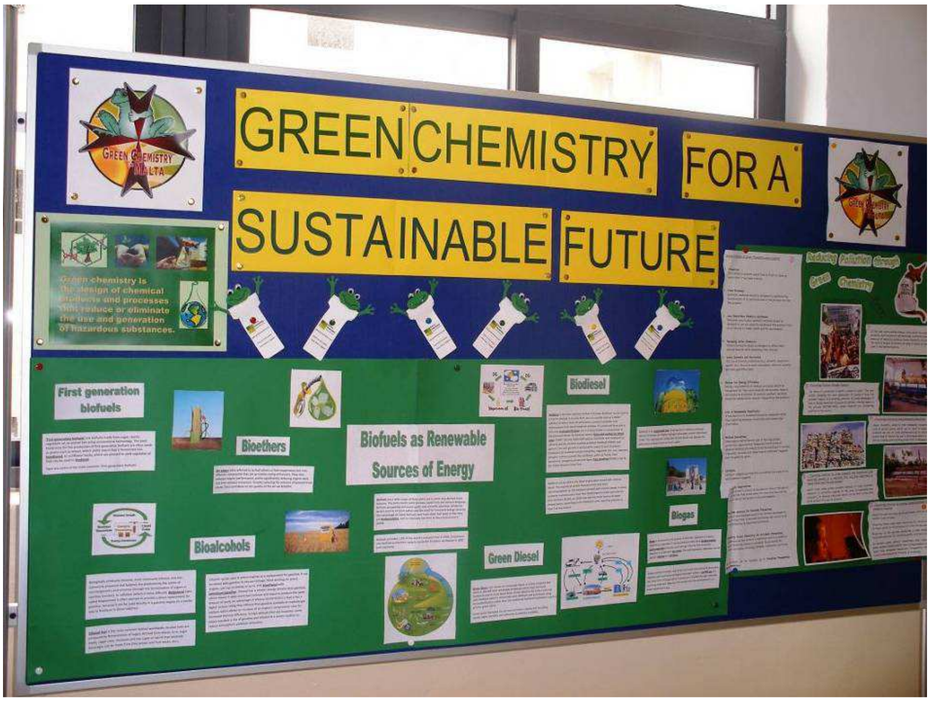
Name: ______________________________ Team: ________ Date: __________

| Team | Title of Poster Presentation | Mark |
|---|---|---|
| **H.** | Waste minimisation and the use of renewable resources from organic substances. | |
| **He.** | Increasing energy efficiency by the use of green chemistry processes. | |
| **Li.** | Maximising atom economy on an industrial scale. | |
| **Be.** | The production and use of degradable materials. | |
| **B.** | Ways of reducing pollution by applying green chemistry. | |
| **C.** | Using safer and non-hazardous solvents. | |
| **N.** | Biofuels as renewable energy resources. | |
| **O.** | The fuel cell and other ways of using non-hazardous sources of energy. | |
| **F.** | The accumulation and prevention of toxic wastes. | |
| **Ne.** | Bioplastics from starch and from other renewable resources. | |
| **Na.** | Bhopal (India) - 1984.<br>How it occurred and what could have been done to prevent this disaster from happening. | |
| **Mg.** | Living a healthier life by appreciating biodegradable plastics. | |

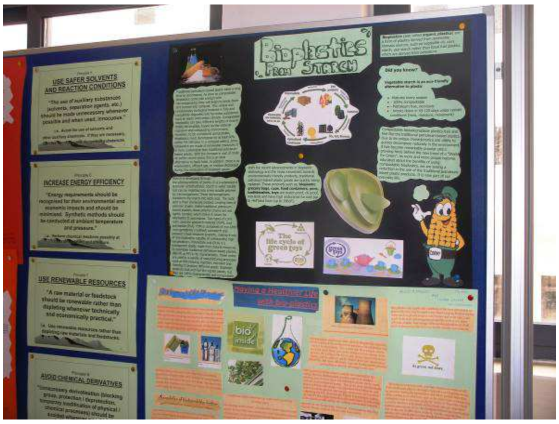
**Appendix 19**

# The Students' Poster Exhibition

Students' posters displayed in
exhibition "Green Chemistry – for a Sustainable Future"
on 16th March 2010





**Appendix 20**

# Chemistry Survey

## Part A2

*This test is intended solely for research purposes. No information given by the respondents will be published without the prior consent of the participants in this educational project. This research study is being carried out by Mr. M. Fenech Caruana in conjunction with the Department of Educational Studies at the University of York (UK).*

**Section A: PERSONAL INFORMATION**

1. Name ______________________________ 2. Date ________________

3. Age last birthday ______________________ 4. Group / Class __________

5. School last attended before applying for Junior College.

State Secondary School ☐ Church Secondary School ☐

Private Secondary School ☐ Other ☐ Specify ____________________

*(Please tick ☑ the appropriate box)*

6. For how long (full scholastic years) have you been studying chemistry before starting your A-level course at the Junior College?

0 years ☐ 1 year ☐ 2 years ☐ 3 years ☐

More than 3 years ☐ Specify ________________________________________

*(Please tick ☑ the appropriate box.)*

7. Do you intend to pursue further studies upon finishing the Junior College?

Yes ☐ No ☐ Undecided ☐

*(Please tick ☑ the appropriate box)*

If yes, please specify any course you wish to follow.

University ☐ Course: ____________________________________________

MCAST ☐ Course: ____________________________________________

Other ☐ Course: ____________________________________________

8. What other subjects (apart from Chemistry and Systems of Knowledge) are you studying at the Junior College?

Advanced level: __________________________________________________

Intermediate level: _______________________________________________

*Answer each question in sections B to D by circling the number corresponding to the statement that indicates your opinion. Numbers are only used as codes and have nothing to do with marks.*

## Section B: CHEMISTRY AT SCHOOL

1. At secondary level, I always found chemistry to be interesting.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

2. Chemical concepts are always abstract and difficult to understand.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

3. Chemistry is more interesting and exciting in the laboratory than in the classroom.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

4. I study chemistry only to pass examinations and possibly make it to university.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

5. Studying chemistry has to be made more interesting in order to make it easier to pass exams.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

6. Studying chemistry improves your aptitudes in the other sciences.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

7. Students perform better in other subjects if they do well in chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

8. I do not regret having chosen chemistry as one of my A-level subjects.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

9. Ways of teaching chemistry must change in order to appeal more to students living in today's society.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

10. The chemistry curriculum needs to be updated to replace some existing topics with new ones to reflect better the present and future contribution of chemistry to society.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

## Section C: CHEMISTRY AND SOCIETY

1. Chemistry contributes to the improvement of the quality of human life.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

2. Chemistry has a beneficial effect on the environment.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

3. Chemistry is doing enough to control the production and release of toxic substances on land, in the sea, or in the atmosphere.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

4. Chemistry tries to protect the environment by identifying possible sources of pollution and treating pollutants, but it should be doing more than that.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

5. Chemistry is still responsible for most environmental problems.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

## Section D: CAREERS IN CHEMISTRY

1. I want to pursue further studies in chemistry on leaving the Junior College.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

2. I intend to choose a career / profession involving chemistry upon finishing my studies.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

3. Showing how chemistry relates to everyday life makes me more interested in choosing a career / profession involving chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

4. Studying 'green chemistry' makes me more interested in choosing a career / profession involving chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

5. I find it hard to imagine myself have a career / profession involving chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

## Section E: GREEN CHEMISTRY AS PART OF SCHOOL CHEMISTRY

*Read the following paragraph and then answer the questions in sections E and F by circling the number corresponding to the statement that indicates your level of agreement.*

Green chemistry, which is sometimes known also as 'sustainable chemistry' refers to the design and introduction of chemical products and processes that reduce or eliminate the use and production of substances that are hazardous to human health or the environment. It encourages the use of environmentally friendly and safer chemicals and chemical processes that: reduce waste, eliminate the need for costly treatment of pollutants, produce safer products and reduce the use of energy and resources. Green chemistry is therefore regarded as 'preventive medicine' for the environment.

1. It is important to start promoting the basic principles of green chemistry in secondary and post-secondary schools.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

2. Green chemistry helps us change the wrong perception of people that chemistry is the main cause of environmental hazards.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

3. Students are generally more interested in learning about green chemistry than about more traditional topics.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

4. Studying green chemistry makes me more interested in studying general chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

5. Practical work can be more useful and interesting if designed to illustrate green chemistry principles.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

6. It is more important to study the foundations of chemistry than to introduce green chemistry in secondary schools.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

7. Green chemistry is a fundamental area of chemistry and should be considered in future examination syllabi and examination papers.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

8. The best way to introduce green chemistry to A-level students is by studying it as a separate topic.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

9. Green chemistry is ideally integrated in the programme of studies in different stages throughout the A-level programme.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

10. The best way of demonstrating green chemistry principles is by designing relevant practical sessions.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

11. Adding the principles of green chemistry to an already vast examination syllabus would make it harder for students to pass the A-level examination in Chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

12. It is useless studying green chemistry for A-level if there are yet no suitable textbooks and educational resources available.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

## Section F: VIEWS OF GREEN CHEMISTRY

1. I think I have a good understanding of what is meant by 'environmental chemistry'.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

2. I think I have a good understanding of what is meant by 'green chemistry'.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

3. 'Environmental chemistry' and 'green chemistry' are pretty much the same thing.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

4. 'Green chemistry' is just a more catchy term for 'environmental chemistry'.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

5. Green chemistry is a new dimension of environmental chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

6. Green chemistry tries to prevent pollution before it starts.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

7. Increasing awareness and practice of green chemistry would have a positive impact on the quality of our lives.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

8. Learning about green chemistry increases the level of awareness of students about environmental problems.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

9. Green chemistry is vital in securing a sustainable future for the next generations.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

10. Green chemistry principles address environmental problems by using a new and more effective approach.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

11. A sound background knowledge of general chemistry is needed to understand the role of green chemistry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

12. Investing in green chemistry research is a safeguard to a healthier future civilisation.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

13. The principles of green chemistry are difficult to apply.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

14. Green chemistry consists of a set of dreams that can never be implemented by the industry.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

15. Green chemistry principles are too expensive to be used widely.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

16. Chemistry can never be rendered ‘green’ as chemical processes always consume huge amounts of energy and create some form of pollution.

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |

**Appendix 21**

# Chemistry Survey

## Part B2

*This test is intended solely for research purposes. No information given by the respondents will be published without the prior consent of the participants in this educational project. This research study is being carried out by Mr. M. Fenech Caruana in conjunction with the Department of Educational Studies at the University of York (UK).*

### Section A: PERSONAL INFORMATION

1. Name ______________________________  2. Date ________________

3. Age last birthday ______________________  4. Group / Class _________

5. School last attended before applying for Junior College.

   State Secondary School ☐  Church Secondary School ☐

   Private Secondary School ☐  Other ☐ Specify ____________________

   *(Please tick ☑ the appropriate box)*

6. For how long (full scholastic years) have you been studying chemistry before starting your A-level course at the Junior College?

   0 years ☐  1 year ☐  2 years ☐  3 years ☐

   More than 3 years ☐  Specify ________________________________________

   *(Please tick ☑ the appropriate box.)*

7. Do you intend to pursue further studies upon finishing the Junior College?

   Yes ☐  No ☐  Undecided ☐

   *(Please tick ☑ the appropriate box)*

   If yes, please specify any course you wish to follow.

   University ☐  Course: ____________________________________________

   MCAST ☐  Course: ____________________________________________

   Other ☐  Course: ____________________________________________

8. What other subjects (apart from Chemistry and Systems of Knowledge) are you studying at the Junior College?

   Advanced level: ____________________________________________

   Intermediate level: __________________________________________

## Section B: UNDERSTANDING GREEN CHEMISTRY CONCEPTS

1. (a) Pollution can be prevented in a number of ways. Suggest THREE measures which may be taken in order to minimise or prevent environmental pollution.

i) ______________________________

ii) ______________________________

iii) ______________________________

(b) What do you understand by the phrase 'pollution prevention at the molecular level'?

______________________________

______________________________

How do you feel about your answer to question 1?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

2. Ethanol reacts with ethanoic acid to produce ethyl ethanoate (an ester) and water.

$$C_2H_5OH + CH_3COOH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

(a) If 65 g of the ester are obtained starting from 46 g (1 mole) of ethanol and 60 g (1 mole) of ethanoic acid, calculate the 'percentage yield' in this reaction.

______________________________

______________________________

(b) Explain what is meant by the term 'atom economy'.

______________________________

______________________________

(c) Work out the ' atom economy' of the above reaction.

______________________________

______________________________

______________________________

How do you feel about your answer to question 2?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

3. A given amount of pure substance X may be synthesized using one of the following techniques:

***Technique A:*** *uses small amounts of substances, F and G, both being expensive and hazardous reagents, and distilled water.*

***Technique B:*** *uses large amounts of substances H and I, both being relatively cheap and non-hazardous, and distilled water.*

***Technique C:*** *uses small amounts of substance F and G (expensive, hazardous) and significant amounts of solvent W (inexpensive) which is highly inflammable.*

Which of the three techniques A, B, and C would you choose? Technique: _____

Give a reason for your answer.

______________________________________________________________________

______________________________________________________________________

How do you feel about your answer to question 3?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

4. A new chemical substance Y has been designed in a research laboratory. The substance may have the following features:

(A) ☐ low toxicity, high specificity (i.e. highly effective for its target application);

(B) ☐ low toxicity, low specificity;

(C) ☐ high toxicity, high specificity;

(D) ☐ high toxicity, low specificity;

(E) ☐ unknown toxicity, high specificity, lowest cost price.

Which of the above do you think would have the best set of requirements for future use by the chemical industry?

*(Please tick ☑ the appropriate box)*

Give a reason for your answer.

______________________________________________________________________

______________________________________________________________________

How do you feel about your answer to question 4?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

5. (a) Many solvents used in laboratories or by the industry are hazardous and highly toxic. Name TWO solvents that are either hazardous or toxic, or both.

i) ______________________________

ii) ______________________________

(b) Explain what is meant by the term ‘green solvent’, giving an example.

______________________________

______________________________

______________________________

How do you feel about your answer to question 5?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

6. Lots of energy is consumed everyday in every part of the world. Producing energy is expensive and contributes to environmental pollution.

One example of a clean form of energy is that provided by the ‘fuel cell’.

(a) Explain the chemistry involved when a ‘fuel cell’ is operating.

______________________________

______________________________

______________________________

______________________________

(b) Name TWO advantages of fuel cells over traditional sources of energy.

______________________________

______________________________

______________________________

______________________________

How do you feel about your answer to question 6?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

7. Fuel prices are generally high because fuels are normally produced from crude oil (petroleum) which is considered as a non-renewable (or depleting) source of energy. People are now using also alternative fuels (called 'biofuels') made from 'renewable feedstocks'.

(a) Explain what is meant by 'renewable feedstocks', giving ONE example.

______________________________________________________________

______________________________________________________________

(b) Give ONE example of a 'biofuel' and ONE additional advantage of biofuels over fossil fuels.

Example of biofuel: ______________________________________

Additional advantage: ____________________________________

How do you feel about your answer to question 7?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

8. A particular drug was synthesised using Method A involving:

- 5 major reactions
- a total of 12 different reagents
- 6 different solvents.

Research chemists found a new way, Method B, of producing the same drug using:

- only 3 major steps
- 7 different reagents
- only 2 solvents.

(a) Name TWO possible benefits, if any, of using the new method B which involves the use of less derivatives.

______________________________________________________________

______________________________________________________________

(b) Name TWO other considerations one would make before deciding that method B is better than method A for industrial production.

______________________________________________________________

______________________________________________________________

How do you feel about your answer to question 8?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

9. A ‘catalyst’ is a substance which speeds up a chemical process without itself being used up at the end of the overall reaction.
Catalysts are considered more environmentally friendly than stoichiometric reagents (i.e. the other reagents that react completely during a reaction).

(a) Give TWO reasons why catalysts are more ‘benign’ to the environment than other reagents.

______________________________________________

______________________________________________

______________________________________________

______________________________________________

(b) Give ONE example of a catalysed reaction that can be used commercially to replace the synthesis of ethanol from ethene.

______________________________________________

______________________________________________

<u>How do you feel about your answer to question 9?</u>

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

10. One way of reducing waste is through recycling. However some useful materials such as plastics are rather difficult to be recycled. One method of dealing with the huge amounts of plastic waste is to design ‘biodegradable’ polymers (biopolymers).

(a) Explain what is meant by ‘biodegradable’ plastics.

______________________________________________

______________________________________________

(b) In what ways will the production of biopolymers help in safeguarding a healthier environment?

______________________________________________

______________________________________________

______________________________________________

______________________________________________

<u>How do you feel about your answer to question 10?</u>

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

11. A chemical process consumes **more** time, energy and resources, and generates **more** pollution unless specific measures are taken.
What needs to be done to ensure that a particular chemical process (which may involve several chemical reactions) would not produce higher quantities of hazardous by-products than what is expected?

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

How do you feel about your answer to question 11?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

12. In 1984, an accidental release of a highly toxic substance (methyl isocyanate) from a pesticide plant in Bhopal, India, killed about 4,000 people within a short time and injured tens of thousands who had to receive hospital treatment. Similar industrial accidents do occasionally happen and create environmental disasters.

In order to prevent such accidents, chemists must work to:

(A) ☐ possibly use a narrower range of chemicals in industry;

(B) ☐ possibly use lower amounts of chemicals per production;

(C) ☐ possibly use only non-toxic, non-hazardous reagents;

(D) ☐ possibly reduce pollution at the source;

(E) ☐ possibly avoid the use of high temperatures and pressures.

*(Please tick ☑ the appropriate box/es)*

Give a reason for your choice.

______________________________________________________________

______________________________________________________________

______________________________________________________________

How do you feel about your answer to question 12?

| Very unconfident | Unconfident | Neither confident nor unconfident | Confident | Very Confident |
|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** |

*(Circle the number corresponding to your level of confidence.)*

13. Explain in your own words what is meant by 'green chemistry'?

14. There are twelve principles of green chemistry that highlight important chemical concepts that need to be practised in order to safeguard a sustainable environment for future generations. Briefly explain ANY THREE of these principles:

15. Give ONE practical example of how the human civilisation can benefit from green chemistry.

**Appendix 22**

## Project: Greening the Chemistry Curriculum in Maltese Educational Institutions

# Focus Group Discussion Plan - 2010

**MAIN FOCUS**
**Students' attitudes and understanding of chemistry / green chemistry concepts in the advanced level chemistry curriculum**

## Introduction

1. Explain the 'rules of the game' – set of simple instructions on how to make the best out of the session by keeping focus on issues being discussed.
2. The importance of expressing oneself as freely as possible.
3. Use of voice recorder + camera, and data protection.
4. Encourage participation of all members of the group.

## Ice-breaker

5. Students introduce themselves (e.g. name, locality, family, previous school, main interests or hobbies, current studies, aspirations, future ambitions, etc.).

## Stimuli Cards *(include statement in italics for green-chemistry students)*

6. Tutor reads out the following statements, each printed on a separate card. Participants then decide whether they agree or not with each statement by sticking on a coloured label on which they write their code (initials). A green label means agreement while a red label implies disagreement. The student may choose not to use any label if s/he is undecided on a particular issue.

**Statement 1:** Chemistry can make the difference in the quality of our lives.
***Green chemistry aims to improve safety in human health and the environment.***

**Statement 2:** Chemistry was instrumental in the progress achieved by mankind.
***Studying green chemistry has become increasingly important.***

**Statement 3:** Chemistry is doing nothing to address the environmental problems it has created in the past.
***Green chemistry safeguards future generations from past mistakes.***
***With green chemistry, students acquire a more positive picture of chemistry.***

**Statement 4:** The A-level chemistry programme is no longer relevant to everyday life.
***Chemistry would become more relevant to us if one understands the basics of green chemistry.***

**Statement 5:** More than ever, the world today needs people studying and doing research in chemistry.
***Green chemistry should only be studied at university level or limited to research work.***

**Statement 6:** Studying chemistry at secondary level (for O-level exam) was far more enjoyable than studying it at sixth form level (for Intermediate or A-level exams).
***Green chemistry gives an extra motivation to students to study and specialise in chemistry.***

**Statement 7:** The A-level chemistry curriculum is overburdened with unnecessary topics and activities.
***Green chemistry concepts should not be presented as a separate topic but integrated in the main A-level chemistry programme.***

**Statement 8:** Chemistry is a science subject that no longer appeals to the younger generation.
***Chemistry would become increasingly popular with the inclusion of green chemistry topics.***

**Statement 9:** Learning chemistry would become more interesting with the inclusion of environmental topics.
***There is room for green chemistry concepts in the A-level chemistry curriculum.***

**Statement 10:** Understanding key chemistry concepts depends mostly on the teaching approach and facilities available to students.
***Green chemistry principles are relatively simple and straightforward to understand.***

**Statement 11:** Learning chemistry at this level helps students understand better the crucial role of chemistry for a sustainable future.
***Hence, green chemistry should be made compulsory and examinable at sixth form level.***

**Statement 12:** More emphasis should be laid on laboratory work in A-level chemistry.
***One concrete way of illustrating green chemistry principles is by introducing green chemistry experiments in the A-level chemistry programme of studies.***

7. Tutor and participants then sort out statements according to labels and then choose 3 cards with the highest no. of green labels (showing consensus) and another 3 with the highest no. of red labels (showing disagreement).

8. Tutor and participants then discuss one issue (out of the six chosen) at a time.

## Conclusion

9. Tutor asks participants (depending on time remaining) whether they would like to add anything to what was already stated or whether they wanted to discuss any of the remaining statements. At this point, students may also share their general views on the introductory programme in green chemistry which they had just been involved.

10. Presentation of a gift pack (including material from the UK Green Chemistry Centre and some stationery items) to each participant.

***Mario Fenech Caruana***
*May 2010*

Appendix 23

# Chemistry Survey (Part A) Results
# ACTUAL COUNT

**Table 1: Results from Chemistry Survey (Part A – Section B)**

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| B1 | GC | 23 | 16 | 2 | 1 | 8 | 13 |
| | non-GC | 30 | 22 | 2 | 5 | 4 | 9 |
| B2 | GC | 1 | 2 | 17 | 13 | 15 | 15 |
| | non-GC | 4 | 4 | 15 | 18 | 17 | 14 |
| B3 | GC | 10 | 10 | 11 | 7 | 12 | 13 |
| | non-GC | 9 | 10 | 11 | 10 | 16 | 16 |
| B4 | GC | 5 | 9 | 25 | 16 | 3 | 5 |
| | non-GC | 8 | 13 | 24 | 17 | 4 | 6 |
| B5 | GC | 19 | 21 | 5 | 3 | 9 | 6 |
| | non-GC | 29 | 30 | 3 | 1 | 4 | 5 |
| B6 | GC | 30 | 27 | 1 | 0 | 2 | 3 |
| | non-GC | 30 | 29 | 3 | 1 | 3 | 6 |
| B7 | GC | 15 | 13 | 5 | 6 | 13 | 11 |
| | non-GC | 11 | 13 | 7 | 5 | 18 | 18 |
| B8 | GC | 28 | 23 | 2 | 2 | 3 | 5 |
| | non-GC | 31 | 21 | 0 | 7 | 5 | 8 |
| B9 | GC | 20 | 18 | 3 | 1 | 10 | 11 |
| | non-GC | 21 | 28 | 4 | 2 | 11 | 6 |
| B10 | GC | 22 | 22 | 2 | 5 | 9 | 3 |
| | non-GC | 23 | 29 | 0 | 1 | 13 | 6 |

## Appendix 23 (continued)

### Table 2: Results from Chemistry Survey (Part A – Section C)

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| C1 | GC | 23 | 25 | 2 | 0 | 8 | 5 |
| | non-GC | 29 | 31 | 3 | 2 | 4 | 3 |
| C2 | GC | 21 | 17 | 3 | 4 | 9 | 9 |
| | non-GC | 25 | 21 | 1 | 1 | 10 | 14 |
| C3 | GC | 4 | 6 | 13 | 16 | 16 | 8 |
| | non-GC | 8 | 7 | 19 | 21 | 9 | 8 |
| C4 | GC | 28 | 24 | 1 | 0 | 4 | 6 |
| | non-GC | 29 | 29 | 0 | 0 | 7 | 7 |
| C5 | GC | 19 | 16 | 6 | 4 | 8 | 10 |
| | non-GC | 20 | 24 | 6 | 2 | 10 | 10 |

### Table 3: Results from Chemistry Survey (Part A – Section D)

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| D1 | GC | 28 | 23 | 0 | 5 | 5 | 2 |
| | non-GC | 30 | 26 | 3 | 6 | 3 | 4 |
| D2 | GC | 30 | 24 | 0 | 3 | 3 | 3 |
| | non-GC | 28 | 23 | 4 | 4 | 4 | 9 |
| D3 | GC | 26 | 23 | 2 | 4 | 5 | 3 |
| | non-GC | 29 | 24 | 2 | 7 | 5 | 5 |
| D4 | GC | 17 | 14 | 2 | 6 | 14 | 10 |
| | non-GC | 17 | 14 | 10 | 11 | 9 | 11 |
| D5 | GC | 4 | 2 | 24 | 18 | 5 | 10 |
| | non-GC | 1 | 11 | 29 | 14 | 6 | 11 |

**Appendix 23 (continued)**

**Table 4: Results from Chemistry Survey (Part A – Section E)**

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| E1 | GC | 31 | 28 | 0 | 1 | 2 | 1 |
| | non-GC | 30 | 31 | 4 | 1 | 2 | 4 |
| E2 | GC | 21 | 24 | 0 | 1 | 12 | 5 |
| | non-GC | 24 | 25 | 3 | 4 | 9 | 7 |
| E3 | GC | 16 | 14 | 4 | 6 | 13 | 10 |
| | non-GC | 13 | 10 | 7 | 9 | 16 | 17 |
| E4 | GC | 19 | 13 | 4 | 5 | 10 | 12 |
| | non-GC | 16 | 20 | 13 | 10 | 7 | 6 |
| E5 | GC | 19 | 25 | 1 | 1 | 13 | 4 |
| | non-GC | 22 | 25 | 5 | 3 | 9 | 8 |
| E6 | GC | 9 | 9 | 11 | 8 | 13 | 13 |
| | non-GC | 12 | 11 | 13 | 10 | 11 | 15 |
| E7 | GC | 21 | 16 | 4 | 7 | 8 | 7 |
| | non-GC | 24 | 22 | 3 | 4 | 9 | 10 |
| E8 | GC | 17 | 13 | 8 | 11 | 8 | 6 |
| | non-GC | 14 | 21 | 12 | 9 | 10 | 6 |
| E9 | GC | 14 | 19 | 6 | 3 | 13 | 8 |
| | non-GC | 14 | 17 | 3 | 6 | 19 | 33 |
| E10 | GC | 29 | 27 | 0 | 2 | 4 | 1 |
| | non-GC | 31 | 28 | 0 | 1 | 5 | 7 |
| E11 | GC | 14 | 17 | 6 | 7 | 13 | 6 |
| | non-GC | 24 | 25 | 8 | 4 | 4 | 7 |
| E12 | GC | 7 | 14 | 18 | 13 | 8 | 3 |
| | non-GC | 16 | 20 | 10 | 5 | 10 | 11 |

## Appendix 23 (continued)

### Table 5: Results from Chemistry Survey (Part A – Section F)

| | | AGREEING (%) | DISAGREEING (%) | NEUTRAL (%) |
|---|---|---|---|---|
| Item | Group | Post-test A2 | Post-test A2 | Post-test A2 |
| F1 | GC | 27 | 0 | 3 |
| | non-GC | 20 | 5 | 11 |
| F2 | GC | 30 | 0 | 0 |
| | non-GC | 16 | 6 | 14 |
| F3 | GC | 9 | 9 | 12 |
| | non-GC | 9 | 11 | 16 |
| F4 | GC | 9 | 10 | 11 |
| | non-GC | 14 | 7 | 15 |
| F5 | GC | 19 | 0 | 11 |
| | non-GC | 18 | 2 | 16 |
| F6 | GC | 26 | 2 | 2 |
| | non-GC | 23 | 3 | 10 |
| F7 | GC | 29 | O | 1 |
| | non-GC | 30 | 1 | 5 |
| F8 | GC | 28 | 0 | 2 |
| | non-GC | 33 | 0 | 3 |
| F9 | GC | 27 | 0 | 3 |
| | non-GC | 30 | 0 | 6 |
| F10 | GC | 27 | 0 | 3 |
| | non-GC | 22 | 1 | 13 |
| F11 | GC | 20 | 2 | 8 |
| | non-GC | 22 | 2 | 12 |
| F12 | GC | 26 | 0 | 4 |
| | non-GC | 32 | 0 | 4 |
| F13 | GC | 3 | 17 | 10 |
| | non-GC | 8 | 9 | 19 |
| F14 | GC | 2 | 22 | 6 |
| | non-GC | 7 | 16 | 13 |
| F15 | GC | 4 | 13 | 13 |
| | non-GC | 14 | 5 | 17 |
| F16 | GC | 3 | 19 | 8 |
| | non-GC | 14 | 8 | 14 |

**Appendix 24**

# Chemistry Survey (Part A) Results

# PERCENTAGE SCORES

**Table 1: Results from Chemistry Survey (Part A – Section B)**

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| B1 | GC | 69.7 | 53.3 | 6.1 | 3.3 | 24.4 | 43.3 |
| | non-GC | 83.3 | 61.1 | 5.6 | 13.8 | 11.1 | 25.0 |
| B2 | GC | 3.0 | 6.7 | 51.5 | 43.3 | 45.5 | 50.0 |
| | non-GC | 11.1 | 11.1 | 41.7 | 50.0 | 47.2 | 38.9 |
| B3 | GC | 30.3 | 33.3 | 33.3 | 23.3 | 36.4 | 43.3 |
| | non-GC | 25.0 | 27.8 | 30.6 | 27.8 | 44.4 | 44.4 |
| B4 | GC | 15.2 | 30.0 | 75.8 | 53.3 | 9.1 | 16.7 |
| | non-GC | 22.2 | 36.1 | 66.7 | 47.2 | 11.1 | 16.7 |
| B5 | GC | 57.6 | 70.0 | 15.2 | 10.0 | 27.2 | 20.0 |
| | non-GC | 80.6 | 83.3 | 8.3 | 2.7 | 11.0 | 13.9 |
| B6 | GC | 90.9 | 90.0 | 3.0 | 0 | 6.1 | 10.1 |
| | non-GC | 83.3 | 80.6 | 8.3 | 2.8 | 8.3 | 16.7 |
| B7 | GC | 45.5 | 43.3 | 15.2 | 20.0 | 39.4 | 36.7 |
| | non-GC | 30.6 | 36.1 | 19.4 | 13.9 | 50.0 | 50.0 |
| B8 | GC | 84.8 | 76.7 | 6.1 | 6.7 | 9.1 | 16.7 |
| | non-GC | 86.1 | 58.3 | 0 | 19.4 | 13.9 | 22.2 |
| B9 | GC | 60.6 | 60.0 | 9.1 | 3.3 | 30.3 | 36.7 |
| | non-GC | 58.3 | 77.8 | 11.1 | 5.6 | 30.6 | 16.7 |
| B10 | GC | 66.7 | 73.3 | 6.1 | 16.7 | 27.3 | 10.0 |
| | non-GC | 63.9 | 80.6 | 0 | 2.8 | 36.1 | 16.7 |

## Appendix 24 (continued)

### Table 2: Results from Chemistry Survey (Part A – Section C)

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| C1 | GC | 69.7 | 83.3 | 6.1 | 0 | 24.3 | 16.6 |
| | non-GC | 80.6 | 86.1 | 8.3 | 5.6 | 11.1 | 8.3 |
| C2 | GC | 63.6 | 56.7 | 9.1 | 13.3 | 27.3 | 30.0 |
| | non-GC | 69.4 | 58.3 | 2.8 | 2.8 | 27.8 | 38.9 |
| C3 | GC | 12.1 | 20.0 | 39.4 | 53.3 | 48.5 | 26.7 |
| | non-GC | 22.2 | 19.4 | 52.8 | 58.3 | 25.0 | 22.2 |
| C4 | GC | 84.8 | 80.0 | 3.0 | 0 | 12.1 | 20.0 |
| | non-GC | 80.6 | 80.6 | 0 | 0 | 19.5 | 19.5 |
| C5 | GC | 57.6 | 53.3 | 18.2 | 13.3 | 24.3 | 33.3 |
| | non-GC | 55.6 | 66.7 | 16.7 | 5.6 | 27.8 | 27.8 |

### Table 3: Results from Chemistry Survey (Part A – Section D)

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| D1 | GC | 84.8 | 76.7 | 0 | 16.7 | 15.1 | 6.7 |
| | non-GC | 83.3 | 72.2 | 8.3 | 16.7 | 8.4 | 11.1 |
| D2 | GC | 90.9 | 80.0 | 0 | 10.0 | 9.1 | 10.0 |
| | non-GC | 77.8 | 63.9 | 11.1 | 11.1 | 11.1 | 25.0 |
| D3 | GC | 78.8 | 76.7 | 6.1 | 13.3 | 15.2 | 10.0 |
| | non-GC | 80.6 | 66.7 | 5.6 | 19.4 | 13.9 | 13.9 |
| D4 | GC | 51.5 | 46.7 | 6.1 | 20.0 | 42.4 | 33.3 |
| | non-GC | 47.2 | 38.9 | 27.8 | 30.6 | 25.0 | 30.5 |
| D5 | GC | 12.1 | 6.7 | 72.2 | 60.0 | 15.2 | 33.3 |
| | non-GC | 2.8 | 30.6 | 80.6 | 38.9 | 16.7 | 30.6 |

**Appendix 24 (continued)**

**Table 4: Results from Chemistry Survey (Part A – Section E)**

| | | AGREEING (%) | | DISAGREEING (%) | | NEUTRAL (%) | |
|---|---|---|---|---|---|---|---|
| Item | Group | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 | Pre-test A1 | Post-test A2 |
| E1 | GC | 93.9 | 93.3 | 0 | 3.3 | 6.1 | 3.3 |
| | non-GC | 83.3 | 86.1 | 11.1 | 2.8 | 5.6 | 11.1 |
| E2 | GC | 63.6 | 80.0 | 0 | 3.3 | 36.4 | 16.7 |
| | non-GC | 66.7 | 69.4 | 8.3 | 11.1 | 25.0 | 19.5 |
| E3 | GC | 48.5 | 46.7 | 12.1 | 20.0 | 39.4 | 33.3 |
| | non-GC | 36.1 | 27.8 | 13.9 | 25.0 | 44.5 | 47.2 |
| E4 | GC | 57.6 | 43.3 | 12.1 | 16.7 | 30.3 | 40.0 |
| | non-GC | 44.4 | 55.6 | 36.1 | 27.8 | 19.4 | 16.4 |
| E5 | GC | 57.6 | 83.3 | 3.0 | 3.3 | 39.4 | 13.3 |
| | non-GC | 61.1 | 69.4 | 13.9 | 8.3 | 25.0 | 22.2 |
| E6 | GC | 27.3 | 30.0 | 33.3 | 26.7 | 39.4 | 43.3 |
| | non-GC | 33.3 | 30.6 | 36.1 | 27.8 | 30.5 | 41.7 |
| E7 | GC | 63.6 | 53.3 | 12.1 | 23.3 | 24.2 | 23.3 |
| | non-GC | 66.7 | 61.1 | 8.3 | 11.1 | 25.0 | 27.8 |
| E8 | GC | 51.5 | 43.3 | 24.2 | 36.7 | 24.2 | 20.0 |
| | non-GC | 38.9 | 58.3 | 33.3 | 25.0 | 27.8 | 16.7 |
| E9 | GC | 42.4 | 63.3 | 18.2 | 10.0 | 39.4 | 26.7 |
| | non-GC | 38.9 | 47.2 | 8.3 | 16.7 | 52.7 | 36.1 |
| E10 | GC | 87.9 | 90.0 | 0 | 6.7 | 12.1 | 3.3 |
| | non-GC | 86.1 | 77.8 | 0 | 2.8 | 13.9 | 19.4 |
| E11 | GC | 42.4 | 56.7 | 18.2 | 23.3 | 39.4 | 20.0 |
| | non-GC | 66.7 | 69.4 | 22.2 | 11.1 | 11.1 | 19.4 |
| E12 | GC | 21.2 | 46.7 | 54.5 | 43.3 | 24.2 | 10 |
| | non-GC | 44.4 | 55.6 | 27.8 | 13.9 | 27.8 | 30.6 |

**Appendix 24 (continued)**

**Table 5: Results from Chemistry Survey (Part A – Section F)**

| | | AGREEING (%) | DISAGREEING (%) | NEUTRAL (%) |
|---|---|---|---|---|
| Item | Group | Post-test A2 | Post-test A2 | Post-test A2 |
| F1 | GC | 90.0 | 0 | 10.0 |
| | non-GC | 55.6 | 13.9 | 30.5 |
| F2 | GC | 100.0 | 0 | 0 |
| | non-GC | 44.4 | 16.7 | 38.8 |
| F3 | GC | 30.0 | 30.0 | 40.0 |
| | non-GC | 25.0 | 30.5 | 44.4 |
| F4 | GC | 30.0 | 33.3 | 36.7 |
| | non-GC | 38.9 | 19.4 | 41.7 |
| F5 | GC | 63.3 | 0 | 36.7 |
| | non-GC | 50.0 | 5.6 | 44.4 |
| F6 | GC | 86.7 | 6.7 | 6.7 |
| | non-GC | 63.9 | 8.3 | 27.7 |
| F7 | GC | 96.7 | 0 | 3.3 |
| | non-GC | 83.3 | 2.8 | 13.9 |
| F8 | GC | 93.3 | 0 | 6.7 |
| | non-GC | 91.7 | 0 | 8.4 |
| F9 | GC | 90.0 | 0 | 10.0 |
| | non-GC | 83.3 | 0 | 16.7 |
| F10 | GC | 90.0 | 0 | 10.0 |
| | non-GC | 61.1 | 2.8 | 36.1 |
| F11 | GC | 66.7 | 6.7 | 26.7 |
| | non-GC | 61.1 | 5.6 | 33.3 |
| F12 | GC | 86.7 | 0 | 13.3 |
| | non-GC | 88.9 | 0 | 11.2 |
| F13 | GC | 10.0 | 56.7 | 33.3 |
| | non-GC | 22.2 | 25.0 | 52.7 |
| F14 | GC | 6.7 | 73.3 | 20.0 |
| | non-GC | 19.4 | 44.4 | 36.1 |
| F15 | GC | 13.3 | 43.4 | 43.3 |
| | non-GC | 38.9 | 13.9 | 47.2 |
| F16 | GC | 10.0 | 63.3 | 26.7 |
| | non-GC | 38.9 | 22.2 | 38.9 |

Appendix 25

## Chemistry Survey (Part A) Results

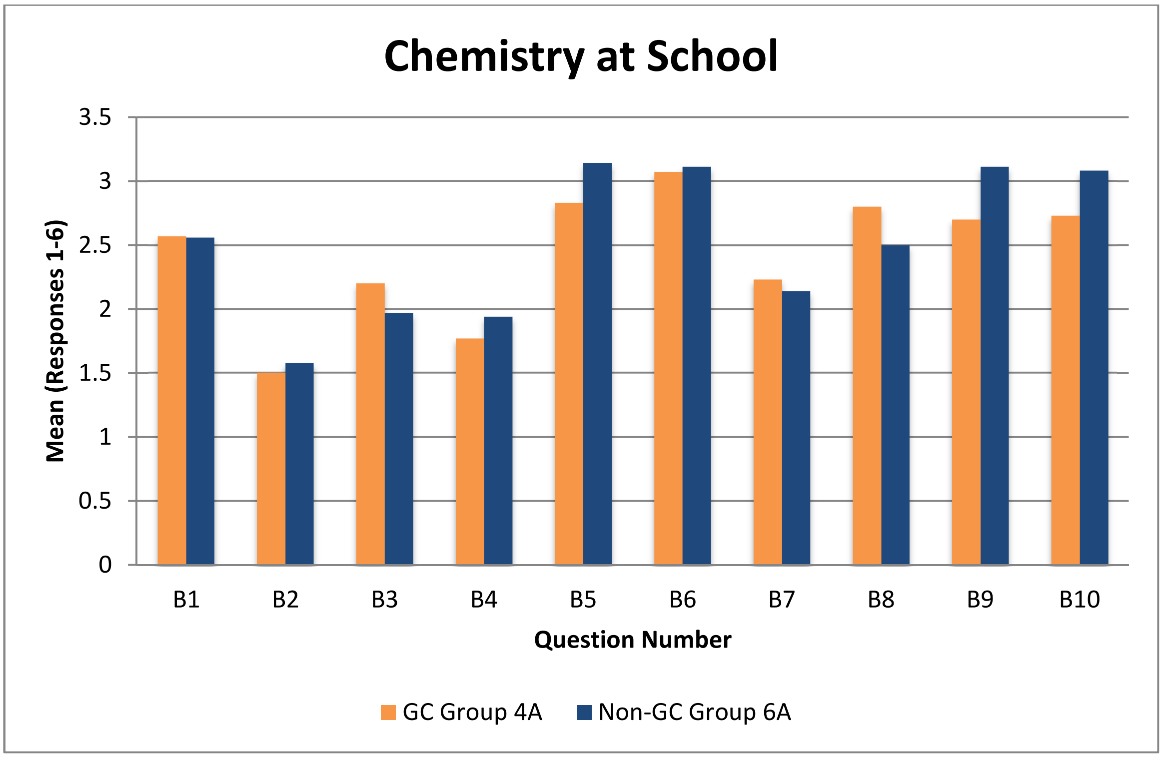
## COMPARING POST-TEST MEANS OF TWO GROUPS

# Post-test A2

Comparing Means of Two Groups
GC Group (n=30) versus Non-GC Group (n=36)

## Section B: Chemistry at School

| Question | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 |
|---|---|---|---|---|---|---|---|---|---|---|
| GC Group | 2.57 | 1.50 | 2.20 | 1.77 | 2.83 | 3.07 | 2.23 | 2.80 | 2.70 | 2.73 |
| Non-GC Group | 2.56 | 1.58 | 1.97 | 1.94 | 3.14 | 3.11 | 2.14 | 2.50 | 3.11 | 3.08 |



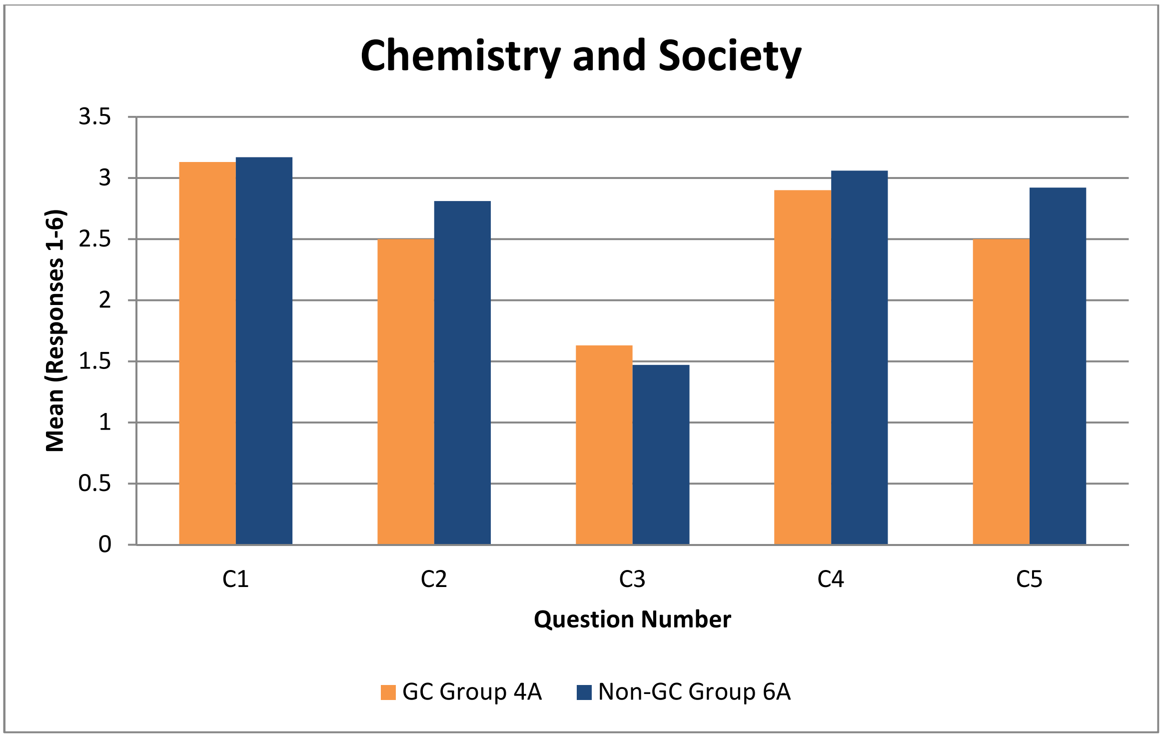
**Appendix 25 (continued)**

# Post-test A2

Comparing Means of Two Groups
GC Group (n=30) versus Non-GC Group (n=36)

## Section C: Chemistry and Society

| Question | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| GC Group | 3.13 | 2.50 | 1.63 | 2.90 | 2.50 |
| Non-GC Group | 3.17 | 2.81 | 1.47 | 3.06 | 2.92 |

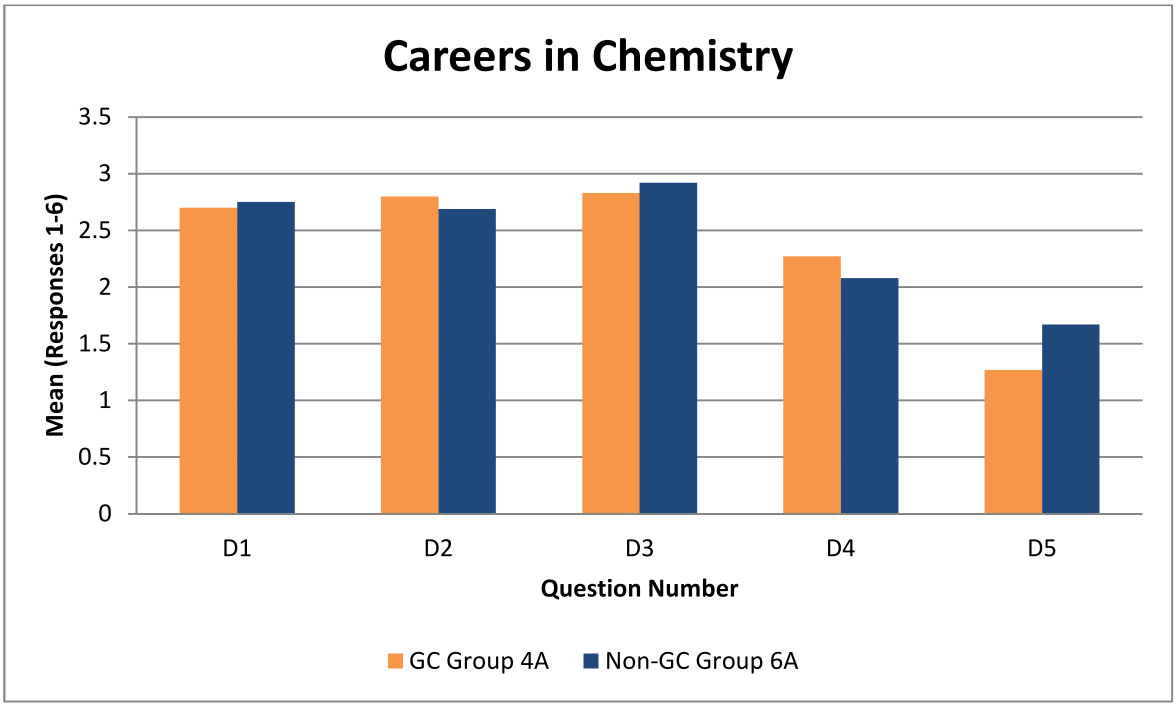


# Post-test A2

## Comparing Means from Two Groups
## GC Group (n=30) versus Non-GC Group (n=36)

## Section D: Careers in Chemistry

| Question | D1 | D2 | D3 | D4 | D5 |
|---|---|---|---|---|---|
| GC Group | 2.70 | 2.80 | 2.83 | 2.27 | 1.27 |
| Non-GC Group | 2.75 | 2.69 | 2.92 | 2.08 | 1.67 |



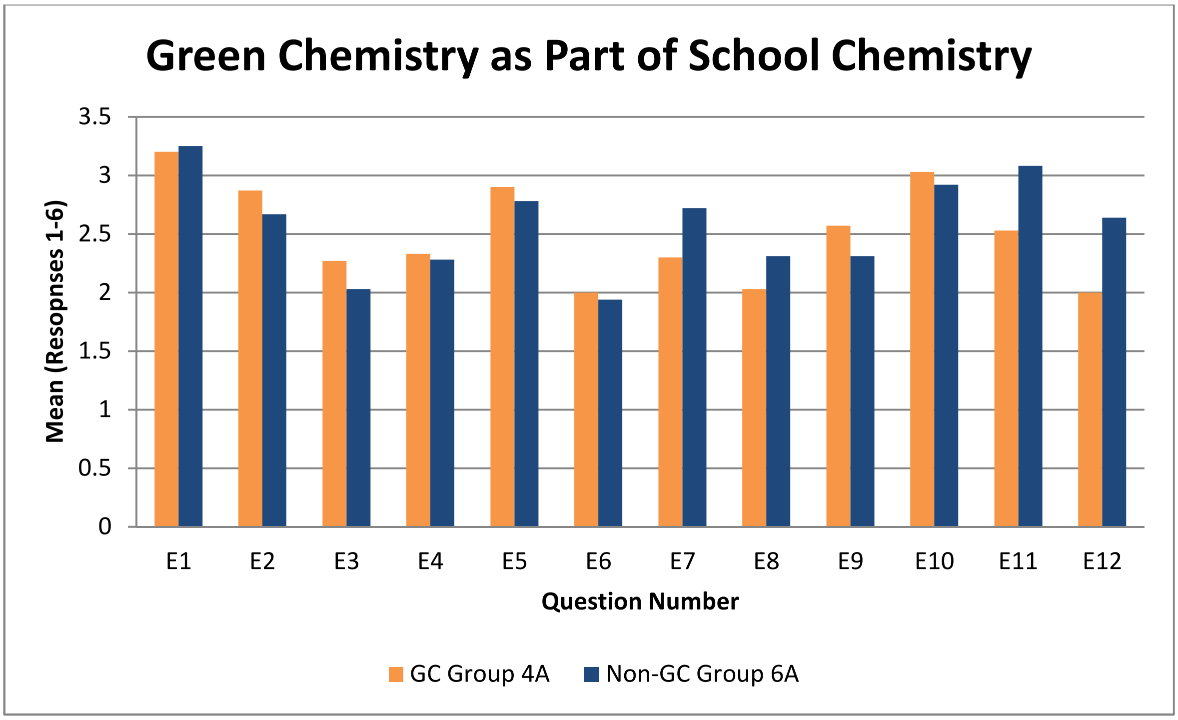
**Appendix 25 (continued)**

# Post-test A2

## Comparing Means from Two Groups
## GC Group (n=30) versus Non-GC Group (n=36)

## Section E: Green Chemistry as Part of School Chemistry

| **Question** | **E1** | **E2** | **E3** | **E4** | **E5** | **E6** | **E7** | **E8** | **E9** | **E10** | **E11** | **E12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GC Group | 3.20 | 2.87 | 2.27 | 2.33 | 2.90 | 2.00 | 2.30 | 2.03 | 2.57 | 3.03 | 2.53 | 2.00 |
| Non-GC Group | 3.25 | 2.67 | 2.03 | 2.28 | 2.78 | 1.94 | 2.72 | 2.31 | 2.31 | 2.92 | 3.08 | 2.64 |

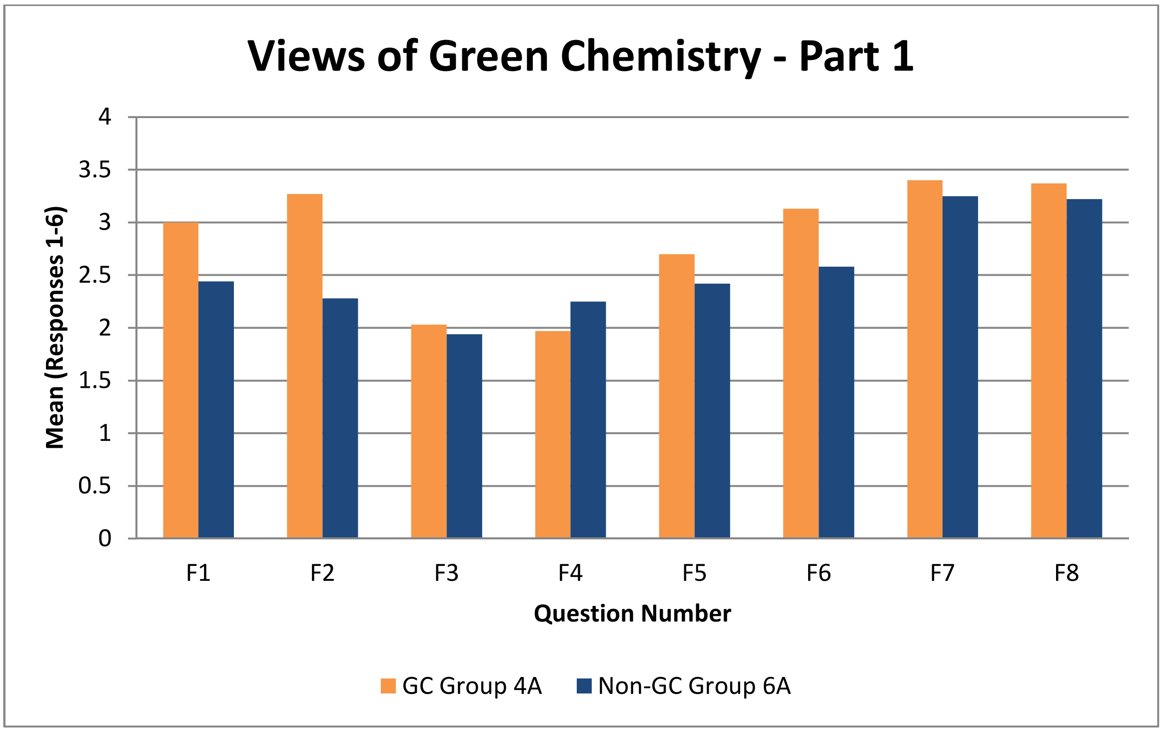


# Post-test A2

## Comparing Means of Two Groups
## GC Group (n=30) versus Non-GC Group (n=36)

## Section F: Views of Green Chemistry (1)

| Question | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 |
|---|---|---|---|---|---|---|---|---|
| GC Group | 3.00 | 3.27 | 2.03 | 1.97 | 2.70 | 3.13 | 3.40 | 3.37 |
| Non-GC Group | 2.44 | 2.28 | 1.94 | 2.25 | 2.42 | 2.58 | 3.25 | 3.22 |



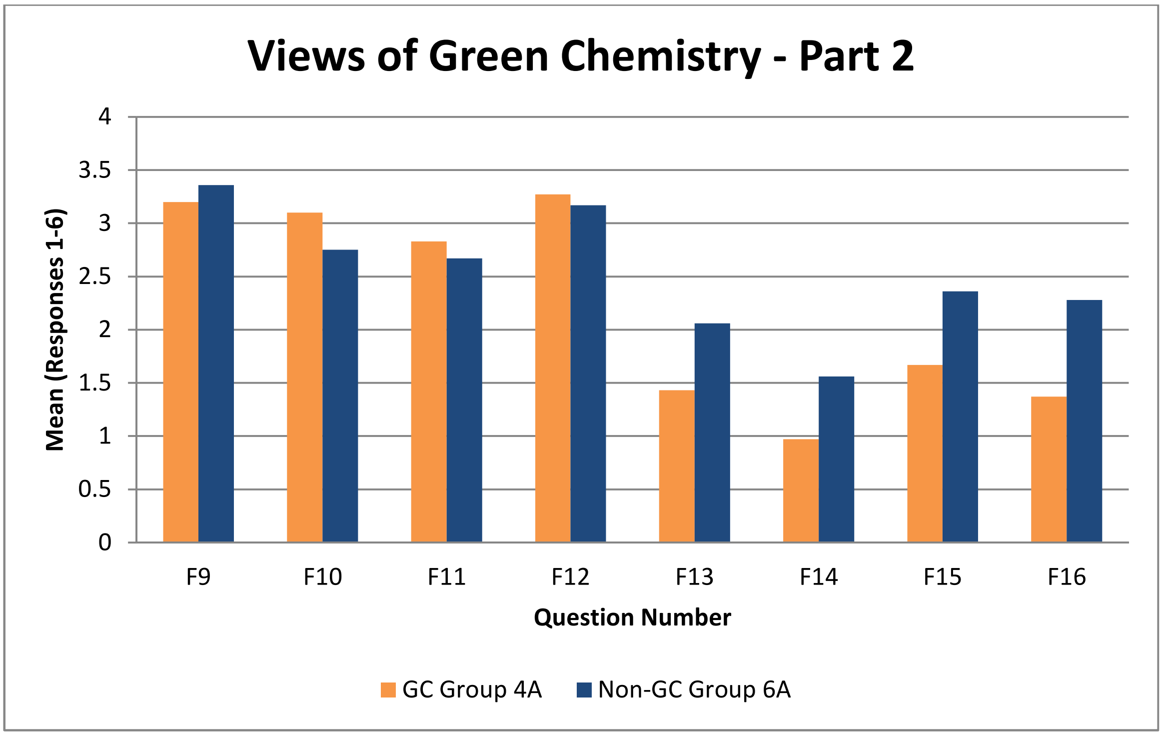
**Appendix 25 (continued)**

# Post-test A2

## Comparing Means of Two Groups
## GC Group (n=30) versus Non-GC Group (n=36)

## Section F: Views of Green Chemistry (2)

| **Question** | **F9** | **F10** | **F11** | **F12** | **F13** | **F14** | **F15** | **F16** |
|---|---|---|---|---|---|---|---|---|
| GC Group | 3.20 | 3.10 | 2.83 | 3.27 | 1.43 | 0.97 | 1.67 | 1.37 |
| Non-GC Group | 3.36 | 2.75 | 2.67 | 3.17 | 2.06 | 1.56 | 2.36 | 2.28 |



## Appendix 26

### Tests of Normality:
### Chemistry Survey (Part A) – Post-test 'Attitudes' Data

| Item | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | p-value | Statistic | df | p-value |
| B1 | 0.279 | 66 | 0.000 | 0.858 | 66 | 0.000 |
| B2 | 0.239 | 66 | 0.000 | 0.870 | 66 | 0.000 |
| B3 | 0.233 | 66 | 0.000 | 0.878 | 66 | 0.000 |
| B4 | 0.264 | 66 | 0.000 | 0.876 | 66 | 0.000 |
| B5 | 0.288 | 66 | 0.000 | 0.823 | 66 | 0.000 |
| B6 | 0.281 | 66 | 0.000 | 0.810 | 66 | 0.000 |
| B7 | 0.219 | 66 | 0.000 | 0.876 | 66 | 0.000 |
| B8 | 0.293 | 66 | 0.000 | 0.830 | 66 | 0.000 |
| B9 | 0.217 | 66 | 0.000 | 0.856 | 66 | 0.000 |
| B10 | 0.306 | 66 | 0.000 | 0.827 | 66 | 0.000 |
| C1 | 0.274 | 66 | 0.000 | 0.790 | 66 | 0.000 |
| C2 | 0.219 | 66 | 0.000 | 0.871 | 66 | 0.000 |
| C3 | 0.258 | 66 | 0.000 | 0.888 | 66 | 0.000 |
| C4 | 0.313 | 66 | 0.000 | 0.775 | 66 | 0.000 |
| C5 | 0.225 | 66 | 0.000 | 0.874 | 66 | 0.000 |
| D1 | 0.334 | 66 | 0.000 | 0.797 | 66 | 0.000 |
| D2 | 0.311 | 66 | 0.000 | 0.818 | 66 | 0.000 |
| D3 | 0.273 | 66 | 0.000 | 0.838 | 66 | 0.000 |
| D4 | 0.199 | 66 | 0.000 | 0.906 | 66 | 0.000 |
| D5 | 0.176 | 66 | 0.000 | 0.896 | 66 | 0.000 |
| E1 | 0.287 | 66 | 0.000 | 0.724 | 66 | 0.000 |
| E2 | 0.355 | 66 | 0.000 | 0.793 | 66 | 0.000 |
| E3 | 0.217 | 66 | 0.000 | 0.900 | 66 | 0.000 |
| E4 | 0.231 | 66 | 0.000 | 0.900 | 66 | 0.000 |
| E5 | 0.356 | 66 | 0.000 | 0.754 | 66 | 0.000 |
| E6 | 0.241 | 66 | 0.000 | 0.850 | 66 | 0.000 |
| E7 | 0.247 | 66 | 0.000 | 0.870 | 66 | 0.000 |
| E8 | 0.285 | 66 | 0.000 | 0.858 | 66 | 0.000 |
| E9 | 0.274 | 66 | 0.000 | 0.856 | 66 | 0.000 |
| E10 | 0.351 | 66 | 0.000 | 0.769 | 66 | 0.000 |
| E11 | 0.225 | 66 | 0.000 | 0.846 | 66 | 0.000 |
| E12 | 0.220 | 66 | 0.000 | 0.900 | 66 | 0.000 |
| F1 | 0.379 | 66 | 0.000 | 0.755 | 66 | 0.000 |
| F2 | 0.323 | 66 | 0.000 | 0.833 | 66 | 0.000 |
| F3 | 0.220 | 66 | 0.000 | 0.836 | 66 | 0.000 |
| F4 | 0.204 | 66 | 0.000 | 0.891 | 66 | 0.000 |
| F5 | 0.317 | 66 | 0.000 | 0.776 | 66 | 0.000 |
| F6 | 0.320 | 66 | 0.000 | 0.827 | 66 | 0.000 |
| F7 | 0.265 | 66 | 0.000 | 0.770 | 66 | 0.000 |
| F8 | 0.343 | 66 | 0.000 | 0.737 | 66 | 0.000 |
| F9 | 0.264 | 66 | 0.000 | 0.778 | 66 | 0.000 |
| F10 | 0.278 | 66 | 0.000 | 0.830 | 66 | 0.000 |
| F11 | 0.247 | 66 | 0.000 | 0.858 | 66 | 0.000 |
| F12 | 0.296 | 66 | 0.000 | 0.780 | 66 | 0.000 |
| F13 | 0.236 | 66 | 0.000 | 0.868 | 66 | 0.000 |
| F14 | 0.182 | 66 | 0.000 | 0.881 | 66 | 0.000 |
| F15 | 0.247 | 66 | 0.000 | 0.892 | 66 | 0.000 |
| F16 | 0.207 | 66 | 0.000 | 0.899 | 66 | 0.000 |

## Appendix 27

### Tests of Normality:
### Chemistry Survey (Part B) – Pre-test 'Understanding' Data

| Item | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | p-value | Statistic | df | p-value |
| 1(a) | 0.374 | 65 | 0.000 | 0.635 | 65 | 0.000 |
| 1(b) | 0.362 | 65 | 0.000 | 0.702 | 65 | 0.000 |
| 2(a) | 0.442 | 65 | 0.000 | 0.637 | 65 | 0.000 |
| 2(b) | 0.472 | 65 | 0.000 | 0.537 | 65 | 0.000 |
| 2(c) | 0.520 | 65 | 0.000 | 0.266 | 65 | 0.000 |
| 3 | 0.420 | 65 | 0.000 | 0.647 | 65 | 0.000 |
| 4 | 0.332 | 65 | 0.000 | 0.823 | 65 | 0.000 |
| 5(a) | 0.472 | 65 | 0.000 | 0.497 | 65 | 0.000 |
| 5(b) | 0.326 | 65 | 0.000 | 0.794 | 65 | 0.000 |
| 6(a) | 0.484 | 65 | 0.000 | 0.404 | 65 | 0.000 |
| 6(b) | 0.287 | 65 | 0.000 | 0.775 | 65 | 0.000 |
| 7(a) | 0.219 | 65 | 0.000 | 0.887 | 65 | 0.000 |
| 7(b) | 0.251 | 65 | 0.000 | 0.859 | 65 | 0.000 |
| 8(a) | 0.221 | 65 | 0.000 | 0.872 | 65 | 0.000 |
| 8(b) | 0.296 | 65 | 0.000 | 0.721 | 65 | 0.000 |
| 9(a) | 0.337 | 65 | 0.000 | 0.805 | 65 | 0.000 |
| 9(b) | 0.487 | 65 | 0.000 | 0.404 | 65 | 0.000 |
| 10(a) | 0.359 | 65 | 0.000 | 0.764 | 65 | 0.000 |
| 10(b) | 0.402 | 65 | 0.000 | 0.700 | 65 | 0.000 |
| 11 | 0.242 | 65 | 0.000 | 0.842 | 65 | 0.000 |
| 12 | 0.419 | 65 | 0.000 | 0.608 | 65 | 0.000 |
| 13 | 0.375 | 65 | 0.000 | 0.671 | 65 | 0.000 |
| 14 | 0.404 | 65 | 0.000 | 0.623 | 65 | 0.000 |
| 15 | 0.413 | 65 | 0.000 | 0.652 | 65 | 0.000 |

df = degrees of freedom

## Appendix 28

### Tests of Normality:
### Chemistry Survey (Part B) – Post-test 'Understanding' Data

| | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | p-value | Statistic | df | p-value |
| 1(a) | 0.295 | 65 | 0.000 | 0.781 | 65 | 0.000 |
| 1(b) | 0.188 | 65 | 0.000 | 0.858 | 65 | 0.000 |
| 2(a) | 0.324 | 65 | 0.000 | 0.707 | 65 | 0.000 |
| 2(b) | 0.267 | 65 | 0.000 | 0.809 | 65 | 0.000 |
| 2(c) | 0.406 | 65 | 0.000 | 0.520 | 65 | 0.000 |
| 3 | 0.476 | 65 | 0.000 | 0.461 | 65 | 0.000 |
| 4 | 0.351 | 65 | 0.000 | 0.788 | 65 | 0.000 |
| 5(a) | 0.319 | 65 | 0.000 | 0.808 | 65 | 0.000 |
| 5(b) | 0.331 | 65 | 0.000 | 0.774 | 65 | 0.000 |
| 6(a) | 0.237 | 65 | 0.000 | 0.803 | 65 | 0.000 |
| 6(b) | 0.345 | 65 | 0.000 | 0.689 | 65 | 0.000 |
| 7(a) | 0.233 | 65 | 0.000 | 0.849 | 65 | 0.000 |
| 7(b) | 0.279 | 65 | 0.000 | 0.755 | 65 | 0.000 |
| 8(a) | 0.345 | 65 | 0.000 | 0.736 | 65 | 0.000 |
| 8(b) | 0.366 | 65 | 0.000 | 0.633 | 65 | 0.000 |
| 9(a) | 0.285 | 65 | 0.000 | 0.781 | 65 | 0.000 |
| 9(b) | 0.459 | 65 | 0.000 | 0.556 | 65 | 0.000 |
| 10(a) | 0.366 | 65 | 0.000 | 0.743 | 65 | 0.000 |
| 10(b) | 0.343 | 65 | 0.000 | 0.733 | 65 | 0.000 |
| 11 | 0.260 | 65 | 0.000 | 0.825 | 65 | 0.000 |
| 12 | 0.464 | 65 | 0.000 | 0.552 | 65 | 0.000 |
| 13 | 0.330 | 65 | 0.000 | 0.722 | 65 | 0.000 |
| 14 | 0.279 | 65 | 0.000 | 0.728 | 65 | 0.000 |
| 15 | 0.358 | 65 | 0.000 | 0.799 | 65 | 0.000 |

df = degrees of freedom

## Appendix 29

### Tests of Normality:
### Difference between Pre-test and Post-test Scores of 'Understanding' Data

| Difference | Kolmogorov-Smirnov | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | p-value | Statistic | df | p-value |
| Diff 1(a) | 0.260 | 65 | 0.000 | 0.888 | 65 | 0.000 |
| Diff 1(b) | 0.182 | 65 | 0.000 | 0.938 | 65 | 0.003 |
| Diff 2(a) | 0.314 | 65 | 0.000 | 0.799 | 65 | 0.000 |
| Diff 2(b) | 0.241 | 65 | 0.000 | 0.906 | 65 | 0.000 |
| Diff 2(c) | 0.373 | 65 | 0.000 | 0.654 | 65 | 0.000 |
| Diff 3 | 0.370 | 65 | 0.000 | 0.769 | 65 | 0.000 |
| Diff 4 | 0.250 | 65 | 0.000 | 0.898 | 65 | 0.000 |
| Diff 5(a) | 0.278 | 65 | 0.000 | 0.880 | 65 | 0.000 |
| Diff 5(b) | 0.211 | 65 | 0.000 | 0.888 | 65 | 0.000 |
| Diff 6(a) | 0.261 | 65 | 0.000 | 0.828 | 65 | 0.000 |
| Diff 6(b) | 0.245 | 65 | 0.000 | 0.885 | 65 | 0.000 |
| Diff 7(a) | 0.151 | 65 | 0.001 | 0.955 | 65 | 0.020 |
| Diff 7(b) | 0.161 | 65 | 0.000 | 0.945 | 65 | 0.006 |
| Diff 8(a) | 0.188 | 65 | 0.000 | 0.920 | 65 | 0.000 |
| Diff 8(b) | 0.221 | 65 | 0.000 | 0.903 | 65 | 0.000 |
| Diff 9(a) | 0.234 | 65 | 0.000 | 0.924 | 65 | 0.001 |
| Diff 9(b) | 0.421 | 65 | 0.000 | 0.689 | 65 | 0.000 |
| Diff 10(a) | 0.345 | 65 | 0.000 | 0.792 | 65 | 0.000 |
| Diff 10(b) | 0.232 | 65 | 0.000 | 0.895 | 65 | 0.000 |
| Diff 11 | 0.187 | 65 | 0.000 | 0.936 | 65 | 0.002 |
| Diff 12 | 0.321 | 65 | 0.000 | 0.829 | 65 | 0.000 |
| Diff 13 | 0.236 | 65 | 0.000 | 0.875 | 65 | 0.000 |
| Diff 14 | 0.197 | 65 | 0.000 | 0.865 | 65 | 0.000 |
| Diff 15 | 0.229 | 65 | 0.000 | 0.918 | 65 | 0.000 |

df = degrees of freedom

## Appendix 30

## Statistics on Chemistry Survey (Part A) Pre-test Data - Part 1

(using Mann-Whitney U test, 2-tailed)

| Group | | N | Mean | Std. Deviation | z-value | p-value |
|---|---|---|---|---|---|---|
| **B1** | GC group | 33 | 2.79 | 0.781 | - 1.054 | 0.292 |
| | Non GC group | 36 | 2.94 | 0.791 | | |
| **B2** | GC group | 33 | 1.42 | 0.708 | - 1.012 | 0.311 |
| | Non GC group | 36 | 1.64 | 0.867 | | |
| **B3** | GC group | 33 | 1.97 | 0.918 | - 0.120 | 0.904 |
| | Non GC group | 36 | 1.94 | 0.955 | | |
| **B4** | GC group | 33 | 1.12 | 0.992 | - 0.241 | 0.810 |
| | Non GC group | 36 | 1.28 | 1.256 | | |
| **B5** | GC group | 33 | 2.64 | 1.141 | - 1.444 | 0.149 |
| | Non GC group | 36 | 3.03 | 0.878 | | |
| **B6** | GC group | 33 | 3.39 | 0.609 | - 0.568 | 0.570 |
| | Non GC group | 36 | 3.17 | 1.000 | | |
| **B7** | GC group | 33 | 2.36 | 0.822 | - 1.026 | 0.305 |
| | Non GC group | 36 | 2.17 | 0.910 | | |
| **B8** | GC group | 33 | 3.09 | 1.011 | - 1.212 | 0.226 |
| | Non GC group | 36 | 3.39 | 0.728 | | |
| **B9** | GC group | 33 | 2.61 | 0.788 | - 1.305 | 0.760 |
| | Non GC group | 36 | 2.53 | 0.910 | | |
| **B10** | GC group | 33 | 2.82 | 0.846 | - 0.178 | 0.858 |
| | Non GC group | 36 | 2.89 | 0.820 | | |
| **C1** | GC group | 33 | 3.00 | 1.031 | - 0.229 | 0.818 |
| | Non GC group | 36 | 3.06 | 0.984 | | |
| **C2** | GC group | 33 | 2.73 | 0.876 | - 0.803 | 0.422 |
| | Non GC group | 36 | 2.92 | 0.841 | | |
| **C3** | GC group | 33 | 1.64 | 0.822 | - 1.006 | 0.314 |
| | Non GC group | 36 | 1.42 | 1.052 | | |
| **C4** | GC group | 33 | 3.09 | 0.723 | - 0.167 | 0.867 |
| | Non GC group | 36 | 3.08 | 0.692 | | |
| **C5** | GC group | 33 | 2.45 | 0.971 | - 0.058 | 0.954 |
| | Non GC group | 36 | 2.47 | 0.878 | | |
| **D1** | GC group | 33 | 3.42 | 0.751 | - 0.658 | 0.510 |
| | Non GC group | 36 | 3.25 | 0.937 | | |
| **D2** | GC group | 33 | 3.39 | 0.659 | - 0.499 | 0.618 |
| | Non GC group | 36 | 3.17 | 1.028 | | |
| **D3** | GC group | 33 | 2.94 | 0.899 | - 1.172 | 0.241 |
| | Non GC group | 36 | 3.17 | 0.878 | | |
| **D4** | GC group | 33 | 2.55 | 0.905 | - 1.007 | 0.314 |
| | Non GC group | 36 | 2.28 | 1.059 | | |
| **D5** | GC group | 33 | 1.12 | 1.219 | - 1.121 | 0.262 |
| | Non GC group | 36 | 0.75 | 0.841 | | |

## Appendix 30 (continued)

## Statistics on Chemistry Survey (Part A) Pre-test Data - Part 2

(using Mann-Whitney U test, 2-tailed)

| Group | | N | Mean | Std. Deviation | z-value | p-value |
|---|---|---|---|---|---|---|
| **E1** | GC group | 33 | 3.30 | 0.585 | - 0.607 | 0.544 |
| | Non GC group | 36 | 3.03 | 1.082 | | |
| **E2** | GC group | 33 | 2.82 | 0.727 | - 0.154 | 0.877 |
| | Non GC group | 36 | 2.78 | 0.959 | | |
| **E3** | GC group | 33 | 2.48 | 0.906 | - 1.236 | 0.216 |
| | Non GC group | 36 | 2.14 | 1.046 | | |
| **E4** | GC group | 33 | 2.67 | 0.957 | - 1.602 | 0.109 |
| | Non GC group | 36 | 2.22 | 1.149 | | |
| **E5** | GC group | 33 | 2.79 | 0.740 | - 0.032 | 0.975 |
| | Non GC group | 36 | 2.72 | 0.974 | | |
| **E6** | GC group | 33 | 1.88 | 0.992 | - 0.477 | 0.634 |
| | Non GC group | 36 | 1.97 | 1.000 | | |
| **E7** | GC group | 33 | 2.55 | 0.869 | - 1.480 | 0.139 |
| | Non GC group | 36 | 2.86 | 0.961 | | |
| **E8** | GC group | 33 | 2.27 | 1.126 | - 0.545 | 0.585 |
| | Non GC group | 36 | 2.11 | 1.304 | | |
| **E9** | GC group | 33 | 2.27 | 0.719 | - 0.529 | 0.597 |
| | Non GC group | 36 | 2.42 | 0.770 | | |
| **E10** | GC group | 33 | 3.12 | 0.650 | - 0.278 | 0.781 |
| | Non GC group | 36 | 3.03 | 0.810 | | |
| **E11** | GC group | 33 | 2.24 | 0.867 | - 2.573 | **0.010 sig** |
| | Non GC group | 36 | 2.83 | 1.183 | | |
| **E12** | GC group | 33 | 1.55 | 1.063 | - 2.905 | **0.004 sig** |
| | Non GC group | 36 | 2.44 | 1.252 | | |

## Appendix 31

## Statistics on Chemistry Survey (Part A) Post-test Data - Part 1

(using Mann-Whitney U test, 2-tailed)

| Group | | N | Mean | Std. Deviation | z-value | p-value |
|---|---|---|---|---|---|---|
| **B1** | GC group | 30 | 2.57 | 0.679 | - 0.329 | 0.742 |
| | Non GC group | 36 | 2.56 | 0.939 | | |
| **B2** | GC group | 30 | 1.50 | 0.820 | - 0.056 | 0.956 |
| | Non GC group | 36 | 1.58 | 0.841 | | |
| **B3** | GC group | 30 | 2.20 | 0.805 | - 1.088 | 0.277 |
| | Non GC group | 36 | 1.97 | 0.845 | | |
| **B4** | GC group | 30 | 1.77 | 1.006 | - 0.458 | 0.647 |
| | Non GC group | 36 | 1.94 | 1.351 | | |
| **B5** | GC group | 30 | 2.83 | 0.913 | - 1.385 | 0.166 |
| | Non GC group | 36 | 3.14 | 0.762 | | |
| **B6** | GC group | 30 | 3.07 | 0.583 | - 0.489 | 0.625 |
| | Non GC group | 36 | 3.11 | 0.785 | | |
| **B7** | GC group | 30 | 2.23 | 0.898 | - 0.557 | 0.578 |
| | Non GC group | 36 | 2.14 | 0.833 | | |
| **B8** | GC group | 30 | 2.80 | 0.961 | - 0.906 | 0.365 |
| | Non GC group | 36 | 2.50 | 1.254 | | |
| **B9** | GC group | 30 | 2.70 | 0.750 | - 2.103 | **0.035 sig** |
| | Non GC group | 36 | 3.11 | 0.919 | | |
| **B10** | GC group | 30 | 2.73 | 1.048 | - 1.220 | 0.222 |
| | Non GC group | 36 | 3.08 | 0.770 | | |
| **C1** | GC group | 30 | 3.13 | 0.681 | - 0.643 | 0.520 |
| | Non GC group | 36 | 3.17 | 0.910 | | |
| **C2** | GC group | 30 | 2.50 | 0.861 | - 1.234 | 0.217 |
| | Non GC group | 36 | 2.81 | 0.856 | | |
| **C3** | GC group | 30 | 1.63 | 1.066 | - 0.589 | 0.556 |
| | Non GC group | 36 | 1.47 | 1.055 | | |
| **C4** | GC group | 30 | 2.90 | 0.548 | - 1.006 | 0.314 |
| | Non GC group | 36 | 3.06 | 0.674 | | |
| **C5** | GC group | 30 | 2.50 | 0.861 | - 1.818 | 0.069 |
| | Non GC group | 36 | 2.92 | 0.906 | | |
| **D1** | GC group | 30 | 2.70 | 0.988 | - 0.785 | 0.432 |
| | Non GC group | 36 | 2.75 | 1.339 | | |
| **D2** | GC group | 30 | 2.80 | 0.887 | - 0.279 | 0.780 |
| | Non GC group | 36 | 2.69 | 1.142 | | |
| **D3** | GC group | 30 | 2.83 | 0.913 | - 0.783 | 0.434 |
| | Non GC group | 36 | 2.92 | 1.180 | | |
| **D4** | GC group | 30 | 2.27 | 1.015 | - 0.683 | 0.495 |
| | Non GC group | 36 | 2.08 | 1.180 | | |
| **D5** | GC group | 30 | 1.27 | 1.048 | - 1.490 | 0.136 |
| | Non GC group | 36 | 1.67 | 1.171 | | |

**Appendix 31 (continued)**

## Statistics on Chemistry Survey (Part A) Post-test Data - Part 2

(using Mann-Whitney U test, 2-tailed)

| Group | | N | Mean | Std. Deviation | z-value | p-value |
|---|---|---|---|---|---|---|
| E1 | GC group | 30 | 3.20 | 0.805 | - 0.450 | 0.653 |
| | Non GC group | 36 | 3.25 | 0.874 | | |
| E2 | GC group | 30 | 2.87 | 0.681 | - 0.936 | 0.349 |
| | Non GC group | 36 | 2.67 | 0.793 | | |
| E3 | GC group | 30 | 2.27 | 0.907 | - 1.148 | 0.251 |
| | Non GC group | 36 | 2.03 | 1.028 | | |
| E4 | GC group | 30 | 2.33 | 0.959 | - 0.027 | 0.979 |
| | Non GC group | 36 | 2.28 | 1.137 | | |
| E5 | GC group | 30 | 2.90 | 0.759 | - 0.737 | 0.461 |
| | Non GC group | 36 | 2.78 | 0.832 | | |
| E6 | GC group | 30 | 2.00 | 0.830 | - 0.123 | 0.902 |
| | Non GC group | 36 | 1.94 | 0.924 | | |
| E7 | GC group | 30 | 2.30 | 1.208 | - 1.346 | 0.178 |
| | Non GC group | 36 | 2.72 | 1.111 | | |
| E8 | GC group | 30 | 2.03 | 1.066 | - 1.108 | 0.268 |
| | Non GC group | 36 | 2.31 | 1.142 | | |
| E9 | GC group | 30 | 2.57 | 0.679 | - 1.050 | 0.294 |
| | Non GC group | 36 | 2.31 | 1.009 | | |
| E10 | GC group | 30 | 3.03 | 0.718 | - 0.951 | 0.341 |
| | Non GC group | 36 | 2.92 | 0.692 | | |
| E11 | GC group | 30 | 2.53 | 1.167 | - 2.003 | **0.045 sig** |
| | Non GC group | 36 | 3.08 | 1.079 | | |
| E12 | GC group | 30 | 2.00 | 1.287 | - 1.973 | **0.049 sig** |
| | Non GC group | 36 | 2.64 | 1.073 | | |
| F1 | GC group | 30 | 3.00 | 0.455 | - 3.202 | **0.001 sig** |
| | Non GC group | 36 | 2.44 | 0.773 | | |
| F2 | GC group | 30 | 3.27 | 0.450 | - 4.989 | **0.000 sig** |
| | Non GC group | 36 | 2.28 | 0.849 | | |
| F3 | GC group | 30 | 2.03 | 0.850 | - 0.350 | 0.726 |
| | Non GC group | 36 | 1.94 | 0.754 | | |
| F4 | GC group | 30 | 1.97 | 0.999 | - 1.273 | 0.203 |
| | Non GC group | 36 | 2.25 | 0.841 | | |
| F5 | GC group | 30 | 2.70 | 0.596 | - 1.669 | 0.095 |
| | Non GC group | 36 | 2.42 | 0.604 | | |
| F6 | GC group | 30 | 3.13 | 0.819 | - 2.944 | **0.003 sig** |
| | Non GC group | 36 | 2.58 | 0.806 | | |
| F7 | GC group | 30 | 3.40 | 0.563 | - 0.594 | 0.552 |
| | Non GC group | 36 | 3.25 | 0.770 | | |
| F8 | GC group | 30 | 3.37 | 0.556 | - 0.973 | 0.330 |
| | Non GC group | 36 | 3.22 | 0.591 | | |
| F9 | GC group | 30 | 3.20 | 0.610 | - 1.169 | 0.243 |
| | Non GC group | 36 | 3.36 | 0.723 | | |
| F10 | GC group | 30 | 3.10 | 0.548 | - 1.997 | **0.046 sig** |
| | Non GC group | 36 | 2.75 | 0.806 | | |
| F11 | GC group | 30 | 2.83 | 0.986 | - 0.879 | 0.380 |
| | Non GC group | 36 | 2.67 | 0.862 | | |
| F12 | GC group | 30 | 3.27 | 0.691 | - 0.720 | 0.471 |
| | Non GC group | 36 | 3.17 | 0.609 | | |
| F13 | GC group | 30 | 1.43 | 0.774 | - 2.789 | **0.005 sig** |
| | Non GC group | 36 | 2.06 | 0.955 | | |
| F14 | GC group | 30 | 0.97 | 0.928 | - 2.207 | **0.027 sig** |
| | Non GC group | 36 | 1.56 | 1.107 | | |
| F15 | GC group | 30 | 1.67 | 0.884 | - 3.194 | **0.001 sig** |
| | Non GC group | 36 | 2.36 | 0.798 | | |
| F16 | GC group | 30 | 1.37 | 0.809 | - 3.596 | **0.000 sig** |
| | Non GC group | 36 | 2.28 | 1.031 | | |

## Appendix 32

## Cronbach's Alpha Test of Reliability on Part A of Chemistry Survey

### Cognitive Attitudes Towards Chemistry in Society (Dimension 1)

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No of Items |
|---|---|---|
| 0.722 | 0.724 | 3 |

Inter-Item Correlation Matrix

| Item | C3 | C4 | C5 |
|---|---|---|---|
| C3 | 1.000 | 0.478 | 0.576 |
| C4 | 0.478 | 1.000 | 0.345 |
| C5 | 0.576 | 0.345 | 1.000 |

### Cognitive Attitudes Towards learning Chemistry at School (Dimension 2)

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No of Items |
|---|---|---|
| 0.717 | 0.718 | 3 |

Inter-Item Correlation Matrix

| Item | B2 | B9 | B10 |
|---|---|---|---|
| B2 | 1.000 | 0.506 | 0.508 |
| B9 | 0.506 | 1.000 | 0.361 |
| B10 | 0.508 | 0.361 | 1.000 |

### Affective Attitudes towards learning Chemistry Theory at School (Dimension 3)

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No of Items |
|---|---|---|
| 0.733 | 0.738 | 4 |

Inter-Item Correlation Matrix

| Item | B1 | B4 | B5 | B8 |
|---|---|---|---|---|
| B1 | 1.000 | 0.470 | 0.470 | 0.238 |
| B4 | 0.470 | 1.000 | 0.395 | 0.400 |
| B5 | 0.470 | 0.395 | 1.000 | 0.509 |
| B8 | 0.238 | 0.400 | 0.509 | 1.000 |

## Appendix 32 (continued)

## Cronbach's Alpha Test of Reliability on Part A of Chemistry Survey

### Behavioural Attitudes towards studying Chemistry (Dimension 5)

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No of Items |
|---|---|---|
| 0.818 | 0.820 | 5 |

Inter-Item Correlation Matrix

| Item | D1 | D2 | D3 | D4 | D5 |
|---|---|---|---|---|---|
| D1 | 1.000 | 0.789 | 0.537 | 0.283 | 0.488 |
| D2 | 0.789 | 1.000 | 0.677 | 0.296 | 0.621 |
| D3 | 0.537 | 0.677 | 1.000 | 0.399 | 0.453 |
| D4 | 0.283 | 0.296 | 0.399 | 1.000 | 0.227 |
| D5 | 0.488 | 0.621 | 0.453 | 0.227 | 1.000 |

### Cognitive Attitudes towards Green Chemistry in Society (Dimension 6)

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No of Items |
|---|---|---|
| 0.786 | 0.799 | 13 |

Inter-Item Correlation Matrix

| Item | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | F13 | F14 | F15 | F16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F4 | 1.000 | 0.119 | 0.229 | 0.038 | 0.038 | 0.132 | 0.193 | 0.035 | -0.034 | 0.286 | 0.262 | 0.142 | 0.018 |
| F5 | 0.119 | 1.000 | 0.265 | 0.278 | 0.159 | 0.098 | 0.220 | 0.227 | 0.170 | 0.131 | 0.245 | 0.018 | -0.022 |
| F6 | 0.229 | 0.265 | 1.000 | 0.278 | 0.288 | 0.406 | 0.302 | 0.003 | 0.205 | 0.303 | 0.422 | 0.330 | 0.305 |
| F7 | 0.038 | 0.278 | 0.278 | 1.000 | 0.507 | 0.500 | 0.374 | 0.157 | 0.508 | 0.103 | 0.446 | 0.299 | -0.041 |
| F8 | 0.038 | 0.159 | 0.288 | 0.507 | 1.000 | 0.497 | 0.362 | 0.026 | 0.413 | 0.164 | 0.364 | 0.322 | 0.191 |
| F9 | 0.132 | 0.098 | 0.406 | 0.500 | 0.497 | 1.000 | 0.500 | 0.172 | 0.565 | 0.042 | 0.268 | 0.224 | -0.013 |
| F10 | 0.193 | 0.220 | 0.302 | 0.374 | 0.362 | 0.500 | 1.000 | 0.245 | 0.508 | 0.171 | 0.308 | 0.303 | 0.058 |
| F11 | 0.035 | 0.227 | 0.003 | 0.157 | 0.026 | 0.172 | 0.245 | 1.000 | 0.198 | 0.125 | 0.112 | 0.116 | -0.076 |
| F12 | -0.034 | 0.170 | 0.205 | 0.508 | 0.413 | 0.565 | 0.508 | 0.198 | 1.000 | 0.047 | 0.247 | 0.281 | 0.048 |
| F13 | 0.286 | 0.131 | 0.303 | 0.103 | 0.164 | 0.042 | 0.171 | 0.125 | 0.047 | 1.000 | 0.443 | 0.308 | 0.304 |
| F14 | 0.262 | 0.245 | 0.422 | 0.446 | 0.364 | 0.268 | 0.308 | 0.112 | 0.247 | 0.443 | 1.000 | 0.596 | 0.385 |
| F15 | 0.142 | 0.018 | 0.330 | 0.299 | 0.322 | 0.224 | 0.303 | 0.116 | 0.281 | 0.308 | 0.596 | 1.000 | 0.517 |
| F16 | 0.018 | -0.022 | 0.305 | -0.041 | 0.191 | -0.013 | 0.058 | -0.076 | 0.048 | 0.304 | 0.385 | 0.517 | 1.000 |

## Appendix 32 (continued)

## Cronbach's Alpha Test of Reliability on Part A of Chemistry Survey

### Cognitive and Affective Attitudes towards Green Chemistry at School (Dimensions 7, 8, 9)

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | No of Items |
|---|---|---|
| 0.717 | 0.729 | 12 |

Inter-Item Correlation Matrix

| Item | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | E9 | E10 | E11 | E12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E1 | 1.000 | 0.131 | 0.191 | 0.442 | 0.125 | 0.313 | 0.395 | 0.127 | 0.109 | 0.060 | 0.104 | 0.051 |
| E2 | 0.131 | 1.000 | 0.158 | 0.232 | 0.147 | 0.011 | 0.185 | 0.314 | 0.183 | 0.486 | 0.228 | 0.065 |
| E3 | 0.191 | 0.158 | 1.000 | 0.653 | 0.375 | 0.426 | 0.220 | -0.045 | 0.372 | 0.234 | 0.115 | 0.060 |
| E4 | 0.442 | 0.232 | 0.653 | 1.000 | 0.225 | 0.333 | 0.370 | 0.115 | 0.154 | 0.226 | 0.217 | 0.090 |
| E5 | 0.125 | 0.147 | 0.375 | 0.225 | 1.000 | 0.329 | 0.176 | -0.019 | 0.320 | 0.369 | 0.087 | 0.107 |
| E6 | 0.313 | 0.011 | 0.426 | 0.333 | 0.329 | 1.000 | 0.110 | 0.069 | 0.163 | 0.178 | -0.068 | 0.132 |
| E7 | 0.395 | 0.185 | 0.220 | 0.370 | 0.176 | 0.110 | 1.000 | 0.234 | 0.205 | 0.038 | 0.256 | 0.096 |
| E8 | 0.127 | 0.314 | -0.045 | 0.115 | -0.019 | 0.069 | 0.234 | 1.000 | 0.149 | 0.241 | -0.091 | -0.259 |
| E9 | 0.109 | 0.183 | 0.372 | 0.154 | 0.320 | 0.163 | 0.205 | 0.149 | 1.000 | 0.204 | 0.180 | 0.164 |
| E10 | 0.060 | 0.486 | 0.234 | 0.226 | 0.369 | 0.178 | 0.038 | 0.241 | 0.204 | 1.000 | 0.185 | 0.212 |
| E11 | 0.104 | 0.228 | 0.115 | 0.217 | 0.087 | -0.068 | 0.256 | -0.091 | 0.180 | 0.185 | 1.000 | 0.144 |
| E12 | 0.051 | 0.065 | 0.050 | 0.090 | 0.107 | 0.132 | 0.096 | -0.259 | 0.164 | 0.212 | 0.144 | 1.000 |

## Appendix 33

# Chemistry Survey (Part B)

### Data from Pre-test B1 – non-GC Group (N=35)

| Question | SU (Level 4) | | PU (Level 3) | | PUSA (Level 2) | | SA (Level 1) | | NU (Level 0) | | Mean Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | % | n | % | n | % | n | % | n | % | |
| 1 (a) | 8 | 23 | 24 | 69 | 2 | 6 | 0 | 0 | 1 | 3 | **3.09** |
| 1 (b) | 1 | 3 | 8 | 23 | 3 | 9 | 5 | 14 | 18 | 51 | **1.11** |
| 2 (a) | 1 | 3 | 0 | 0 | 0 | 0 | 30 | 86 | 4 | 11 | **0.97** |
| 2 (b) | 0 | 0 | 2 | 6 | 6 | 17 | 2 | 6 | 25 | 71 | **0.57** |
| 2 (c) | 0 | 0 | 1 | 3 | 0 | 0 | 4 | 11 | 30 | 86 | **0.20** |
| 3 | 0 | 0 | 23 | 66 | 8 | 23 | 3 | 9 | 1 | 3 | **2.51** |
| 4 | 4 | 11 | 19 | 54 | 5 | 14 | 4 | 11 | 3 | 9 | **2.49** |
| 5 (a) | 0 | 0 | 5 | 14 | 0 | 0 | 25 | 71 | 5 | 14 | **1.14** |
| 5 (b) | 4 | 11 | 16 | 46 | 4 | 11 | 3 | 9 | 8 | 23 | **2.14** |
| 6 (a) | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 11 | 31 | 89 | **0.11** |
| 6 (b) | 7 | 20 | 16 | 46 | 2 | 6 | 2 | 6 | 8 | 23 | **2.34** |
| 7 (a) | 1 | 3 | 12 | 34 | 9 | 26 | 8 | 23 | 5 | 14 | **1.89** |
| 7 (b) | 8 | 23 | 5 | 14 | 5 | 14 | 9 | 26 | 8 | 23 | **1.89** |
| 8 (a) | 6 | 17 | 15 | 43 | 10 | 29 | 2 | 6 | 2 | 6 | **2.60** |
| 8 (b) | 15 | 43 | 11 | 31 | 3 | 9 | 3 | 9 | 3 | 9 | **2.91** |
| 9 (a) | 10 | 29 | 16 | 46 | 0 | 0 | 7 | 20 | 2 | 6 | **2.71** |
| 9 (b) | 0 | 0 | 1 | 3 | 0 | 0 | 5 | 14 | 29 | 83 | **0.24** |
| 10 (a) | 7 | 20 | 16 | 46 | 3 | 9 | 3 | 9 | 6 | 17 | **2.43** |
| 10 (b) | 7 | 20 | 22 | 63 | 1 | 3 | 2 | 6 | 3 | 9 | **2.80** |
| 11 | 3 | 9 | 9 | 26 | 3 | 9 | 13 | 37 | 7 | 20 | **1.66** |
| 12 | 0 | 0 | 24 | 69 | 4 | 11 | 4 | 11 | 3 | 9 | **2.40** |
| 13 | 1 | 3 | 18 | 51 | 11 | 31 | 2 | 6 | 3 | 9 | **2.34** |
| 14 | 0 | 0 | 13 | 37 | 0 | 0 | 3 | 9 | 19 | 54 | **1.20** |
| 15 | 0 | 0 | 19 | 54 | 4 | 11 | 8 | 23 | 4 | 11 | **2.09** |

Key:

SU = sound understanding; PU = partial understanding; PUSA = partial understanding with specific alternative conception; SA = specific alternative conception; NU = no understanding; N = total number of respondents; n = number of students per level of understanding.

**Appendix 34**

## Chemistry Survey (Part B)

### Data from Pre-test B1 – GC Group (N=32)

| Question | SU (Level 4) | | PU (Level 3) | | PUSA (Level 2) | | SA (Level 1) | | NU (Level 0) | | Mean Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | % | n | % | n | % | n | % | n | % | |
| 1 (a) | 4 | 13 | 26 | 81 | 2 | 6 | 0 | 0 | 0 | 0 | **3.06** |
| 1 (b) | 0 | 0 | 4 | 13 | 2 | 6 | 3 | 9 | 23 | 72 | **0.61** |
| 2 (a) | 10 | 31 | 0 | 0 | 0 | 0 | 14 | 44 | 7 | 22 | **1.69** |
| 2 (b) | 0 | 0 | 1 | 3 | 2 | 6 | 2 | 6 | 27 | 84 | **0.28** |
| 2 (c) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 31 | 89 | **0.00** |
| 3 | 3 | 9 | 25 | 72 | 3 | 9 | 0 | 0 | 1 | 3 | **2.91** |
| 4 | 2 | 6 | 19 | 59 | 7 | 22 | 4 | 13 | 0 | 0 | **2.59** |
| 5 (a) | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 100 | 0 | 0 | **1.00** |
| 5 (b) | 1 | 3 | 19 | 59 | 4 | 13 | 2 | 6 | 6 | 19 | **2.22** |
| 6 (a) | 1 | 3 | 0 | 0 | 2 | 6 | 3 | 9 | 26 | 81 | **0.34** |
| 6 (b) | 4 | 13 | 9 | 28 | 1 | 3 | 0 | 0 | 18 | 56 | **1.41** |
| 7 (a) | 2 | 6 | 9 | 28 | 5 | 16 | 14 | 44 | 2 | 6 | **1.84** |
| 7 (b) | 4 | 13 | 4 | 13 | 3 | 9 | 14 | 44 | 7 | 22 | **1.50** |
| 8 (a) | 10 | 31 | 10 | 31 | 11 | 34 | 1 | 3 | 0 | 0 | **2.91** |
| 8 (b) | 18 | 56 | 12 | 34 | 0 | 0 | 0 | 0 | 2 | 6 | **3.38** |
| 9 (a) | 5 | 16 | 15 | 43 | 1 | 3 | 3 | 9 | 8 | 25 | **2.19** |
| 9 (b) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 6 | 30 | 86 | **0.06** |
| 10 (a) | 7 | 22 | 19 | 59 | 1 | 3 | 0 | 0 | 5 | 16 | **2.72** |
| 10 (b) | 6 | 19 | 20 | 57 | 1 | 3 | 1 | 3 | 4 | 13 | **2.72** |
| 11 | 0 | 0 | 11 | 34 | 2 | 6 | 8 | 25 | 11 | 34 | **1.41** |
| 12 | 0 | 0 | 23 | 72 | 6 | 19 | 1 | 3 | 2 | 6 | **2.56** |
| 13 | 0 | 0 | 26 | 81 | 3 | 9 | 0 | 0 | 3 | 9 | **2.63** |
| 14 | 0 | 0 | 6 | 19 | 1 | 3 | 0 | 0 | 25 | 78 | **0.63** |
| 15 | 0 | 0 | 27 | 84 | 1 | 3 | 3 | 9 | 1 | 3 | **2.69** |

Key:

SU = sound understanding; PU = partial understanding; PUSA = partial understanding with specific alternative conception; SA = specific alternative conception; NU = no understanding; N = total number of respondents; n = number of students per level of understanding.

## Appendix 35

# Chemistry Survey (Part B)

### Data from Post-test B2 – non-GC Group (N=36)

| Question | SU (Level 4) | | PU (Level 3) | | PUSA (Level 2) | | SA (Level 1) | | NU (Level 0) | | Mean Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | % | n | % | n | % | n | % | n | % | |
| 1 (a) | 4 | 11 | 28 | 78 | 3 | 8 | 1 | 3 | 0 | 0 | **3.00** |
| 1 (b) | 0 | 0 | 7 | 19 | 5 | 14 | 8 | 22 | 16 | 44 | **1.08** |
| 2 (a) | 13 | 36 | 0 | 0 | 0 | 0 | 19 | 53 | 4 | 11 | **1.97** |
| 2 (b) | 0 | 0 | 2 | 6 | 3 | 8 | 4 | 11 | 27 | 75 | **0.44** |
| 2 (c) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 6 | 34 | 94 | **0.06** |
| 3 | 0 | 0 | 32 | 89 | 2 | 6 | 2 | 6 | 0 | 0 | **2.83** |
| 4 | 1 | 3 | 20 | 56 | 9 | 25 | 6 | 17 | 0 | 0 | **2.44** |
| 5 (a) | 1 | 3 | 8 | 22 | 2 | 6 | 22 | 61 | 3 | 8 | **1.50** |
| 5 (b) | 5 | 14 | 22 | 61 | 8 | 22 | 0 | 0 | 1 | 3 | **2.81** |
| 6 (a) | 0 | 0 | 5 | 14 | 1 | 3 | 10 | 28 | 20 | 56 | **0.75** |
| 6 (b) | 6 | 17 | 23 | 64 | 1 | 3 | 3 | 8 | 3 | 8 | **2.72** |
| 7 (a) | 3 | 8 | 7 | 19 | 2 | 6 | 21 | 58 | 3 | 8 | **1.61** |
| 7 (b) | 9 | 25 | 7 | 19 | 1 | 3 | 8 | 22 | 11 | 31 | **1.86** |
| 8 (a) | 14 | 39 | 9 | 25 | 13 | 36 | 0 | 0 | 0 | 0 | **3.03** |
| 8 (b) | 20 | 56 | 8 | 22 | 2 | 6 | 3 | 8 | 3 | 8 | **3.08** |
| 9 (a) | 10 | 28 | 18 | 50 | 5 | 14 | 1 | 3 | 2 | 6 | **2.92** |
| 9 (b) | 2 | 6 | 0 | 0 | 1 | 3 | 1 | 3 | 32 | 89 | **0.31** |
| 10 (a) | 4 | 11 | 23 | 64 | 2 | 6 | 4 | 11 | 3 | 8 | **2.58** |
| 10 (b) | 6 | 17 | 22 | 61 | 4 | 11 | 0 | 0 | 4 | 11 | **2.72** |
| 11 | 3 | 8 | 8 | 22 | 0 | 0 | 10 | 28 | 15 | 42 | **1.28** |
| 12 | 1 | 3 | 26 | 72 | 4 | 11 | 4 | 11 | 1 | 3 | **2.61** |
| 13 | 0 | 0 | 29 | 81 | 6 | 17 | 0 | 0 | 1 | 3 | **2.75** |
| 14 | 0 | 0 | 4 | 11 | 1 | 3 | 5 | 14 | 26 | 72 | **0.53** |
| 15 | 0 | 0 | 20 | 56 | 2 | 6 | 7 | 19 | 7 | 19 | **1.97** |

Key:

SU = sound understanding; PU = partial understanding; PUSA = partial understanding with specific alternative conception; SA = specific alternative conception; NU = no understanding; N = total number of respondents; n = number of students per level of understanding.

## Appendix 36

# Chemistry Survey (Part B)

## Data from Post-test B2 – GC Group (N=30)

| Question | SU (Level 4) | | PU (Level 3) | | PUSA (Level 2) | | SA (Level 1) | | NU (Level 0) | | Mean Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | % | n | % | n | % | n | % | n | % | |
| 1 (a) | 17 | 57 | 10 | 33 | 3 | 10 | 0 | 0 | 0 | 0 | **3.47** |
| 1 (b) | 11 | 37 | 8 | 27 | 3 | 10 | 4 | 13 | 4 | 13 | **2.60** |
| 2 (a) | 18 | 60 | 0 | 0 | 0 | 0 | 10 | 33 | 2 | 7 | **2.73** |
| 2 (b) | 8 | 27 | 7 | 23 | 7 | 23 | 5 | 17 | 3 | 10 | **2.40** |
| 2 (c) | 5 | 17 | 1 | 3 | 0 | 0 | 10 | 33 | 14 | 47 | **1.10** |
| 3 | 3 | 10 | 26 | 87 | 1 | 3 | 0 | 0 | 0 | 0 | **3.07** |
| 4 | 3 | 10 | 19 | 63 | 4 | 13 | 4 | 13 | 0 | 0 | **2.70** |
| 5 (a) | 1 | 3 | 15 | 50 | 0 | 0 | 10 | 33 | 4 | 13 | **1.97** |
| 5 (b) | 9 | 30 | 19 | 63 | 1 | 3 | 1 | 3 | 0 | 0 | **3.20** |
| 6 (a) | 8 | 27 | 11 | 37 | 1 | 3 | 3 | 10 | 7 | 23 | **2.33** |
| 6 (b) | 19 | 63 | 10 | 33 | 0 | 0 | 0 | 0 | 1 | 3 | **3.53** |
| 7 (a) | 14 | 47 | 11 | 37 | 4 | 13 | 1 | 3 | 0 | 0 | **3.27** |
| 7 (b) | 22 | 73 | 6 | 20 | 0 | 0 | 2 | 7 | 0 | 0 | **3.60** |
| 8 (a) | 22 | 73 | 4 | 13 | 3 | 10 | 1 | 3 | 0 | 0 | **3.57** |
| 8 (b) | 22 | 73 | 6 | 20 | 1 | 3 | 0 | 0 | 1 | 3 | **3.60** |
| 9 (a) | 14 | 47 | 12 | 40 | 3 | 10 | 1 | 3 | 0 | 0 | **3.30** |
| 9 (b) | 8 | 27 | 2 | 7 | 1 | 3 | 0 | 0 | 19 | 63 | **1.33** |
| 10 (a) | 11 | 37 | 17 | 57 | 2 | 7 | 0 | 0 | 0 | 0 | **3.30** |
| 10 (b) | 13 | 43 | 13 | 43 | 2 | 7 | 0 | 0 | 2 | 7 | **3.17** |
| 11 | 2 | 7 | 16 | 53 | 0 | 0 | 10 | 33 | 2 | 7 | **2.20** |
| 12 | 2 | 7 | 27 | 90 | 1 | 3 | 0 | 0 | 0 | 0 | **3.03** |
| 13 | 16 | 53 | 14 | 47 | 0 | 0 | 0 | 0 | 0 | 0 | **3.53** |
| 14 | 24 | 80 | 3 | 10 | 0 | 0 | 0 | 0 | 3 | 10 | **3.50** |
| 15 | 9 | 30 | 16 | 53 | 2 | 7 | 3 | 10 | 0 | 0 | **3.03** |

Key:
SU = sound understanding; PU = partial understanding; PUSA = partial understanding with specific alternative conception; SA = specific alternative conception; NU = no understanding;
N = total number of respondents; n = number of students per level of understanding.

## Appendix 37

# Chemistry Survey (Part B)

## Comparing Mean Levels of Understanding

| Question | Non-GC Mean Level (Pre-test B1) | Non-GC Mean Level (Post-test B2) | Change | GC Mean Level (Pre-test B1) | GC Mean Level (Post-test B2) | Change |
|---|---|---|---|---|---|---|
| 1 (a) | 3.09 | 3.00 | **- 0.09** | 3.06 | 3.47 | **+ 0.41** |
| 1 (b) | 1.11 | 1.08 | **- 0.03** | 0.61 | 2.60 | **+ 1.99** |
| 2 (a) | 0.97 | 1.97 | **+ 1.00** | 1.69 | 2.73 | **+ 1.04** |
| 2 (b) | 0.57 | 0.44 | **- 0.13** | 0.28 | 2.40 | **+ 2.12** |
| 2 (c) | 0.20 | 0.06 | **- 0.14** | 0.00 | 1.10 | **+ 1.10** |
| 3 | 2.51 | 2.83 | **+ 0.32** | 2.91 | 3.07 | **+ 0.16** |
| 4 | 2.49 | 2.44 | **- 0.05** | 2.59 | 2.70 | **+ 0.11** |
| 5 (a) | 1.14 | 1.50 | **+ 0.36** | 1.00 | 1.97 | **+ 0.97** |
| 5 (b) | 2.14 | 2.81 | **+ 0.67** | 2.22 | 3.20 | **+ 0.98** |
| 6 (a) | 0.11 | 0.75 | **+ 0.64** | 0.34 | 2.33 | **+ 1.99** |
| 6 (b) | 2.34 | 2.72 | **+ 0.38** | 1.41 | 3.53 | **+ 2.12** |
| 7 (a) | 1.89 | 1.61 | **- 0.28** | 1.84 | 3.27 | **+ 1.43** |
| 7 (b) | 1.89 | 1.86 | **- 0.03** | 1.50 | 3.60 | **+ 2.10** |
| 8 (a) | 2.60 | 3.03 | **+ 0.43** | 2.91 | 3.57 | **+ 0.66** |
| 8 (b) | 2.91 | 3.08 | **+ 0.17** | 3.38 | 3.60 | **+ 0.22** |
| 9 (a) | 2.71 | 2.92 | **+ 0.21** | 2.19 | 3.30 | **+ 1.11** |
| 9 (b) | 0.24 | 0.31 | **+ 0.07** | 0.06 | 1.33 | **+ 1.27** |
| 10 (a) | 2.43 | 2.58 | **+ 0.15** | 2.72 | 3.30 | **+ 0.58** |
| 10 (b) | 2.80 | 2.72 | **- 0.08** | 2.72 | 3.17 | **+ 0.45** |
| 11 | 1.66 | 1.28 | **- 0.38** | 1.41 | 2.20 | **+ 0.79** |
| 12 | 2.40 | 2.61 | **+ 0.21** | 2.56 | 3.03 | **+ 0.47** |
| 13 | 2.34 | 2.75 | **+ 0.41** | 2.63 | 3.53 | **+ 0.90** |
| 14 | 1.20 | 0.53 | **- 0.67** | 0.63 | 3.50 | **+ 2.87** |
| 15 | 2.09 | 1.97 | **- 0.12** | 2.69 | 3.03 | **+ 0.34** |
| GLOBAL | **1.83** | **1.95** | + 0.12 | **1.81** | **2.90** | + 1.09 |

**Appendix 38**

## Chemistry Survey (Part B)

**Statistical results comparing PRE-TEST data of non-GC group versus GC group**
**(using Mann-Whitney U test, 2-tailed)**

| Item | Non-GC Group (N=35) | | | GC Group (N=32) | | | z-value | p-value | Significance |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | SEM | Mean | SD | SEM | | | |
| 1(a) | 3.09 | 0.74 | 0.13 | 3.06 | 0.44 | 0.08 | - 0.633 | 0.524 | ns |
| 1(b) | 1.11 | 1.35 | 0.23 | 0.61 | 1.09 | 0.19 | - 1.576 | 0.115 | ns |
| 2(a) | 0.97 | 0.62 | 0.10 | 1.69 | 1.64 | 0.29 | - 1.562 | 0.118 | ns |
| 2(b) | 0.57 | 0.98 | 0.17 | 0.28 | 0.73 | 0.13 | - 1.467 | 0.142 | ns |
| 2(c) | 0.20 | 0.58 | 0.10 | 0.00 | 0.00 | 0.00 | - 2.137 | 0.033 | * |
| 3 | 2.51 | 0.78 | 0.13 | 2.91 | 0.69 | 0.12 | - 2.236 | 0.025 | * |
| 4 | 2.49 | 1.12 | 0.19 | 2.59 | 0.80 | 0.14 | - 0.102 | 0.919 | ns |
| 5(a) | 1.14 | 0.85 | 0.14 | 1.00 | 0.00 | 0.00 | 0.000 | 1.000 | ns |
| 5(b) | 2.14 | 1.40 | 0.24 | 2.22 | 1.24 | 0.22 | - 0.043 | 0.966 | ns |
| 6(a) | 0.11 | 0.32 | 0.05 | 0.34 | 0.87 | 0.15 | - 1.071 | 0.284 | ns |
| 6(b) | 2.34 | 1.47 | 0.25 | 1.41 | 1.66 | 0.29 | - 2.234 | 0.025 | * |
| 7(a) | 1.89 | 1.13 | 0.19 | 1.84 | 1.11 | 0.20 | - 0.658 | 0.510 | ns |
| 7(b) | 1.89 | 1.51 | 0.26 | 1.50 | 1.32 | 0.23 | - 0.787 | 0.431 | ns |
| 8(a) | 2.60 | 1.03 | 0.17 | 2.91 | 0.89 | 0.16 | - 0.984 | 0.325 | ns |
| 8(b) | 2.91 | 1.29 | 0.22 | 3.38 | 1.01 | 0.18 | - 1.126 | 0.260 | ns |
| 9(a) | 2.71 | 1.25 | 0.21 | 2.19 | 1.49 | 0.26 | - 1.463 | 0.143 | ns |
| 9(b) | 0.24 | 0.61 | 0.10 | 0.06 | 0.25 | 0.04 | - 1.828 | 0.068 | ns |
| 10(a) | 2.43 | 1.38 | 0.23 | 2.72 | 1.28 | 0.23 | - 1.118 | 0.264 | ns |
| 10(b) | 2.80 | 1.11 | 0.19 | 2.72 | 1.20 | 0.21 | - 0.015 | 0.988 | ns |
| 11 | 1.66 | 1.30 | 0.22 | 1.41 | 1.29 | 0.23 | - 1.194 | 0.232 | ns |
| 12 | 2.40 | 1.01 | 0.17 | 2.56 | 0.84 | 0.15 | - 0.558 | 0.577 | ns |
| 13 | 2.34 | 0.97 | 0.16 | 2.63 | 0.91 | 0.16 | - 1.722 | 0.085 | ns |
| 14 | 1.20 | 1.43 | 0.24 | 0.63 | 1.21 | 0.21 | - 1.778 | 0.075 | ns |
| 15 | 2.09 | 1.12 | 0.19 | 2.69 | 0.78 | 0.14 | - 2.426 | 0.015 | * |

*SD = Standard Deviation* *SEM = Standard Error of the Mean*

| p-values: | | | |
|---|---|---|---|
| | >0.050 | non-significant | ns |
| | 0.010-0.050 | significant | * |
| | 0.001-0.010 | very significant | ** |
| | <0.001 | extremely significant | *** |

**Appendix 39**

## Chemistry Survey (Part B)

### Statistical results comparing POST-TEST data of non-GC group versus GC group (using Mann-Whitney U test, 2-tailed)

| Item | Non-GC Group (N=36) | | | GC Group (N=30) | | | z-value | p-value | Significance |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | SEM | Mean | SD | SEM | | | |
| 1(a) | 3.00 | 0.53 | 0.09 | 3.47 | 0.68 | 0.12 | - 3.253 | 0.001 | ** |
| 1(b) | 1.08 | 1.18 | 0.20 | 2.60 | 1.45 | 0.27 | - 3.976 | 0.000 | *** |
| 2(a) | 1.97 | 1.58 | 0.26 | 2.73 | 1.60 | 0.29 | - 1.704 | 0.088 | ns |
| 2(b) | 0.44 | 0.88 | 0.15 | 2.40 | 1.33 | 0.24 | - 5.443 | 0.000 | *** |
| 2(c) | 0.06 | 0.23 | 0.04 | 1.10 | 1.47 | 0.27 | - 4.294 | 0.000 | *** |
| 3 | 2.83 | 0.51 | 0.08 | 3.07 | 0.37 | 0.07 | - 2.076 | 0.038 | * |
| 4 | 2.44 | 0.81 | 0.13 | 2.70 | 0.84 | 0.15 | - 1.452 | 0.146 | ns |
| 5(a) | 1.50 | 1.03 | 0.17 | 1.97 | 1.25 | 0.23 | - 1.438 | 0.151 | ns |
| 5(b) | 2.81 | 0.75 | 0.12 | 3.20 | 0.66 | 0.12 | - 2.182 | 0.029 | * |
| 6(a) | 0.75 | 1.05 | 0.18 | 2.33 | 1.56 | 0.29 | - 3.866 | 0.000 | *** |
| 6(b) | 2.72 | 1.11 | 0.19 | 3.53 | 0.82 | 0.15 | - 3.789 | 0.000 | *** |
| 7(a) | 1.61 | 1.15 | 0.19 | 3.27 | 0.83 | 0.15 | - 5.152 | 0.000 | *** |
| 7(b) | 1.86 | 1.64 | 0.27 | 3.60 | 0.81 | 0.15 | - 4.412 | 0.000 | *** |
| 8(a) | 3.03 | 0.88 | 0.15 | 3.57 | 0.82 | 0.15 | - 2.611 | 0.009 | ** |
| 8(b) | 3.08 | 1.32 | 0.22 | 3.60 | 0.86 | 0.16 | - 1.587 | 0.112 | ns |
| 9(a) | 2.92 | 1.02 | 0.17 | 3.30 | 0.79 | 0.15 | - 1.491 | 0.136 | ns |
| 9(b) | 0.31 | 0.98 | 0.16 | 1.33 | 1.83 | 0.33 | - 2.244 | 0.025 | * |
| 10(a) | 2.58 | 1.11 | 0.18 | 3.30 | 0.60 | 0.11 | - 2.780 | 0.005 | ** |
| 10(b) | 2.72 | 1.11 | 0.19 | 3.17 | 1.05 | 0.19 | - 2.130 | 0.033 | * |
| 11 | 1.28 | 1.43 | 0.24 | 2.20 | 1.19 | 0.22 | - 2.941 | 0.003 | ** |
| 12 | 2.61 | 0.84 | 0.14 | 3.03 | 0.32 | 0.06 | - 2.277 | 0.023 | * |
| 13 | 2.74 | 0.61 | 0.10 | 3.53 | 0.51 | 0.09 | - 5.121 | 0.000 | *** |
| 14 | 0.53 | 1.00 | 0.17 | 3.50 | 1.22 | 0.22 | - 6.376 | 0.000 | *** |
| 15 | 1.97 | 1.25 | 0.21 | 3.03 | 0.89 | 0.16 | - 3.576 | 0.000 | *** |

*SD = Standard Deviation* *SEM = Standard Error of the Mean*

| | | | |
|---|---|---|---|
| *p-values:* | *> 0.050* | *non-significant* | *ns* |
| | *0.010-0.050* | *significant* | * |
| | *0.001-0.010* | *very significant* | ** |
| | *< 0.001* | *extremely significant* | *** |

**Appendix 40**

## Chemistry Survey (Part B)

### Statistical results comparing NON-GC GROUP data (Pre-test vs Post-test)

### (using Wilcoxon Signed-Rank test, 2-tailed)

| Item | Non-GC PRE-TEST (N=35) | | | Non-GC POST-TEST (N=35) | | | z-value | p-value | Significance |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | SEM | Mean | SD | SEM | | | |
| 1(a) | 3.09 | 0.74 | 0.13 | 2.97 | 0.57 | 0.10 | - 0.834 | 0.404 | ns |
| 1(b) | 1.11 | 1.35 | 0.23 | 1.11 | 1.18 | 0.20 | - 0.038 | 0.970 | ns |
| 2(a) | 0.97 | 0.62 | 0.10 | 2.03 | 1.56 | 0.26 | - 3.500 | 0.000 | *** |
| 2(b) | 0.57 | 0.98 | 0.17 | 0.46 | 0.89 | 0.15 | - 0.683 | 0.495 | ns |
| 2(c) | 0.20 | 0.58 | 0.10 | 0.06 | 0.24 | 0.04 | - 1.414 | 0.157 | ns |
| 3 | 2.51 | 0.78 | 0.13 | 2.83 | 0.51 | 0.09 | - 2.296 | 0.022 | * |
| 4 | 2.49 | 1.12 | 0.19 | 2.43 | 0.81 | 0.14 | - 0.379 | 0.705 | ns |
| 5(a) | 1.14 | 0.85 | 0.14 | 1.51 | 1.04 | 0.18 | - 1.710 | 0.087 | ns |
| 5(b) | 2.11 | 1.41 | 0.24 | 2.83 | 0.79 | 0.13 | - 2.659 | 0.008 | ** |
| 6(a) | 0.11 | 0.32 | 0.05 | 0.77 | 1.06 | 0.18 | - 3.043 | 0.002 | ** |
| 6(b) | 2.34 | 1.47 | 0.25 | 2.77 | 1.09 | 0.18 | - 1.588 | 0.112 | ns |
| 7(a) | 1.89 | 1.13 | 0.19 | 1.57 | 1.14 | 0.19 | - 1.340 | 0.180 | ns |
| 7(b) | 1.89 | 1.51 | 0.26 | 1.83 | 1.65 | 0.28 | - 0.266 | 0.790 | ns |
| 8(a) | 2.60 | 1.03 | 0.17 | 3.03 | 0.89 | 0.15 | - 1.976 | 0.048 | * |
| 8(b) | 2.91 | 1.29 | 0.22 | 3.09 | 1.34 | 0.23 | - 0.526 | 0.599 | ns |
| 9(a) | 2.71 | 1.25 | 0.21 | 2.95 | 1.03 | 0.17 | - 1.005 | 0.315 | ns |
| 9(b) | 0.23 | 0.60 | 0.10 | 0.40 | 1.09 | 0.18 | - 0.122 | 0.903 | ns |
| 10(a) | 2.43 | 1.38 | 0.23 | 2.66 | 1.03 | 0.17 | - 1.049 | 0.294 | ns |
| 10(b) | 2.80 | 1.11 | 0.19 | 2.71 | 1.13 | 0.19 | - 0.220 | 0.826 | ns |
| 11 | 1.74 | 1.29 | 0.22 | 1.23 | 1.43 | 0.24 | - 1.521 | 0.128 | ns |
| 12 | 2.40 | 1.01 | 0.17 | 2.66 | 0.80 | 0.14 | - 1.162 | 0.245 | ns |
| 13 | 2.34 | 0.97 | 0.16 | 2.74 | 0.61 | 0.10 | - 1.907 | 0.057 | ns |
| 14 | 1.20 | 1.43 | 0.24 | 0.54 | 1.01 | 0.17 | 2.698 | 0.007 | ** |
| 15 | 2.09 | 1.12 | 0.19 | 2.03 | 1.22 | 0.21 | 0.381 | 0.703 | ns |

*SD = Standard Deviation* *SEM = Standard Error of the Mean*

| *p-values:* | *>0.050* | *non-significant* | *ns* |
|---|---|---|---|
| | *0.010-0.050* | *significant* | * |
| | *0.001-0.010* | *very significant* | ** |
| | *<0.001* | *extremely significant* | *** |

## Appendix 41

# Chemistry Survey (Part B)

**Statistical results comparing GC GROUP data (Pre-test vs Post-test)**

**(using Wilcoxon Signed-Rank test, 2-tailed)**

| Item | GC PRE-TEST (N=30) | | | GC POST-TEST (N=30) | | | z-value | p-value | Significance |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | SEM | Mean | SD | SEM | | | |
| 1(a) | 3.07 | 0.45 | 0.08 | 3.47 | 0.68 | 0.12 | - 2.307 | 0.021 | * |
| 1(b) | 0.63 | 1.10 | 0.20 | 2.60 | 1.45 | 0.27 | - 4.167 | 0.000 | *** |
| 2(a) | 1.80 | 1.63 | 0.30 | 2.73 | 1.60 | 0.29 | - 2.477 | 0.013 | * |
| 2(b) | 0.30 | 0.75 | 0.14 | 2.40 | 1.33 | 0.24 | - 4.360 | 0.000 | *** |
| 2(c) | 0.00 | 0.00 | 0.00 | 1.10 | 1.47 | 0.27 | - 3.630 | 0.000 | *** |
| 3 | 2.87 | 0.68 | 0.12 | 3.07 | 0.37 | 0.07 | - 1.310 | 0.190 | ns |
| 4 | 2.57 | 0.82 | 0.15 | 2.70 | 0.84 | 0.15 | - 0.881 | 0.378 | ns |
| 5(a) | 1.00 | 0.00 | 0.00 | 1.97 | 1.25 | 0.23 | - 3.737 | 0.000 | *** |
| 5(b) | 2.17 | 1.26 | 0.23 | 3.20 | 0.66 | 0.12 | - 3.896 | 0.000 | *** |
| 6(a) | 0.37 | 0.89 | 0.16 | 2.33 | 1.56 | 0.29 | - 4.066 | 0.000 | *** |
| 6(b) | 1.40 | 1.67 | 0.31 | 3.53 | 0.82 | 0.15 | - 4.063 | 0.000 | *** |
| 7(a) | 1.73 | 1.05 | 0.19 | 3.27 | 0.83 | 0.15 | - 4.344 | 0.000 | *** |
| 7(b) | 1.57 | 1.33 | 0.24 | 3.60 | 0.81 | 0.15 | - 4.408 | 0.000 | *** |
| 8(a) | 2.90 | 0.88 | 0.16 | 3.57 | 0.82 | 0.15 | - 2.355 | 0.019 | * |
| 8(b) | 3.23 | 1.19 | 0.22 | 3.60 | 0.86 | 0.16 | - 1.399 | 0.162 | ns |
| 9(a) | 2.23 | 1.48 | 0.27 | 3.30 | 0.79 | 0.15 | - 3.020 | 0.003 | ** |
| 9(b) | 0.07 | 0.25 | 0.05 | 1.33 | 1.83 | 0.33 | - 3.052 | 0.002 | ** |
| 10(a) | 2.80 | 1.21 | 0.22 | 3.30 | 0.60 | 0.11 | - 2.288 | 0.022 | * |
| 10(b) | 2.80 | 1.13 | 0.21 | 3.17 | 1.05 | 0.19 | - 2.066 | 0.039 | * |
| 11 | 1.40 | 1.33 | 0.24 | 2.20 | 1.19 | 0.22 | - 2.407 | 0.016 | * |
| 12 | 2.57 | 0.86 | 0.16 | 3.03 | 0.32 | 0.06 | - 2.507 | 0.012 | * |
| 13 | 2.60 | 0.93 | 0.17 | 3.53 | 0.51 | 0.09 | - 4.013 | 0.000 | *** |
| 14 | 0.67 | 1.24 | 0.23 | 3.50 | 1.22 | 0.22 | - 4.580 | 0.000 | *** |
| 15 | 2.67 | 0.80 | 0.15 | 3.03 | 0.89 | 0.16 | - 1.466 | 0.148 | ns |

*SD = Standard Deviation* *SEM = Standard Error of the Mean*

| | | | |
|---|---|---|---|
| *p-values:* | *>0.050* | *non-significant* | *ns* |
| | *0.010-0.050* | *significant* | * |
| | *0.001-0.010* | *very significant* | ** |
| | *<0.001* | *extremely significant* | *** |

**List of Abbreviations**

| | |
|---|---|
| ACS | American Chemical Society |
| A-level | Advanced Level |
| AM | Advanced Matriculation |
| AQA | Assessment & Qualifications Alliance |
| AS | Advanced Supplementary |
| BSc | Bachelor of Science |
| CAQDAS | Computer Assisted Qualitative Analysis Software |
| CCEA | Council for the Curriculum, Examinations & Assessment (N. Ireland) |
| CEFIC | European Chemical Industry Council |
| CIE | Cambridge International Examinations |
| CIEC | Chemical Industry Education Centre |
| EU | European Union |
| EuCheMS | European Association for Chemical & Molecular Sciences |
| FAMEs | Fatty Acid Methyl Esters |
| GC | Green Chemistry |
| GCE | General Certificate of Education |
| GCEdNet | Green Chemistry Educational Network |
| GCI | Green Chemistry Institute |
| GCN | Green Chemistry Network |
| GCSE | General Certificate of Secondary Education |
| GEMs | Greener Education Materials for Chemists |
| IB | International Baccalaureate |
| IEA | International Studies of Educational Achievement |
| IM | Intermediate Matriculation |
| ITS | Institute of Tourism Studies |
| IUPAC | International Union of Pure & Applied Chemists |
| JCQ | Joint Council for Qualifications |
| LCA | Life Cycle Analysis |

| | |
|---|---|
| MCAST | Malta College of Arts, Science & Technology |
| MD | Doctor of Medicine |
| MW | Mann-Whitney (test) |
| NCHE | National Commission for Higher Education |
| NEHA | National Environment Health Association |
| NNFCC | National Non-Food Crop Centre |
| NRC | National Research Council |
| OCR | Oxford, Cambridge & RSA Examinations |
| OECD | Organisation for the Economic Cooperation & Development |
| OFSTED | Office for Standards in Education, Children's Services and Skills |
| O-level | Ordinary Level |
| OPPT | Office of Pollution Prevention and Toxics |
| PERC | Perchloroethylene |
| REACH | Registration, Evaluation, Authorisation & Restriction of Chemicals |
| ROSE | Relevance of Science Education |
| RSC | Royal Society of Chemistry |
| SD | Standard Deviation |
| SEC | Secondary Education Certificate |
| SEM | Standard Error of the Mean |
| SPSS | Statistical Package for the Social Sciences |
| SQA | Scottish Qualifications Authority |
| TAP | Thesis Advisory Panel |
| TIMSS | Third International Mathematics & Science Study |
| UK | United Kingdom |
| UNWCED | United Nations World Commission on Environment & Development |
| US (or USA) | United States of America |
| USEPA | United States Environmental Protection Agency |
| WJEC-CBAC | Welsh Joint Education Committee |
| WSR | Wilcoxon Signed-Rank (test) |

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