IDENTIFICATION OF THE DIFFICULTIES IN TEACHING AND LEARNING OF INTRODUCTORY ORGANIC CHEMISTRY IN IRELAND AND THE DEVELOPMENT OF A SECOND-LEVEL INTERVENTION PROGRAMME TO ADDRESS THESE

ANNE O’DWYER
B.Sc. Physical Education and Chemistry

Supervisors: Dr. Peter E. Childs and Dr. Noreen Hanly
Department of Chemical and Environmental Sciences, University of Limerick

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ABSTRACT

Identification of the difficulties in Teaching and Learning of Introductory Organic Chemistry in Ireland and the development of a Second-Level Intervention Programme to address these.

This project involved the effective implementation of Chemistry Education Research (CER) into classroom practice. The project was carried out in two cycles. Cycle One of the project involved two investigations: one at Second-Level and one at Third-Level. Cycle Two involved the development, implementation and evaluation of an intervention in the Irish Second-Level schools programme to address the issues identified in Cycle One. The difficulties of Organic Chemistry have been investigated and researched in many other countries. However, there has been no explicit research carried out investigating the difficulties experienced by novices learning Organic Chemistry in Ireland. This Action Research project involved an investigation of the difficulties experienced by those learning Organic Chemistry at Second-Level and at introductory Third-Level in Ireland.

The Second-Level study involved the completion of questionnaires by Chemistry teachers in 73 Second-Level schools and pupils in 35 Second-Level schools teaching Leaving Certificate Chemistry in Ireland. At Third-Level, questionnaires were completed by lecturers in 12 different Third-Level Irish Institutions and to students in three different Institutions. These questionnaires provided an insight into the Teaching and Learning of Organic Chemistry. It was found that those teaching and learning Organic Chemistry at Second-Level and Third-Level experience many common topics as difficult: IUPAC Nomenclature; Functional Groups; Characteristics of Organic Compounds; Reaction Types; Reaction Mechanisms and Practical work.

Organic Chemistry accounts for a substantial amount of the Leaving Certificate Chemistry syllabus (20%) and examination (25%). Using the findings from Cycle One and those from CER, Organic Chemistry in Action! was developed. This intervention programme is a unique evidence-based resource designed to facilitate the Teaching and Learning of Organic Chemistry. The teaching materials were developed by using specific design criteria, proven to be effective in previous innovative Chemistry teaching programmes. The intervention materials were designed with specific reference to the current Irish Leaving Certificate Chemistry syllabus. The Organic Chemistry in Action! materials are adaptable and can be used with introductory Third-Level Organic Chemistry as well as the proposed new Leaving Certificate Chemistry syllabus. The Organic Chemistry in Action! programme was trialled with 87 sixth year Chemistry pupils in six Second-Level schools. The effectiveness of the programme was evaluated using feedback from the participants (Chemistry teachers and pupils) as well as comparisons with a Control Group of 121 pupils from nine different Second-Level schools which investigated both attitudes and understanding.

The results of this intervention programme have shown an improvement in the attitudes, interest and understanding of the participating pupils, even though it was implemented within the constraints of the current, often examination-focused Leaving Certificate programme. The Intervention Group outperformed the Control Group in several key areas despite evidence that the Control Group had a better background in Science and Mathematics. The results indicate that this inquiry-based approach, which also aimed to develop cognitive skills and to relate Chemistry to real life contexts, was successful in addressing in part, some of the difficulties in teaching and learning Organic Chemistry at Second-Level.
PUBLICATIONS AND PRESENTATIONS

Refereed Conference Proceedings:

Non-refereed Publications


Oral Conference Presentations


**Workshops**


O’Dwyer, A. and Childs, P.E., *Organic Chemistry in Action! at Third Level*, School of Chemistry, NUIG (National University of Ireland, Galway), Galway, 10 June 2011.

**Accepted Conference Abstracts**


DECLARATION

This thesis is presented in fulfilment of the requirements for the degree of Doctor of Philosophy. It is entirely my own work and has not been submitted to any other University, Institution of Higher Education, or for any other academic award in this University. Where use has been made of the work of other people, it has been fully acknowledged and fully referenced.

Signature: ___________________________    2012

Anne O’ Dwyer
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Appendix A  Organic Section of the Leaving Certificate syllabi
    Organic section of current Leaving Certificate Chemistry syllabus
    Organic section of the proposed Leaving Certificate Chemistry syllabus

Appendix B  2011 Leaving Certificate examination papers
    Higher Level Leaving Certificate Chemistry examination paper 2011
    Ordinary Level Leaving Certificate examination paper 2011

Appendix C  Ethics Application for Second-Level Study
    Completed Ethics form as submitted
    Necessary documentation submitted with Ethics Application
    Letter of Ethical Approval

Appendix D  Ethics Application for Third-Level Study
    Completed Ethics form as submitted
    Necessary documentation submitted with Ethics Application
    Letter of Ethical Approval

Appendix E  Ethics Application for evaluation of Cycle Two
    Completed Ethics form as submitted
    Necessary documentation submitted with Ethics Application
    Letter of Ethical Approval
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Appendix F  Cycle One: Second-Level Study Questionnaires
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- Chemistry Teacher Review Questionnaire
- Control Group- Second-Level Pupil Questionnaire (II)
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**Appendix I** ISTA Workshop

- Chemistry Teacher Hand-out
- Chemistry Teacher Questionnaire

**Appendix J** Organic Chemistry in Action! – Print resources

- Pupil Workbook (I)
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**Appendix K** Transcriptions of Teacher Diaries

- Teacher Diary- School A
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- Teacher Diary- School C
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**Appendix L** Transcriptions of Teacher Interviews

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- Oral Conference Presentations
- Workshops
- Accepted Conference Abstracts

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<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>A-Level</td>
<td>Advanced Level</td>
</tr>
<tr>
<td>AS-Level</td>
<td>Advanced Subsidiary Level</td>
</tr>
<tr>
<td>ACS</td>
<td>American Chemical Society</td>
</tr>
<tr>
<td>ANOVA</td>
<td>ANalysis OF VAriance</td>
</tr>
<tr>
<td>ASTI</td>
<td>Association of Secondary Teachers in Ireland</td>
</tr>
<tr>
<td>CAMe</td>
<td>Cognitive Acceleration through Mathematics Education</td>
</tr>
<tr>
<td>CAO</td>
<td>Central Applications Office</td>
</tr>
<tr>
<td>CASE</td>
<td>Cognitive Acceleration through Science Education</td>
</tr>
<tr>
<td>CAT</td>
<td>Curriculum Analysis Taxonomy</td>
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<tr>
<td>DART</td>
<td>Directed Activities Related to Text</td>
</tr>
<tr>
<td>DBT</td>
<td>Digit Backwards Test</td>
</tr>
<tr>
<td>DES</td>
<td>Department of Education and Skills</td>
</tr>
<tr>
<td>ECTN</td>
<td>European Chemistry Thematic Network</td>
</tr>
<tr>
<td>ECTS</td>
<td>European Credit Transfer and accumulation System</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FIT</td>
<td>Figure Intersection Test</td>
</tr>
<tr>
<td>HOCS</td>
<td>Higher Order Cognitive Skills</td>
</tr>
<tr>
<td>HL</td>
<td>Higher Level</td>
</tr>
<tr>
<td>IRCSET</td>
<td>Irish Research Council for Science Engineering and Technology</td>
</tr>
<tr>
<td>ISTA</td>
<td>Irish Science Teachers’ Association</td>
</tr>
<tr>
<td>ITS Chemistry</td>
<td>Increasing Thinking Skills in Chemistry</td>
</tr>
<tr>
<td>IUPAC</td>
<td>International Union of Pure and Applied Chemistry</td>
</tr>
<tr>
<td>JC</td>
<td>Junior Certificate</td>
</tr>
<tr>
<td>LC</td>
<td>Leaving Certificate</td>
</tr>
<tr>
<td>NCCA</td>
<td>National Council for Curriculum and Assessment</td>
</tr>
<tr>
<td>NCE-MSTL</td>
<td>National Centre for Excellence in Mathematics and Science Teaching and...</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Learning</td>
<td>OCIA!</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>OL</td>
<td>Ordinary Level</td>
</tr>
<tr>
<td>PISA</td>
<td>Programme for International Student Assessment</td>
</tr>
<tr>
<td>PLANK</td>
<td>PLAtforms for New Knowledge</td>
</tr>
<tr>
<td>POGIL</td>
<td>Process-Orientated Guided Inquiry Learning</td>
</tr>
<tr>
<td>POLES</td>
<td>Provided Outlines LEnding Support</td>
</tr>
<tr>
<td>ROSE</td>
<td>Relevance of Science Education</td>
</tr>
<tr>
<td>RQ</td>
<td>Research Question</td>
</tr>
<tr>
<td>SAC</td>
<td>Salters’ Advanced Chemistry</td>
</tr>
<tr>
<td>SEC</td>
<td>State Examinations Commission</td>
</tr>
<tr>
<td>SESE</td>
<td>Social Environmental and Scientific Education</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>SWH</td>
<td>Science Writing Heuristic</td>
</tr>
<tr>
<td>21CS</td>
<td>Twenty First Century Science</td>
</tr>
<tr>
<td>TIMMS</td>
<td>Trends in International Maths and Science Study</td>
</tr>
<tr>
<td>ULREC</td>
<td>University of Limerick Research Ethics Committee</td>
</tr>
<tr>
<td>VSEPR</td>
<td>Valence Shell Electron Pair Repulsion Theory</td>
</tr>
<tr>
<td>ZPD</td>
<td>Zone of Proximal Development</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction
1.1 - The need for change in Chemistry Education

Johnstone (2010) has recognised a snowball effect of recurring misconceptions in Chemistry education at Second-Level and Third-Level over the past 40 years. Too much attention has been given to the ‘chemical’, and not enough attention given to the ‘education’ part of ‘Chemical Education’ (Ellis 1994, Mahaffy 2005). Ellis (1994) and many others have highlighted the gap in communication between those who carry out the research in chemical education and those who are trying to teach Chemistry. Very often many of the research studies involve sample groups of learners who are within the top group in a school or college, so the findings may not be as applicable to the typical learner. Many of the revised curricula are still failing to understand how pupils and students learn. The Nuffield report on Science Education in Europe (Osborne and Dillon 2008) highlighted how the content and pedagogy associated with Science curricula are increasingly failing to engage learners. This report also found that there is a strong negative correlation between learners’ interest in Science and their achievement in examinations. These findings suggest that current revised school curricula are not facilitating the learners’ interest and understanding in Science subjects.

“We have been busy changing the menu in the ship’s restaurant while the ship had been sinking”

(Johnstone, 2010, p. 22)

Rather than developing new curricula and programmes for teaching Chemistry, it is more important for educators to first understand the processes of learning. Johnstone (2010) listed nine areas of Chemistry that were established as difficult in 1971. Many of these same topics were again identified as difficult by Ratcliffe (2002), Jimoh (2005), Johnstone (2006) and also by Childs and Sheehan (2009) in an Irish context. This provides confirmation that there is an evident and persistent problem with how Chemistry is being taught and highlights the need for change.

“Have we, in our attempt to present Chemistry as a logical discipline not only lost its relationship to the psychology of the learner but also lost the vital ingredient that allows the learner to perceive their studies as meaningful in relation to their lifestyle, their attitudes and their aspirations?”

(Reid, 2000, p.388)

Teaching and learning are not synonymous (Anderson and Bodner 2008). We can teach, and teach well, without having the learners learn. Even though there has been much research over the past thirty years about the teaching and learning of Chemistry, much of the focus seems to
be on the ‘classic core’ Chemistry topics of the mole concept, the particulate nature of matter, equilibrium, chemical calculations and reactions. While extensive research has also been carried out in investigating the difficulties that learners have with Organic Chemistry in other parts of the world, (Bhattacharyya and Bodner 2005, Ferguson and Bodner 2008, Nash et al. 2000, Stamovlasis and Tsaparlis 2000) very little has been investigated in this field of interest in Ireland.

1.2- Rationale for this project

In the current economic climate, much emphasis is put on the development of chemical and pharmaceutical industries. Ireland has attracted many of the world’s leading pharmaceutical companies. The investment of these companies has contributed to and facilitated the growth in the pharmaceutical industry in Ireland. The teaching and learning of Chemistry at Second-Level and Third-Level will have a significant effect on the knowledge, understanding and skills of Irish graduates available to work in these industries. Organic Chemistry is a core area of Chemistry which possible employees in the industry need to be able to understand clearly. For these reasons, and others, Organic Chemistry is a particularly important subject at Second-Level and Third-Level. Organic Chemistry accounts for a significant proportion of the Leaving Certificate Chemistry syllabus. In total about 20% of the syllabus is made up of Organic Chemistry, and 25% of the Leaving Certificate Chemistry examination paper. While the overall uptake in Leaving Certificate Chemistry has increased over the past decade (SEC 2011), there is much evidence from the Chief Examiner’s reports (SEC 2005, SEC 2008) that Organic Chemistry is not well understood by the Leaving Certificate Chemistry candidates and often avoided in the examinations.

Recognising the importance of Organic Chemistry in Ireland, and its significance in the Leaving Certificate Chemistry syllabus, this project addresses these issues in an attempt to target the difficulties with this topic and develop a teaching programme to alleviate these difficulties.

The research aims of this project are:

- To investigate the difficulties in teaching and learning Organic Chemistry in Ireland.
- To develop an intervention programme to target the difficult topics in Organic Chemistry by promoting real understanding and positive attitudes towards the subject.
CHAPTER ONE

INTRODUCTION

1.3 - Structure of this project

This research project was carried out in two cycles.

1.3.1. Cycle One- Investigation of the difficulties in Organic Chemistry:

Cycle One involved a review of the Chemical Education Research (CER) literature with a particular focus on Organic Chemistry and the process of learning. Successful intervention programmes and approaches used in other countries were investigated. This cycle also involved two investigations: a Second-Level study and a Third-Level study. Both of these studies sought information from those teaching and learning Organic Chemistry.

The research questions addressed in Cycle One were:

1. What are the most difficult topics to teach and learn at Second-Level and Third-Level introductory Organic Chemistry?
2. Why is Organic Chemistry difficult?

1.3.2. Cycle Two- Development, Implementation and Evaluation of an intervention programme:

Cycle Two of the project was informed through use of the information, research and evidence that was gathered in Cycle One. This involved the design of an evidence-based intervention programme for teaching Leaving Certificate Organic Chemistry. This intervention programme was named Organic Chemistry in Action! The programme was trialled and evaluated in six Second-Level Irish schools.

The research questions addressed in Cycle Two were:

3. What effect can a specially-designed teaching programme using ideas from CER, have on the attitudes and interest of pupils studying Leaving Certificate Organic Chemistry?
4. What effect can improved teaching strategies and resources have on the pupils’ understanding in Leaving Certificate Organic Chemistry?
5. What effect can a specially-designed teaching programme using ideas from CER have on the interest, motivation and teaching style of Leaving Certificate Chemistry teachers?
6. Is it feasible to improve the teaching of Leaving Certificate Organic Chemistry through use of a specially-designed teaching programme?
Figure 1.1. Time-line and summary of each phase of the project.

Note: In Figure 1.1 and for the remainder of this thesis, learners at Second-Level are referred to as ‘pupils’ and learners at Third-Level are referred to as ‘students’.
1.4- Structure of the Thesis

Chapter 1 – Introduction:
This chapter provides a brief background for the rationale for this project by highlighting the need to address the teaching of Chemistry and Organic Chemistry in particular. The project aims are outlined with the guiding research questions. The structure of the two-cycle Action Research project is outlined with reference to the time scale that the project was carried out within. Each of the chapters in the thesis report are introduced here.

Chapter 2- Science Education in Ireland:
This chapter provides background on the current situation of Science and Mathematics Education in Ireland with a particular focus on Second-Level education. The importance of studying Science and Chemistry at school is outlined as an economic benefit as well as life-skill. The current Leaving Certificate Chemistry syllabus is discussed with reference to the proposed revised syllabus. Particular focus is given to the Organic Chemistry content in both of these Leaving Certificate syllabi.

Chapter 3- Teaching and Learning Chemistry:
This chapter reviews the current CER literature. It provides a description of the factors that contribute to the difficulties experienced by those teaching and learning Chemistry. It looks at the extrinsic and intrinsic factors contributing to the difficulties. This chapter takes a particular focus on the difficulties of Organic Chemistry: understanding why the subject is difficult; looking at the Organic Chemistry content of the Leaving Certificate Chemistry syllabus; investigating interventions that have been successful in improving the teaching and learning of Chemistry.

Chapter 4- Methodology:
This chapter outlines the theoretical framework of the whole project. It explains the ‘Action Research’ approach that was adopted for this study. Different research methods were used in both cycles of the study as necessary. The research methods that were chosen and used in both cycles of the project are discussed in this chapter, along with a rationale for their appropriateness. The validity and reliability of the chosen methods are discussed as well as the ethical implications of the project. The methodology of Cycle One is outlined. Details of the Second-Level and Third-Level studies are defined by detailing the design, distribution
and evaluation of the questionnaires used. The methodology of the evaluation of Cycle Two is outlined also. A triangulation of methods was used to assess the effectiveness of the intervention programme; teachers’ perspectives, pupils’ perspectives and comparisons with a Control Group. The methods of evaluation used for each of these lenses are explained in this chapter. The limitations of both cycles of the project are discussed at the end of this chapter.

Chapter 5- *Organic Chemistry in Action!*:
Details of the design, development and implementation of the *Organic Chemistry in Action!* programme are outlined in detail in this chapter. The selection of content and design criteria are explained through use of examples and illustrations from the resource materials. Details of the participants (Intervention Group and Control Group) are provided. The teacher training and support offered during the implementation phase is also described.

Chapter 6- Results (I) Second-Level Study:
This chapter presents the findings from the Second-Level study which was carried out as part of Cycle One. The findings from the Second-Level Pupil Questionnaire (I) are presented along with an analysis of performance in each question in the Second-Level Diagnostic Test. Feedback from the Second-Level Chemistry teachers is also presented.

Chapter 7- Results (II) Third-Level Study:
The second study carried out as part of Cycle One in this project was the Third-Level study. This study involved those learning and teaching introductory Organic Chemistry at Third-Level. This chapter presents the findings from the Third-Level study. The findings from the Third-Level Student Questionnaire are presented along with an analysis of performance in each question in the Third-Level Diagnostic Test. Feedback from the Organic Chemistry lecturers is also presented.

Chapter 8- Results (III) *Organic Chemistry in Action!* programme.
As outlined in Chapter Four, the intervention programme was evaluated using three lenses; from the perspective of the participating teachers and pupils as well comparison with a Control Group. Four research methods were used to gather data from the teachers: Classroom Observations, Teacher Diaries, Teacher Questionnaires and Teacher Interviews. Feedback from the participating pupils was sought through a Focus Group, Classroom Observations
and a Pupil Questionnaire. The same Test for Understanding was given to the pupils in the Intervention Group and Control Group. Comparison of performance in this test provides feedback about the pupils’ level of understanding in Organic Chemistry. The results from the three lenses are presented in this chapter.

Chapter 9 – Discussion of Findings
In this chapter, each of the six research questions outlined above (Section 1.3) are addressed. Each question is answered with relevance to the findings presented in Chapters Six, Seven and Eight and the Chemistry Education literature presented in Chapters Two and Three. The main limitations of this research study are reviewed in light of the findings discussed. Implications of this research are also outlined with respect to current curriculum development in Leaving Certificate Chemistry.

Chapter 10 – Conclusion
This chapter provides a summary of the main findings of this research project, highlighting the unique contribution of this research. Further work planned for the immediate future is also outlined.
1.5- Summary

Many of the difficulties with Organic Chemistry experienced by Second-Level pupils and students studying the topic at Third-Level are the same. One reason is that many of the Third-Level students, like the Leaving Certificate pupils, are experiencing Organic Chemistry for the first time. Research has been carried out (involving teachers and learners) at Second-Level and Third-Level. This research and existing CER has provided ideas and guidelines for the design and development of a unique Organic Chemistry programme. This *Organic Chemistry in Action!* programme, is based on the Organic Chemistry section of the current Leaving Certificate syllabus. It has been designed to accommodate both the teachers’ and pupils’ needs. Through the design, implementation and evaluation of the evidence-based intervention programme, this project is an integration of research and practice in Chemical Education. Subject knowledge assessment of participating pupils, as well as feedback from the participating teachers and pupils, provided information to evaluate the usefulness and effectiveness of the Organic Chemistry intervention programme. The overall feedback from teachers and pupils was positive and evidence suggests the intervention programme was effective in improving pupils’ attitudes and understanding of Organic Chemistry. Implications for the intervention programme have been outlined with reference to the proposed new Leaving Certificate Chemistry syllabus.
Chapter 2
Science Education in Ireland
2.1 - Why study Science?

This introduction will discuss two different reasons why pupils at Second-Level and students at Third-Level need to study Science to some basic level. Many believe that school Science should serve as a preparation for a Science degree and ultimately a career in Science, while others value Science education as an opportunity for learners to develop a general scientific knowledge and understanding of the world that they live in, often described as scientific literacy.

2.1.1. Science to Drive the Economy

The growth of biopharmaceutical and pharmaceutical companies in Ireland has increased rapidly from the 1980’s so that it currently employs 25,300 people (Forfás 2010). Ireland has attracted many world leading pharmaceutical companies, with eight of the top ten global pharmaceutical companies based here. Industry leaders including Pfizer, Eli Lilly, Genzyme, Merck, Elan, GeneMedix and Allergan have significant investment in Ireland, which has facilitated rapid growth and development of the pharmaceutical industry (Forfás 2010).

In 2010, the Irish pharmaceutical and chemical sector exported products to the value of €50.8 billion. During a time of economic crisis, this was an increase in 7.3% from €47.2 billion in 2009 (Pharmachemical Ireland 2011b). Chemicals and chemical products accounted for nearly 60% of goods exports from Ireland in 2011 (Coffey 2011). Ireland’s pharmaceutical exports are currently the 7th largest in value in the world, and Ireland is the largest net exporter of pharmaceuticals in the world (Pharmachemical Ireland 2011a). Figure 2.1 shows the predicted employment in the biopharmaceutical and pharmaceutical sector in Ireland until 2015.

![Figure 2.1 Biopharma-pharmachemical sector employment 2000-201, reproduced from (Forfás 2010)](image-url)
While job losses are expected among craft persons, clerks and sale persons, job gains for chemical, production, mechanical and electronic engineers, biological and other natural scientists, scientific and laboratory technicians and business analysts are expected (Forfás 2010). This report on Future Skills requirements of the biopharma-pharmaceutical sector recommends that to ensure that Ireland can excel in the skills arena in the future, Science and Technology programmes will need to better prepare Irish graduates for the industry environment. This can be done by strengthening the practical application of Science courses and encouraging innovation among students. In order to sustain the companies listed above and attract further investment, Ireland must strive to ensure a constant supply of good quality Science graduates.

The Expert Group on Future Skills Needs (2008) recognised that as employment in sectors such as agriculture and the manufacturing of machinery decline, areas such as medical devices, pharmaceuticals and biotechnology hold the key to future growth. The availability of a skilled workforce is one of the key attractions for foreign companies locating in Ireland. It is also one of the key factors that drives the development of indigenous Irish industry. (Forfás 2008). It is important more than ever; in this current economic down-turn that Ireland maintains and further develops its reputation as a country with a highly skilled workforce. A skilled workforce should be able to respond to the changing needs of the economy and society that we live in.

“We fully recognise that Ireland can only succeed in long term technological and enterprise development if it has a sustainable base of excellent Science. Our schools, Universities and Institutes of Technology... are the bedrock on which this system should be built. We will continue to invest, in the knowledge that we can reap the long term economic benefits for the economy.” (Department Of Enterprise Trade And Employment 2006)

The teaching and learning of Science in Second-Level education is particularly important because it plays a major role in underpinning the study of Science-related courses at Third-Level. By improving teaching and learning strategies in Second-Level schools in Ireland, more pupils may be encouraged to take up Science at Third-Level in preparation for employment in the Irish Chemical Industry. Since most of Ireland’s chemical and pharmachemical industry is based on Organic Chemistry, this subject is particularly important at Second-Level and Third-Level.
2.1.2. Science for Understanding

As discussed in Section 2.1.1 above, the function of Science Education to provide a skilled workforce is a worthwhile and valuable aim. However, it is important to consider the pupils who study school Science without continuing to pursue Science Education at Third-Level or a career in Science.

“The problem with framing the discussion about school Science in terms of the supply of the next generation of scientists is that it defines the primary goal of Science education as a pipeline, albeit leaky.”

(Osborne and Dillon, 2008, pg. 7)

By focusing solely on the future scientists and engineers, there is a failure to recognise global and broader values of Science. Science Education should be universal and appealing to all learners, rather than the minority who will pursue careers in the field. Osborne and Dillon (2008) proposed that school Science should offer an education in Science, rather than a form of pre-professional training. People in today’s society need to have a basic scientific knowledge in order to understand global and local issues e.g. global warming, climate change, water treatment etc. To enable people to engage in such socio-scientific issues, school Science needs to show learners of all abilities ‘how science works’ and how it is relevant to everyday life.

In their report to the Nuffield Foundation on Science Education in Europe, Osborne and Dillon (2008) made seven key recommendations for Science education. These recommendations are summarised here:

1. The primary goal of Science education across the EU should be to educate learners both about the major explanations of the material world that Science offers and about the way Science works.

2. More attempts at innovative curricula and ways of organising the teaching of Science that address the issue of low learner motivation are required.

3. EU countries need to invest in improving the human and physical resources available to schools for informing learners, both about careers in Science – where the emphasis should be on why working in Science is an important cultural and humanitarian activity – and careers from Science where the emphasis should be on the extensive range of potential careers that the study of Science affords.
4. EU countries should ensure that teachers of Science of the highest quality are provided for pupils in Primary-Level and lower Second-Level school. The emphasis in Science education before 14 should be on engaging pupils with Science and scientific phenomena.

5. Developing and extending the ways in which Science is taught is essential for improving learner engagement.

6. EU governments should invest significantly in research and development in assessment in Science education. The aim should be to develop items and methods that assess the skills, knowledge and competencies expected of a scientifically literate citizen.

7. Good quality teachers, with up-to-date knowledge and skills, are the foundation of any system of formal Science education. Systems to ensure the recruitment, retention and continuous professional training of such individuals must be a policy priority in Europe. (Osborne and Dillon 2008)

These recommendations propose that school Science should allow the learners to engage in Science and to recognise and understand its relevance in their own lives and not just the lives of scientists.

“In an era of rapid technological change, the goal of "scientific literacy for all" has become a primary objective of a general education. Science is one of three literacy domains, along with reading and mathematics that is included in measures of educational achievement by the OECD”.

(Report and Recommendations – Task Force on the Physical Sciences, 2002, pg. i)
2.2– Science and Mathematics in Irish Education

In contrast to this demand for a scientifically educated population described above, there has in recent years been a decline of interest in Science throughout the Irish education system (DES 2002). Since the early 1990’s there has been a decline in take-up of Science among Second-Level pupils. Although participation at lower Second-Level has been relatively stable, this is not the case at Senior Cycle. In 2011 only 14.1% of Leaving Certificate pupils were enrolled in Chemistry and 12.0% in Physics, a marked decline on the situation in 1990 when 16.0% took Chemistry and 20.0% took Physics (SEC 2011). Physical sciences uptake is also put in context by enrolment levels in Leaving Certificate Biology, which stood at 55.8% in 2011 (up from below 40.0% in 2002) (SEC 2011). This gap in uptake between Biology and the physical sciences is unusually wide in Ireland compared to other countries.

However, despite this poor uptake of the physical sciences in the Irish education system, the Programme for International Student Assessment (PISA) report conducted by the Organisation for Economic Co-operation and Development (OECD) in 2007 found that Irish Second-Level pupils (aged 15-18) scored just above the OECD average in their Science performance. (This was measured on the PISA 2006 Science scale). This PISA report involved more than 400,000 Second-Level participants from 57 countries worldwide. The above average performance of Irish 15-18 year olds in this report is very encouraging. Table 2.1 below summarises how the Irish pupils’ performance in Science in the PISA reports has remained consistent over the past 10 years. In comparison, their performance in Reading and Mathematics has decreased. The important relationship between Reading and Mathematics with Science will be discussed in detail in Chapter Three (Section 3.2).

Table 2.1 Ireland’s performance in the PISA from 2000 to 2009 (OECD 2010)

<table>
<thead>
<tr>
<th>Year</th>
<th>Reading</th>
<th>Maths</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>496</td>
<td>487</td>
<td>508</td>
</tr>
<tr>
<td>2006</td>
<td>517</td>
<td>501</td>
<td>509</td>
</tr>
<tr>
<td>2003</td>
<td>515</td>
<td>503</td>
<td>505</td>
</tr>
<tr>
<td>2000</td>
<td>527</td>
<td>503</td>
<td>513</td>
</tr>
</tbody>
</table>
2.2.1. The Irish Education System.

The Irish education system is made up of three main levels: primary, secondary and tertiary. These levels are illustrated and outlined in Figure 2.2 below.

![Figure 2.2: Structure of the Irish Education System.](image)

**Primary Level**
- Duration 8 years
- Compulsory
- Pupils’ age: 4-12 years
- No terminal examination

**Second-Level**
- Duration 5 or 6 years
- Pupils' age: 13-18 years
- **Junior Cycle** (3 year programme) - Compulsory
  Terminal examination: Junior Certificate examination
- Optional intermediate year - **Transition Year**.
- **Senior Cycle** (2 year programme) - Not compulsory
  Terminal examination: Leaving Certificate examination

**Third-Level**
- Not compulsory
- Entry is dictated by performance in the Leaving Certificate examination
- Post Leaving Certificate courses (PLCs)
- Apprenticeship Training
- Universities
- Institutes of Technology
- NUI Colleges
- State-Aided institutions
- Private colleges
- Colleges of Education

As outlined in Figure 2.2, compulsory education in Ireland ceases after the Junior Certificate examination in Second-Level. However, Ireland has one of the highest rates of participation in education in the world; 80.5% of Irish 18 year olds were still in full-time education in 2010.
and approximately 53.5% of 21 year olds were enrolled in full-time education at Third-Level (DES 2011b). The Department of Education and Skills (DES) is responsible for education policy, curricula, syllabi and assessment. The National Council for Curriculum and Assessment (NCCA) advises the Minister of Education and Skills on the design and development of curricula and how they are assessed at Primary-Level and Second-Level. The State Examination Commission (SEC) is responsible for the development, assessment, accreditation and certification of the second-level examinations.

**Primary-Level Education**

Pupils enter primary schools in Ireland at age 4-5 years. There are two infant classes (junior and senior), before the pupils begin first class. The pupils progress from first class to sixth class before leaving Primary-Level education at the age of 12-13 years. There are no formal examinations at the end of the Primary-Level education.

There are two main types of primary schools: state-funded schools and private schools. The state-funded schools include religious schools, non-denominational schools and multi-denominational schools as well as Gaelscoils (Irish-speaking schools).

The Primary Curriculum is divided into the following key areas: Languages, Mathematics, Social, Environmental and Scientific Education, Arts Education, Physical Education and Social, Personal and Health Education.

Social, Environmental and Scientific Education (SESE) is where Science education is covered at Primary-Level. This subject aims to provide opportunity for the learner to:

- Explore, investigate and develop an understanding of the natural, human, social and cultural dimensions of local and wider environments.
- Learn and practise a wide range of skills.
- Acquire open, critical and responsible attitudes.
- Live as an informed and caring member of local, national, European and global communities.

(DES 1999b)
Second-Level Education

Second-Level education builds on what the pupils have learned at Primary-Level. There are several different types of Second-Level schools in Ireland but they all offer the same state curricula which are outlined by the DES. The different school types include secondary schools, community schools and comprehensive schools, which are generally denominational. It is important to note that the title ‘secondary school’ in Ireland refers to only one type of Second-Level school. Vocational schools are usually non-denominational. Pupils enter Second-Level schools (about age 12-13 years) after completion of the Primary-Level education.

Second-Level education may be divided into two distinct cycles: junior and senior. The Transition Year is an optional intermediate year after the Junior Cycle and before pupils begin the Senior Cycle of Second-Level education.

The Junior Cycle is a three year programme which terminates with the Junior Certificate examination. The Junior Cycle falls within the compulsory period of education in Ireland. There are two courses: the mainstream Junior Certificate Programme and the Junior Certificate Schools’ Programme. Pupils who are at risk of leaving education early may follow this Junior Certificate Schools’ Programme. The Junior Certificate examination is a written examination taken in eight to ten subjects at the end of the first three years of Second-Level education. 56,930 pupils sat the Junior Certificate examination in 2011 (SEC 2011). There are practical examinations, project work and aural exams for some of the subjects as well as the written examination. Coursework accounts for 35% of the Junior Certificate Science course. The Junior Certificate Science course will be discussed in more detail in Section 2.2.2 below.

After the Junior Certificate programme (3 years), the pupils have a choice to take an optional one year Transition Year programme or to progress straight into the Leaving Certificate programme (2 years). The Transition Year (TY) programme is available to all Second-Level schools in Ireland, but currently approximately 75% of Second-Level schools offer the TY programme (NCCA 2011c). Overall, just about 50% of the Leaving Certificate cohort take the TY programme. The TY curriculum is made up of core subjects, sampling subjects, TY specific modules and ‘once off’ activities. Science is listed as one of the sampling subjects in the TY curriculum. The TY curriculum encourages pupils to study areas of Science that they
have not encountered before e.g. astronomy, the chemical industry in Ireland, and food and agricultural industry. The TY guidelines also stress that this year should not be used as an opportunity to begin Leaving Certificate curricula with the pupils. However, recent work by Hayes (2011) found that almost 90% of teachers use the year to teach from the Leaving Certificate Science syllabi (Hayes 2011). The practical work for Science in this year should be more investigatory rather than instructional, as is the case for much of the mandatory Science experiments at junior and senior cycles. The study of Science in TY should enable the pupils to have a broader understanding of the subject and of its pervasive role in today’s world (DES 1994). In a study carried out by the Association of Secondary Teachers in Ireland (ASTI) involving 334 schools in 2009, it was found that 76% of schools offering the TY programme, provide a Science module for the pupils (ASTI 2009).

The Senior Cycle is a two-year programme. The Senior Cycle terminates with the Leaving Certificate examination. Pupils study a minimum of six subjects for this examination. The grades scored in each subject are converted to points (out of 100). Each candidate is given a total score marked out of 600 points for their Leaving Certificate examination. These points determine the pupils’ entry to Third-Level education. The Central Applications Office (CAO) office is responsible for processing the pupils’ applications to Third-Level institutions according to their Leaving Certificate points. The participating Third-Level institutions have a minimum number of entry points for each course which can vary from year to year depending on the course demand.

In 2011, 54,341 pupils sat the Leaving Certificate examination (SEC 2011). The Leaving Certificate examination is a written examination at the end of the Senior Cycle. As in the Junior Certificate, parts of some subjects are assessed by project work, mandatory practical activities, oral and aural examinations. Each of the current Leaving Certificate Science subjects include mandatory experiments. While the pupils are expected to keep a laboratory note-book with a record of each mandatory experiment carried out, these experiments are only assessed as part of the written examination. There are five Science subjects that the pupils can study for their Leaving Certificate examination. These are Biology, Chemistry, Physics, Physics & Chemistry (as a combined subject) and Agricultural Science.
2.2.2. Junior Certificate Science

Science is not a compulsory subject for the Junior Certificate in Ireland. Ireland is unique among 21 other European countries in not having Science as a compulsory subject at lower Second-Level (Oireachtas Library and Research Services, 2009). Second-Level schools vary as to whether they provide Science for all Junior Cycle pupils or whether it is time-tabled against other subjects. While schools cannot be expected to privilege particular kinds of subjects, time-tableing should facilitate the widest choice possible for pupils (Smyth and Hannon 2003).

As well as Science not being a compulsory subject, Irish Second-Level pupils receive a lower proportion of teaching time in Science when compared to the OECD and EU average. Despite this poor provision of Science, the Irish pupils 15-18 years old scored above average in the PISA Science performance test (OECD 2007). The importance of Science subjects to the future ‘knowledge economy’ is such that Science needs to be made a compulsory subject at Junior Cycle (Engineers Ireland 2012). While the majority of pupils do study Science for their Junior Certificate, it tends to be females and the lower ability pupils that are less likely to study Science. It has also been recommended that making Junior Certificate Science compulsory would help to enhance the equity and accessibility of the subject (Smyth and Hannon 2003).

The revised Junior Certificate Science syllabus was introduced in 2003 and examined for the first time in 2006. The previous Science syllabus was introduced in 1989. This old 1989 syllabus was no longer examined after June 2008. Junior Certificate Science includes Biology, Chemistry and Physics. The revised syllabus differed from the previous syllabus introduced in in 1989 in a number of respects:

- An increased emphasis on scientific investigation and on the application of Science process skills in pupil activities.
- The overall length of the syllabus was reduced to allow for pupil engagement in learning activities that will enable them to gain a better understanding of the Science concepts involved and to develop their Science process skills.
- Topics were presented under three main headings—Biology, Chemistry and Physics—each of which is sub-divided into three sections.
• Within each syllabus section, topics and sub-topics are described, together with associated learning outcomes. The learning outcomes embody the investigative approach emphasised in the revised syllabus and form the basis of the assessment arrangements. 

(NCCA 2003)

In comparison to the previous course, which was assessed only by a terminal written examination, this revised syllabus contains two items of coursework (A and B) which are assessed, as well as a terminal written examination at the end of the three year course. Coursework A comprises the carrying out and recording of the 30 mandatory pupil activities identified in the syllabus. This component of the coursework is worth 10% of the final grade. Coursework B involves the pupils in carrying out investigative work based on the syllabus topics and learning outcomes. The pupils submit a report of this work. This investigative work may take the form of two separate investigations selected from three to be nominated each year by the SEC (one each in Biology, Chemistry and Physics), or a single Science investigation of the pupil’s own choosing, which meets specified criteria. Coursework B is worth 25% of the final grade. The written examination is worth 65%.

Even though the provision of Science at Junior Certificate is not compulsory, the participation rates are still quite high. Over the past 10 years (with the exception of 2004) over 86% of the Junior Certificate cohort, have studied Science. The participation in Junior Certificate Science as a percentage of the total Junior Certificate cohort is presented in Figure 2.3 below.

![Percentage of total Junior Certificate cohort studying Science](image)

*Figure 2.3 Participation in Junior Certificate Science as a percentage of the total Junior Certificate cohort. (SEC 2011)*
It can be seen that over 86.0% of the Junior Certificate candidates (with the exception of 2004) studied Science. The percentage of pupils studying Science hit a high of 90% in 2010, but this has decreased slightly to 88.8% in 2011. The number of participants studying Science each year is listed in Table 2.2 which follows.

**Table 2.2 Percentage of Junior Certificate Science students taking the Higher Level and Ordinary Level examinations 2001-2011 (SEC 2011).**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total number of participants</th>
<th>Higher Level (% of candidates)</th>
<th>Ordinary Level (% of candidates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>50,578</td>
<td>60.9</td>
<td>39.1</td>
</tr>
<tr>
<td>2002</td>
<td>52,092</td>
<td>62.2</td>
<td>37.8</td>
</tr>
<tr>
<td>2003</td>
<td>51,090</td>
<td>63.9</td>
<td>36.1</td>
</tr>
<tr>
<td>2004</td>
<td>47,726</td>
<td>62.1</td>
<td>37.9</td>
</tr>
<tr>
<td>2005</td>
<td>48,877</td>
<td>63.1</td>
<td>36.9</td>
</tr>
<tr>
<td>2006</td>
<td>50,069</td>
<td>67.2</td>
<td>32.8</td>
</tr>
<tr>
<td>2007</td>
<td>49,747</td>
<td>70.1</td>
<td>29.9</td>
</tr>
<tr>
<td>2008</td>
<td>48,691</td>
<td>68.9</td>
<td>31.1</td>
</tr>
<tr>
<td>2009</td>
<td>48,531</td>
<td>70.6</td>
<td>29.4</td>
</tr>
<tr>
<td>2010</td>
<td>49,448</td>
<td>71.8</td>
<td>28.2</td>
</tr>
<tr>
<td>2011</td>
<td>50,339</td>
<td>75.3</td>
<td>24.7</td>
</tr>
</tbody>
</table>

Table 2.2 shows a breakdown of the percentage of Junior Certificate candidates studying Higher Level and Ordinary Level Science. It also shows the total number of candidates that studied Science each year. From the percentages listed in Table 2.2, the trend of increasing numbers taking the Higher Level course can easily be observed. There has been an increase of almost 15% of candidates now taking the Higher Level course with a parallel decrease in the percentage studying Ordinary Level Science. An investigation involving 334 schools teaching Junior Certificate Science found that Higher and Ordinary Level Science classes are amalgamated in over 70% of schools (ASTI 2009).

Table 2.3 shows a breakdown of the percentage of males and females studying Junior Certificate Science over the past 10 years. Up until 2009, there were slightly more males than females studying Junior Certificate Science. This imbalance of males and females taking Science was also observed in the years prior to 2002 and was noted by the Task Force Report on the Physical Sciences in 2002. However, in 2010, there were more females (52.1%) than males (47.9%) studying the subject for the Junior Certificate. The Task Force on Physical Sciences (2002) found that female candidates who take Science are more likely to take it at a Higher Level.
Table 2.3 Percentage breakdown of male and female pupils studying Junior Certificate Science 2001-2010 (SEC 2011).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total number of participants</th>
<th>Males (% of total Science candidates)</th>
<th>Females (% of total Science candidates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>50,578</td>
<td>52.9</td>
<td>47.1</td>
</tr>
<tr>
<td>2002</td>
<td>52,092</td>
<td>52.5</td>
<td>47.5</td>
</tr>
<tr>
<td>2003</td>
<td>51,090</td>
<td>52.7</td>
<td>47.3</td>
</tr>
<tr>
<td>2004</td>
<td>47,726</td>
<td>52.4</td>
<td>47.6</td>
</tr>
<tr>
<td>2005</td>
<td>48,877</td>
<td>54.4</td>
<td>47.6</td>
</tr>
<tr>
<td>2006</td>
<td>50,069</td>
<td>52.8</td>
<td>47.2</td>
</tr>
<tr>
<td>2007</td>
<td>49,747</td>
<td>52</td>
<td>48</td>
</tr>
<tr>
<td>2008</td>
<td>48,691</td>
<td>52.4</td>
<td>47.6</td>
</tr>
<tr>
<td>2009</td>
<td>48,531</td>
<td>52.6</td>
<td>47.4</td>
</tr>
<tr>
<td>2010</td>
<td>49,448</td>
<td>47.9</td>
<td>52.1</td>
</tr>
</tbody>
</table>

Table 2.4 shows the pupils’ performance in the Higher Level Junior Certificate examinations from 2001 to 2011. There has been a decrease of 5.6% in the percentage of A grades achieved over this 10 year period. The percentage of pupils achieving B grades at Higher Level has remained consistent, at about ~30%, while the percentage of C grades has increased by about ~6%. Overall there has been a decrease in the percentage of lower grades, suggesting that as the percentage of pupils studying Higher Level Science is increasing, performance of the whole cohort is not weakening. However, the decreasing percentage of A grades should be an issue of come concern.

Table 2.4. Percentage breakdown of grade and cumulative percentage of A, B, C grades and E, F, NG grades in Higher Level Junior Certificate Science for years 2001-2011 (SEC 2011).

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>ABC</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>NG</th>
<th>E,F,NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>14.8</td>
<td>30.1</td>
<td>31.5</td>
<td>76.4</td>
<td>18.5</td>
<td>4.3</td>
<td>0.8</td>
<td>0.1</td>
<td>5.2</td>
</tr>
<tr>
<td>2002</td>
<td>15.3</td>
<td>27.9</td>
<td>29.9</td>
<td>73.1</td>
<td>20.5</td>
<td>5.4</td>
<td>1</td>
<td>0.1</td>
<td>6.5</td>
</tr>
<tr>
<td>2003</td>
<td>14.8</td>
<td>29.3</td>
<td>31.9</td>
<td>76.4</td>
<td>19.4</td>
<td>4</td>
<td>0.5</td>
<td>0</td>
<td>4.5</td>
</tr>
<tr>
<td>2004</td>
<td>16.3</td>
<td>29.4</td>
<td>28.7</td>
<td>74.4</td>
<td>19.2</td>
<td>5.2</td>
<td>1.1</td>
<td>0.1</td>
<td>6.4</td>
</tr>
<tr>
<td>2005</td>
<td>14.5</td>
<td>27.5</td>
<td>29.2</td>
<td>71.2</td>
<td>21.9</td>
<td>5.8</td>
<td>1</td>
<td>0.1</td>
<td>6.9</td>
</tr>
<tr>
<td>2006</td>
<td>10.5</td>
<td>30.9</td>
<td>37.7</td>
<td>79.1</td>
<td>18.4</td>
<td>2</td>
<td>0.4</td>
<td>0.1</td>
<td>2.5</td>
</tr>
<tr>
<td>2007</td>
<td>10.2</td>
<td>31</td>
<td>36.8</td>
<td>78</td>
<td>20</td>
<td>1.8</td>
<td>0.2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2008</td>
<td>8.1</td>
<td>29.9</td>
<td>41.3</td>
<td>79.3</td>
<td>19.5</td>
<td>1</td>
<td>0.2</td>
<td>0</td>
<td>1.2</td>
</tr>
<tr>
<td>2009</td>
<td>9.2</td>
<td>30.4</td>
<td>37.7</td>
<td>77.3</td>
<td>20.9</td>
<td>1.7</td>
<td>0.2</td>
<td>0</td>
<td>1.9</td>
</tr>
<tr>
<td>2010</td>
<td>10.4</td>
<td>34.9</td>
<td>38</td>
<td>93.3</td>
<td>15.7</td>
<td>0.8</td>
<td>0.2</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>2011</td>
<td>9.2</td>
<td>30.4</td>
<td>37.7</td>
<td>77.3</td>
<td>20.9</td>
<td>1.7</td>
<td>0.2</td>
<td>0</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Table 2.5 shows the pupils’ performance in the Ordinary Level Junior Certificate Science examinations for the past 10 years. Overall, there is a decrease the percentage of A, B and C grades achieved. This corresponds to the increase in the percentage of D grades and E, F, NG grades. While the pupils’ performance in the Ordinary Level examination seems to be weakening, it should be noted that the numbers studying Ordinary Level Science are also decreasing.

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>ABC</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>NG</th>
<th>E,F,NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>7.7</td>
<td>37.6</td>
<td>37.9</td>
<td>83.2</td>
<td>14.4</td>
<td>2.1</td>
<td>0.3</td>
<td>0</td>
<td>2.4</td>
</tr>
<tr>
<td>2002</td>
<td>5.8</td>
<td>31.9</td>
<td>36.9</td>
<td>74.6</td>
<td>19.5</td>
<td>4.7</td>
<td>1</td>
<td>0.1</td>
<td>5.8</td>
</tr>
<tr>
<td>2003</td>
<td>6.4</td>
<td>32.7</td>
<td>38.4</td>
<td>77.5</td>
<td>19</td>
<td>3</td>
<td>0.4</td>
<td>0</td>
<td>3.4</td>
</tr>
<tr>
<td>2004</td>
<td>12.2</td>
<td>44.8</td>
<td>31.6</td>
<td>88.6</td>
<td>9.9</td>
<td>1.2</td>
<td>0.2</td>
<td>0</td>
<td>1.4</td>
</tr>
<tr>
<td>2005</td>
<td>7.7</td>
<td>32.6</td>
<td>35.2</td>
<td>75.5</td>
<td>19.6</td>
<td>4.3</td>
<td>0.6</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>2006</td>
<td>1.9</td>
<td>24.8</td>
<td>45.4</td>
<td>72.1</td>
<td>21.4</td>
<td>4.2</td>
<td>1.8</td>
<td>0.2</td>
<td>6.2</td>
</tr>
<tr>
<td>2007</td>
<td>2.7</td>
<td>34.7</td>
<td>41.4</td>
<td>78.8</td>
<td>16.1</td>
<td>3.8</td>
<td>1.2</td>
<td>0.1</td>
<td>5.1</td>
</tr>
<tr>
<td>2008</td>
<td>3.4</td>
<td>36.7</td>
<td>43.3</td>
<td>83</td>
<td>13</td>
<td>2.8</td>
<td>0.7</td>
<td>0</td>
<td>3.5</td>
</tr>
<tr>
<td>2009</td>
<td>2.5</td>
<td>33</td>
<td>44.2</td>
<td>79.7</td>
<td>15.9</td>
<td>3.3</td>
<td>1</td>
<td>0.1</td>
<td>4.4</td>
</tr>
<tr>
<td>2010</td>
<td>1.8</td>
<td>32.6</td>
<td>45.8</td>
<td>80.2</td>
<td>15.4</td>
<td>3.2</td>
<td>1.1</td>
<td>0.2</td>
<td>4.5</td>
</tr>
<tr>
<td>2011</td>
<td>1.4</td>
<td>30</td>
<td>47.2</td>
<td>78.6</td>
<td>17.3</td>
<td>3</td>
<td>1.1</td>
<td>1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

2.2.3. Leaving Certificate Sciences

Five Science subjects are available for study for the Leaving Certificate. These include Biology, Chemistry, Physics, Physics & Chemistry and Agricultural Science. Pupils may take any combination of the Science subjects, except Physics & Chemistry may not be taken with Physics or Chemistry as individual subjects. It can be seen from Figure 2.4 that Biology is the most preferred Science subject to study at senior cycle. Although, participation rates in Chemistry and Agricultural Science are still low, they have increased over the past 10 years. In comparison the percentage of pupils studying Physics and Physics & Chemistry has decreased in recent years. However, while Biology is the most popular Science subject for the Leaving Certificate, it is clear that there is still a large decrease in Science uptake from the Junior Certificate where up to 90% of the pupils are studying Science (Figure 2.3). The PISA report (OECD 2007) found that Irish pupils with a more advantaged socio-economic background were more likely to show an interest in Science. One significant feature of a pupil’s background was whether they had a parent in a Science-related career. The pupils’
uptake of Science at Senior Cycle may be a reflection of the pupils’ experience of Junior Certificate Science. Smyth and Hannon (2003) found that Science take-up for the Leaving Certificate tends to be higher in schools which emphasise practical work.

“An emphasis on the practical aspects of Science and its relevance for everyday life would appear to result in more positive attitudes to the subject and, therefore, greater take-up”

(Smyth and Hannon 2003)

As well as experiences from the Junior Certificate Science, subject options and choices and time-tabling issues are all factors to be considered when discussing the poor uptake of Science subjects for the Leaving Certificate, and in particular the poor uptake of the physical sciences. There are differences between schools in the take-up of Biology, Chemistry and Physics. Although there is a strong infrastructure for Science education in Irish Second-Level schools, cutbacks in education are undermining the schools’ capacity to offer all Science subjects. The increasing pupil-teacher ratio and loss of grants for Physics and Chemistry have affected the provision of these subjects at Senior Cycle. 14% of schools dropped Science subjects from the school timetable in 2007. 65% of these schools no longer offer Physics and 33% no longer offer Chemistry (ASTI 2009). Table 2.6 below summarises the number and percentage of Second-Level schools offering each of the Leaving Certificate Science subjects in 2011.
Table 2.6 Provision of Leaving Certificate Science subjects in Ireland 2010-2011 (DES 2011b)

<table>
<thead>
<tr>
<th>Provision of Leaving Certificate Science subjects</th>
<th>Number of Second-Level schools</th>
<th>% of total number of Second-Level schools (698)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>685</td>
<td>98.1</td>
</tr>
<tr>
<td>Chemistry</td>
<td>563</td>
<td>80.7</td>
</tr>
<tr>
<td>Physics</td>
<td>535</td>
<td>76.6</td>
</tr>
<tr>
<td>Agricultural Science</td>
<td>316</td>
<td>45.3</td>
</tr>
<tr>
<td>Physics &amp; Chemistry</td>
<td>40</td>
<td>1.43</td>
</tr>
</tbody>
</table>

As well as limiting the subject choice available to pupils, education cut-backs have also led to amalgamation of classes in many cases. Higher Level and Ordinary Level classes are now amalgamated in 7 out of 10 schools and 1 in 10 schools have amalgamated 5th and 6th Year classes (ASTI 2009). In their report, Smyth and Hannon (2003) also highlighted that Science subjects are not made available to all pupils (Table 2.6). The vast majority of schools provide Biology for the Leaving Certificate but a significant minority of schools do not provide Physics and Chemistry. These are mainly smaller schools and those serving more disadvantaged populations. The Junior Cycle Science Survey Report (ASTI 2009) highlighted the need to up-skill Science teachers to ensure pupils take physical science subjects. 60% (n= 334) of Junior Cycle Science teachers who responded to this survey stated that they teach Biology at Senior Cycle, followed by 40% teaching Chemistry and only 22% teaching Physics. This finding raises the question of how to ensure that a greater number of Science teachers acquire the qualifications to teach the physical sciences.

54,341 pupils sat the Leaving Certificate in 2011. Table 2.7 shows a breakdown of the participation in each of the Science subjects by gender and level. A greater number of females studied Biology and Chemistry, while the other subjects (Physics, Physics & Chemistry and Agricultural Science) were more popular among the males. Over 80% of those that studied Chemistry, Agricultural Science and Physics & Chemistry took the subjects at Higher Level. However, the percentage of pupils studying Higher Level Biology and Physics was lower (below 75%).

The trends observed in Table 2.7 were also observed by Smyth and Hannon (2003). Boys who take Chemistry and girls who take any of the Science subjects tend to be a selective
group, disproportionately of higher ability and from professional backgrounds. In comparison, boys taking Physics and Biology tend to be from a range of different ability levels and backgrounds (Smyth and Hannon 2003). This report recommended the promotion of Science as ‘Science for all’ rather than the view of science as an elite subject. 40% of teachers agree that pupils have a more negative attitude towards Science than other subjects. This may be driven by a perception of the difficulty of the subject, given that this factor is seen to be the greatest barrier to the up-take of Physics and Chemistry for the Leaving Certificate. 50% of teachers surveyed felt that pupils perceived the subjects as too theoretical and removed from everyday life (ASTI 2009).
### Table 2.7  Gender and Level breakdown of participation in Science subjects in the 2011 Leaving Certificate (SEC 2011).

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>8,410 (27.7%)</td>
<td>14,267 (47.0%)</td>
<td>22,677 (74.7%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>3,241 (10.7%)</td>
<td>4,431 (14.5%)</td>
<td>7,672 (25.3%)</td>
</tr>
<tr>
<td></td>
<td>11,651 (38.4%)</td>
<td>18,698 (61.6%)</td>
<td>30,349 (55.8%</td>
</tr>
<tr>
<td></td>
<td>Biology candidates</td>
<td>Biology candidates</td>
<td>total LC cohort</td>
</tr>
<tr>
<td><strong>Chemistry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,743 (35.7%)</td>
<td>3,529 (46.0%)</td>
<td>6,272 (81.7%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>692 (9.0%)</td>
<td>713 (9.3%)</td>
<td>1,405 (18.3%)</td>
</tr>
<tr>
<td></td>
<td>3,435 (47.7%)</td>
<td>4,242 (55.3%)</td>
<td>7,677 (14.1% of total LC cohort)</td>
</tr>
<tr>
<td></td>
<td>Chemistry candidates</td>
<td>Chemistry candidates</td>
<td></td>
</tr>
<tr>
<td><strong>Physics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>3,462 (53.1%)</td>
<td>1,322 (20.3%)</td>
<td>4,782 (73.4%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>1,436 (22.0%)</td>
<td>298 (4.6%)</td>
<td>1,734 (26.6%)</td>
</tr>
<tr>
<td></td>
<td>4,898 (75.2%)</td>
<td>1,620 (24.9%)</td>
<td>6,516 (12.0% of total LC cohort)</td>
</tr>
<tr>
<td></td>
<td>Physics candidates</td>
<td>Physics candidates</td>
<td></td>
</tr>
<tr>
<td><strong>Agricultural Science</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>3,181 (49.1%)</td>
<td>2,106 (32.5%)</td>
<td>5,287 (81.6%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>901 (13.9%)</td>
<td>285 (4.4%)</td>
<td>1,186 (18.3%)</td>
</tr>
<tr>
<td></td>
<td>4,082 (63.1%)</td>
<td>2,391 (36.9%)</td>
<td>6,473 (11.9% of total LC cohort)</td>
</tr>
<tr>
<td></td>
<td>Agricultural Science candidates</td>
<td>Agricultural Science candidates</td>
<td></td>
</tr>
<tr>
<td><strong>Physics and Chemistry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>211 (44.7%)</td>
<td>168 (35.6%)</td>
<td>379 (80.3%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>61 (12.9%)</td>
<td>32 (6.8%)</td>
<td>93 (19.7%)</td>
</tr>
<tr>
<td></td>
<td>272 (57.6%)</td>
<td>200 (42.3%)</td>
<td>472 (0.9% of total LC cohort)</td>
</tr>
<tr>
<td></td>
<td>Physics and Chemistry candidates</td>
<td>Physics and Chemistry candidates</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** LC is an abbreviation for Leaving Certificate.
Figure 2.5 presents many of the reasons why pupils do not choose to study Physics or Chemistry for their Leaving Certificate (ASTI 2009). The main barriers are the perception of the subject as difficult and its irrelevance to everyday life and careers. These are the crucial issues that need to be addressed in order to reduce this negative perception that pupils hold toward the physical sciences.

The Report of the Task Force on Education of Mathematics and Science at Second-Level has made a number of recommendations to improve the uptake of the physical science subjects at Senior Cycle. These proposals include making Science compulsory at Junior Cycle, using the Transition Year to encourage Science uptake and the provision of more career guidance to inform pupils about careers in Science, Technology, Engineering and Mathematics. This report also highlighted the need to provide improved resources for laboratories in Second-Level schools (Engineers Ireland 2012). However, these changes have not addressed the perception of Physics and Chemistry as difficult subjects.
2.2.3.1. Leaving Certificate Chemistry.

This section will take a closer look at the uptake, performance and gender participation in Leaving Certificate Chemistry.

The 1980’s saw a gradual decline in participation rates in Leaving Certificate Chemistry. The number of candidates taking the Leaving Certificate Chemistry course reached a low of 11.1% in 1999 and 2000. However, in recent years there has been a steady increase to a high 14.3% in 2009 and 14.1% in 2011 (SEC 2011). Figure 2.6 shows the slowly increasing uptake of Leaving Certificate Chemistry over the past 13 years. The uptake of Chemistry at Leaving Certificate has increased by almost 3% over the past 13 years. Even though, the overall uptake is still quite low in comparison to the Biology uptake, this is an encouraging trend.

![Uptake of Leaving Certificate Chemistry](image)

**Figure 2.6 Percentage of total Leaving Certificate cohort studying Chemistry from 1998 to 2011(SEC 2011)**

Factors which have contributed to this improved participation include a rebalancing of syllabus content and the level of accessibility of the examination papers in 2000 in response to research carried out by the Education Research Centre (SEC 2005). This revised syllabus was first examined in 2002. Implementation of this syllabus incorporated in-service programmes for teachers, as well as new and improved text books and resources. Despite this, Chemistry is still viewed as a ‘difficult’ Leaving Certificate subject (Desmond 2008). As well as requiring logical thinking, mathematical ability and understanding of a complex vocabulary while learning Chemistry, pupils are required to apply these demands under the pressure of an examination situation.

Table 2.8 shows the participation in Leaving Certificate Chemistry by gender and level over the past 10 years.
Table 2.8 Participation in Leaving Certificate Chemistry from 2001 to 2011 by gender and level (SEC 2011)

<table>
<thead>
<tr>
<th>Level</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,284 (35.9%)</td>
<td>2,930 (46.1%)</td>
<td>5,214 (82.0%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>640 (10.1%)</td>
<td>501 (7.9%)</td>
<td>1,141 (18.0%)</td>
</tr>
<tr>
<td></td>
<td>2,924 (46.0%)</td>
<td>3,431 (54.0%)</td>
<td>6,355 (11.2% of total LC cohort)</td>
</tr>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,418 (37.2%)</td>
<td>3,147 (48.4%)</td>
<td>5,565 (85.7%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>599 (9.2%)</td>
<td>33 (5.1%)</td>
<td>932 (14.3%)</td>
</tr>
<tr>
<td></td>
<td>3,017 (46.4%)</td>
<td>3,480 (53.6%)</td>
<td>6,497 (11.7% of total LC cohort)</td>
</tr>
<tr>
<td>2003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,483 (37.0%)</td>
<td>3,248 (48.5%)</td>
<td>5,731 (85.5%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>602 (9.0%)</td>
<td>365 (5.5%)</td>
<td>967 (14.5%)</td>
</tr>
<tr>
<td></td>
<td>3,085 (46.0%)</td>
<td>3,613 (54.0%)</td>
<td>6,698 (11.9% of total LC cohort)</td>
</tr>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,608 (36.1%)</td>
<td>3,597 (49.8%)</td>
<td>6,205 (85.9%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>572 (7.9%)</td>
<td>450 (6.1%)</td>
<td>1,022 (14.0%)</td>
</tr>
<tr>
<td></td>
<td>3,180 (44.1%)</td>
<td>4,047 (55.9%)</td>
<td>7,227 (13.1% of total LC cohort)</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,544 (34.5%)</td>
<td>3,489 (47.4%)</td>
<td>6,033 (81.9%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>688 (9.3%)</td>
<td>645 (8.8%)</td>
<td>1,333 (18.1%)</td>
</tr>
<tr>
<td></td>
<td>3,232 (43.8%)</td>
<td>4,134 (56.2%)</td>
<td>7,366 (13.6% of total LC cohort)</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,444 (34.6%)</td>
<td>3,268 (46.2%)</td>
<td>5,712 (80.8%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>730 (10.3%)</td>
<td>629 (8.9%)</td>
<td>1,359 (19.2%)</td>
</tr>
<tr>
<td></td>
<td>3,174 (44.9%)</td>
<td>3,897 (55.1%)</td>
<td>7,071 (13.9% of total LC cohort)</td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,407 (34.8%)</td>
<td>3,322 (48%)</td>
<td>5,729 (82.7%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>644 (9.3%)</td>
<td>553 (8.0%)</td>
<td>1,197 (17.3%)</td>
</tr>
<tr>
<td></td>
<td>3,051 (44.1%)</td>
<td>3,875 (55.9%)</td>
<td>6,926 (13.6% of total LC cohort)</td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,504 (35.2%)</td>
<td>3,400 (47.8%)</td>
<td>5,904 (83.0%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>615 (8.6%)</td>
<td>595 (8.4%)</td>
<td>1,210 (17.0%)</td>
</tr>
<tr>
<td></td>
<td>3,119 (43.8%)</td>
<td>3,995 (56.2%)</td>
<td>7,114 (13.6% of total LC cohort)</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,614 (35.3%)</td>
<td>3,423 (46.2%)</td>
<td>6,037 (81.5%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>673 (9.1%)</td>
<td>693 (9.4%)</td>
<td>1,366 (18.5%)</td>
</tr>
<tr>
<td></td>
<td>3,287 (44.4%)</td>
<td>4,116 (55.6%)</td>
<td>7,403 (14.3% of total LC cohort)</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,688 (35.6%)</td>
<td>3,610 (47.8%)</td>
<td>6,298 (83.4%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>612 (8.1%)</td>
<td>638 (8.5%)</td>
<td>1,250 (16.6%)</td>
</tr>
<tr>
<td></td>
<td>3,300 (43.7%)</td>
<td>4,248 (56.3%)</td>
<td>7,548 (13.9% of total LC cohort)</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>2,743 (35.7%)</td>
<td>3,529 (46%)</td>
<td>6,272 (81.7%)</td>
</tr>
<tr>
<td>Ordinary</td>
<td>692 (9.0%)</td>
<td>713 (9.3%)</td>
<td>1,405 (18.3%)</td>
</tr>
<tr>
<td></td>
<td>3,435 (44.7%)</td>
<td>4,242 (55.3%)</td>
<td>7,677 (14.1% of total LC cohort)</td>
</tr>
</tbody>
</table>
Following many intervention projects in the 1980’s, the study of Physics and Chemistry was promoted and increased in girl’s schools as well as in co-educational schools. By 1996, 48.3% of the Leaving Certificate cohort studying Chemistry were females (Duane and Regan 2009). In 2011, 55.3% of the pupils studying Chemistry for the Leaving Certificate were females. Over the past 10 years, consistently more females than males have studied Leaving Certificate Chemistry.

It is interesting to note that when the gender breakdown across the Higher and Ordinary level examinations is analysed it is seen that a greater percentage of female candidates take Chemistry at Higher Level in comparison to the males. The exceptionally high proportion of female candidates taking the Higher Level examination is an indication that the pursuit of Ordinary Level Chemistry is not considered by many females (SEC 2002). Overall, the proportion of pupils taking Higher Level Chemistry (average = 83.3%) is much higher than in other subjects. For this reason, Chemistry is often described as an elitist subject; while few study Chemistry, most of those who do, study it at Higher Level. This indicates that Leaving Certificate Chemistry is taken by higher ability candidates and shunned by weaker candidates, even at Ordinary Level.

Table 2.9 is a summary of the pupils’ performance in Higher Level Chemistry since 2001. The percentage of A grades and the cumulative percentage of ABC grades have increased by over 11% in the past 11 years. 2001 was the last year that the old syllabus was examined. The results from 2002-2011 refer to the current Leaving Certificate syllabus.

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>ABC</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>E,F,NG</th>
<th>E,F,NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>11.4</td>
<td>27</td>
<td>26.1</td>
<td>64.5</td>
<td>22.8</td>
<td>7.3</td>
<td>4</td>
<td>1.2</td>
<td>12.5</td>
</tr>
<tr>
<td>2002</td>
<td>23</td>
<td>29.7</td>
<td>24.6</td>
<td>77.3</td>
<td>15.9</td>
<td>4.8</td>
<td>1.8</td>
<td>3</td>
<td>9.6</td>
</tr>
<tr>
<td>2003</td>
<td>26</td>
<td>30</td>
<td>22.8</td>
<td>78.8</td>
<td>9</td>
<td>4.2</td>
<td>1.2</td>
<td>0.4</td>
<td>5.8</td>
</tr>
<tr>
<td>2004</td>
<td>23</td>
<td>30</td>
<td>22.8</td>
<td>75.8</td>
<td>16.2</td>
<td>5.6</td>
<td>1.9</td>
<td>0.3</td>
<td>7.8</td>
</tr>
<tr>
<td>2005</td>
<td>22.2</td>
<td>30.3</td>
<td>24.3</td>
<td>76.8</td>
<td>16.5</td>
<td>4.8</td>
<td>1.6</td>
<td>0.4</td>
<td>6.8</td>
</tr>
<tr>
<td>2006</td>
<td>22.2</td>
<td>28.8</td>
<td>24.6</td>
<td>75.6</td>
<td>16.8</td>
<td>5.1</td>
<td>1.8</td>
<td>0.3</td>
<td>7.2</td>
</tr>
<tr>
<td>2007</td>
<td>21</td>
<td>33</td>
<td>24.9</td>
<td>78.9</td>
<td>15.6</td>
<td>3.6</td>
<td>1.6</td>
<td>0.3</td>
<td>5.5</td>
</tr>
<tr>
<td>2008</td>
<td>23.8</td>
<td>30.9</td>
<td>24</td>
<td>78.7</td>
<td>15.6</td>
<td>4.1</td>
<td>1.3</td>
<td>0.3</td>
<td>5.7</td>
</tr>
<tr>
<td>2009</td>
<td>22</td>
<td>31.2</td>
<td>36.9</td>
<td>90.1</td>
<td>15.6</td>
<td>4.6</td>
<td>1.8</td>
<td>0.5</td>
<td>6.9</td>
</tr>
<tr>
<td>2010</td>
<td>21</td>
<td>29.4</td>
<td>24.9</td>
<td>75.3</td>
<td>16.8</td>
<td>5.1</td>
<td>2.2</td>
<td>0.5</td>
<td>7.8</td>
</tr>
<tr>
<td>2011</td>
<td>22</td>
<td>30.6</td>
<td>23.7</td>
<td>76.3</td>
<td>15.3</td>
<td>5.6</td>
<td>2.4</td>
<td>0.6</td>
<td>8.6</td>
</tr>
</tbody>
</table>
There has been a decrease of almost 4% in the number of pupils failing the Higher Level examination paper. Since the introduction of the revised syllabus in 2002, results of the Higher Level paper in 2007 and 2009 saw the highest percentage of pupils attaining A, B and C grades: 78.9% and 90.1% respectively. The highest percentage of A grades was attained in 2003, with 26.0% of the Higher Level pupils scoring A grades. 2007 also saw the lowest failure rate of just 5.5% (Table 2.9). Overall, from 2002 to 2011, the average percentage of the Higher Level cohort attaining A, B and C grades is 77.1%, the average attaining D grades is 16.0% and the average percentage of pupils failing the Higher Level examination is 7.7%.

The percentage of A grades in the 2011 examination has been an improvement from the 2010 average. However, the failure rate in 2011 has increased by 0.8% from 2010. The application of consequential marking in recent years has removed the problem of candidates who make an error early in answering a mathematical problem losing large quantities of marks. Such changes in the marking scheme have encouraged pupils to attempt these often intimidating calculations and questions. This development has undoubtedly facilitated the improved grade distribution in recent years (SEC 2008).

Table 2.10 shows the pupils’ performance in the Ordinary Level examinations over the past 11 years.

Table 2.10 Percentage breakdown of grade and cumulative percentage of A,B,C grades and E,F,NG grades in Ordinary Level Leaving Certificate Chemistry for years 2001-2011(SEC 2011)

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>ABC</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>NG</th>
<th>EFNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>15.0</td>
<td>27.3</td>
<td>26.1</td>
<td>68.4</td>
<td>21.0</td>
<td>6.30</td>
<td>3.60</td>
<td>0.50</td>
<td>10.4</td>
</tr>
<tr>
<td>2002</td>
<td>4.70</td>
<td>20.7</td>
<td>30.3</td>
<td>55.7</td>
<td>26.4</td>
<td>9.20</td>
<td>6.80</td>
<td>1.90</td>
<td>17.9</td>
</tr>
<tr>
<td>2003</td>
<td>15.1</td>
<td>35.7</td>
<td>27.9</td>
<td>78.7</td>
<td>14.7</td>
<td>5.10</td>
<td>1.40</td>
<td>0.10</td>
<td>6.60</td>
</tr>
<tr>
<td>2004</td>
<td>9.20</td>
<td>29.7</td>
<td>31.2</td>
<td>70.1</td>
<td>21.0</td>
<td>5.10</td>
<td>3.20</td>
<td>0.70</td>
<td>9.00</td>
</tr>
<tr>
<td>2005</td>
<td>10.1</td>
<td>26.1</td>
<td>26.7</td>
<td>62.9</td>
<td>23.4</td>
<td>7.80</td>
<td>3.70</td>
<td>0.50</td>
<td>12.0</td>
</tr>
<tr>
<td>2006</td>
<td>7.00</td>
<td>25.5</td>
<td>27.6</td>
<td>60.1</td>
<td>24.6</td>
<td>8.20</td>
<td>6.00</td>
<td>1.30</td>
<td>15.5</td>
</tr>
<tr>
<td>2007</td>
<td>8.00</td>
<td>23.7</td>
<td>26.7</td>
<td>58.4</td>
<td>24.6</td>
<td>10.4</td>
<td>5.30</td>
<td>1.10</td>
<td>16.8</td>
</tr>
<tr>
<td>2008</td>
<td>1.90</td>
<td>30.3</td>
<td>24.0</td>
<td>56.2</td>
<td>18.6</td>
<td>7.80</td>
<td>4.90</td>
<td>1.20</td>
<td>13.9</td>
</tr>
<tr>
<td>2009</td>
<td>9.20</td>
<td>39.0</td>
<td>28.5</td>
<td>76.7</td>
<td>21.6</td>
<td>8.70</td>
<td>5.60</td>
<td>1.00</td>
<td>15.3</td>
</tr>
<tr>
<td>2010</td>
<td>7.60</td>
<td>22.2</td>
<td>26.4</td>
<td>56.2</td>
<td>25.5</td>
<td>10.1</td>
<td>6.80</td>
<td>1.60</td>
<td>18.5</td>
</tr>
<tr>
<td>2011</td>
<td>9.10</td>
<td>27.3</td>
<td>28.2</td>
<td>64.6</td>
<td>22.5</td>
<td>6.80</td>
<td>4.80</td>
<td>1.20</td>
<td>12.8</td>
</tr>
</tbody>
</table>

The changes in the structure and layout of the Ordinary Level examination paper, which occurred in the 1999-2001 period, resulted in an improved distribution of grades for Ordinary
Level candidates over that period. As in the Higher Level examinations, 2003 saw the highest percentage (15.1%) of students receiving A grades. 2003 also has the lowest failure rate (6.6%) for the Ordinary Level candidates since the introduction of the revised syllabus in 2002. The first examination of the revised syllabus showed a reverse of this trend, with fewer candidates receiving A, B and C grades and the percentage of candidates receiving E, F and NG grades increasing from 6.8% in 2000 to 17.9% in 2002 with the first examination of the revised syllabus. 2003 and 2004 saw fewer candidates failing the examination, but these percentages have begun to increase again in recent years. The highest failure rate (18.5%) over the past 10 years was in the 2010 examination. 2010 also saw the lowest percentage (56.2%) of A, B and C grades since 2002.

It can be seen from Table 2.11 above that the female candidates consistently attained a higher percentage of the A, B and C grades than their male counterparts in the 2002, 2005, 2008 and 2011 Higher Level Chemistry examinations. Conversely, the male candidates attained a higher percentage of D grades and failures in the same examinations. However, in 2008, the male candidates slightly outperformed female candidates with a higher A grade return of 24.3% (the overall A grade rate was 23.7% and the A grade rate for female candidates was 23.3%). This is an exact reversal of the situation observed in the Chief Examiner’s Reports of 2002 and 2005, where the females outperformed the males in terms of A grades.

Table 2.11 Distribution of Higher Level Leaving Certificate Chemistry grades by gender (SEC 2011).

<table>
<thead>
<tr>
<th>Year</th>
<th>Gender</th>
<th>% Grades</th>
<th>ABC % D Grades</th>
<th>% Grades EFNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Male</td>
<td>74.0</td>
<td>16.8</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>77.5</td>
<td>16.6</td>
<td>8.2</td>
</tr>
<tr>
<td>2008</td>
<td>Male</td>
<td>75.6</td>
<td>17.5</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>81.0</td>
<td>14.2</td>
<td>4.7</td>
</tr>
<tr>
<td>2005</td>
<td>Male</td>
<td>75.0</td>
<td>17.1</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>78.0</td>
<td>16.1</td>
<td>5.9</td>
</tr>
<tr>
<td>2002</td>
<td>Male</td>
<td>74.2</td>
<td>17.9</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>79.3</td>
<td>14.5</td>
<td>6.2</td>
</tr>
</tbody>
</table>

A similar trend was also observed in the Ordinary Level examination results for these years (SEC 2002, 2005, 2008). The Chief Examiner (D.E.S., 2002) noted that this phenomenon is common in most subject areas and the pattern is not significantly different from what has been observed for several years.
2.2.4. Mathematics at Second-Level

Mathematics is compulsory for Junior Certificate pupils. The pupils can sit the Mathematics examination at three levels; Higher, Ordinary or Foundation. The study of Mathematics has relevance to the learners’ understanding of Science and Chemistry. The important role of Mathematics and how it can contribute to the perceived difficulties in Chemistry will be discussed in Chapter Three (Section 3.2).

The current Junior Certificate Mathematics syllabus was introduced in 2000 and first examined in 2003. This revised syllabus emphasises teaching for understanding and active teaching methods. Over the past ten years, there has been a decrease in the percentage of pupils studying Mathematics at Ordinary Level and Foundation Level for the Junior Certificate. There has also been a distinct increase in the percentage of pupils studying Mathematics at Higher level. This increased from 35.7% in 2001 to 45.6% in 2011, although it is still below the NCCA’s target of 60% (Engineers Ireland 2012). The Junior Certificate Mathematics curriculum and how it is taught has an impact on the pupils’ uptake of Higher Level Mathematics for the Leaving Certificate. In the Taskforce of Mathematics and Science at Second-Level, it was suggested that improving how Mathematics is taught at Junior Cycle will have a positive effect and lead to increased uptake of the subject at Higher Level for the Leaving Certificate (Engineers Ireland 2012).

Leaving Certificate Mathematics is also offered at three levels. The current Higher Level and Ordinary Level courses were introduced in 1992. The current Foundation Level course for the Leaving Certificate was first introduced in 1995 and then examined in 1997. While the average percentage of Junior Certificate pupils studying Higher Level Mathematics is about 46%, the percentage of pupils that continue to study Higher Level Mathematics for their Leaving Certificate is much lower. Currently, nearly two thirds of Higher Level students at Junior Cycle drop to Ordinary Level in Senior Cycle (Engineers Ireland 2012). Figure 2.7 shows the pupils’ participation in Leaving Certificate Mathematics at the three different levels over the past 10 years. While the number of pupils taking Ordinary Level Mathematics has remained relatively stable (average = 71.7%), the trend lines in the graph highlight the decreasing number of pupils taking Higher Level (18% in 2001 to 15.8% in 2011) and the increasing number of pupils opting for the Foundation Level course (9.5% in 2001 to 12.1% in 2011). This overall decline in the level at which pupils are studying Mathematics for their Leaving Certificate was also observed by Engineers Ireland (2010).
When the current Higher Level Mathematics syllabus was introduced, the ultimate aim was to increase the uptake to 20-25% of the cohort. The uptake level is currently at 15.8%. While this is an increase from the level of below 12% when the syllabus was introduced in 1992, the uptake of Higher Level Mathematics is now decreasing. The initial target was to have a ratio of 20-25%:50-60%:20-25% at Higher, Ordinary and Foundation Level respectively (NCCA 2005). The ratio currently is in the region of 16%:72%:12%. Both the Higher and Foundation Level numbers have over the past 10 years fallen well short of their intended targets, and the trend suggests that this drift from their targets may continue.

Time and effort tend to be the most significant reasons given by pupils who are capable of studying Higher Level Mathematics but choose not to (Engineers Ireland 2012). With the pressure for points (for entry to Third-Level) across all of their subjects, pupils find Higher Level Mathematics requires significantly more time than other subjects meaning they can’t afford to take it. This often makes the decision to drop down to Ordinary Level a “strategic” one and Mathematics is treated as a spare (7th) subject that will not be used for points in the CAO system. While anecdotal evidence may suggest that Higher Level Mathematics is dominated by males, this domination is not too high. Over the past 10 years the average participation rate has been 46.3% for the females and 53.7% for the males. This higher majority of males studying Higher Level Mathematics mirrors international trends (Engineers Ireland 2012). The decision of the Third-Level institutions to award bonus points for Higher Level Leaving Certificate Mathematics was introduced in 2012. This system awards 25 bonus
points to an applicant’s total points (CAO 2012). This initiative may encourage a higher percentage of pupils to study Higher Level Mathematics. The percentage of pupils failing Higher Level Mathematics is decreasing. Even though the failure rate at Ordinary Level has decreased over the past 10 years, the current rate of 9.9% in 2011 is very high (in comparison to just 3.1% of E, F, NG grades at Higher Level). Engineers Ireland (2010) attributed this high failure rate at Ordinary Level to the fact that Foundation Level Mathematics is not recognised by Third-Level institutions. This places pressure on many pupils to take the Ordinary Level paper when the Foundation paper may be more suitable to their ability and needs. These pupils may not have the cognitive ability to understand the abstract concepts required at Ordinary Level.

The target of the new ‘Project Maths’ programme is to have at least 60% of the cohort at Higher Level for Junior Certificate and 30% at Leaving Certificate Mathematics (NCCA 2009). These Project Maths syllabi aim to change what pupils learn in Mathematics, how they learn and how it is assessed. There will be just two syllabi at Junior Cycle (Higher and Ordinary) while the three levels of Mathematics will remain at Senior Cycle. Figure 2.8 outlines the progressive changes and gradual introduction of the revised Mathematics syllabi at Junior and Senior Cycle. The Senior Cycle Project Maths will be assessed in total in June 2014, while the Junior Cycle syllabus will be assessed in total in the following year (June 2015).

![Figure 2.8 Project Maths timeline, reproduced from (DES 2011c)](image)
2.2.5. Uptake of Mathematics and Science at Third-Level.

45% of people between the age of 25 and 34 in Ireland have a Third-Level qualification, placing Ireland eighth in the world for University education attainment, and first out of ten European countries ranked in 2010 (Pharmachemical Ireland 2011a). Between 2011 and 2014, the total number of full-time students enrolled in higher education (at undergraduate or postgraduate level) is expected to increase, going from 161,000 in 2010 to in excess of 190,000 by 2014, regardless of the impact of migration and fertility patterns (Fás 2011).

The Relevance of Science Education (ROSE) report found that great majority of learners do not want ‘to become a scientist’ (55%) or ‘to get a job in technology’ (44%). Girls’ and boys’ preferences for careers related to Science were dominated by activities that had a biological/medical/health theme (Matthews 2007). The uptake of Science at Senior Cycle in Second-Level was already discussed (Figure 2.4). Biology can clearly be identified as the most popular Science subject at Senior Cycle, while the uptake for the physical sciences remains low. However, Smyth and Hannon (2003) reported that the majority of pupils who do take Physics or Chemistry for the Leaving Certificate go on to Third-Level education, and when they do so, they tend to take Science-related courses. Despite this trend, a minority of students still enter engineering and computing courses without a Science background or without Higher Level Mathematics (Smyth and Hannon 2003). Mathematics and Science are essential components of scientific and engineering courses at Third-Level. Engineers Ireland (2010) have expressed concern at the gradually falling numbers of those achieving honours grades in these subjects at Leaving Certificate Level, particularly when the country is in a difficult economic situation.

Greater numbers of engineering graduates were emerging from our Third-Level institutions during the period of high economic growth. However, in recent years, there has been a gradual decrease in the demand for some engineering courses. This has caused the entry points for Third-Level colleges to fall in both Universities and Institutes of Technology. Ireland is currently striving to recover from a worldwide recession and there is great need to up-skill our young people. However, decreased entry points at Third-Level have meant that a broader range of students (with a broader range of ability) are occupying these Third-Level courses (Darmody and Fleming 2009). The range of mixed abilities in Science and
Mathematics courses at Third-Level poses its own challenges and implications for Third-Level educators.

Eight of the 17 categories listed by the CAO are shown in Figure 2.9. The categories not shown were the less popular categories with average first preference applications below 4%.

![Level 8 CAO first preference applications](image)

*Figure 2.9 Level 8 CAO first preferences from 2006-2011 (CAO 2010, CAO 2011a).*

The categories shown were the most popular categories over the past six years. The Arts and Social Science has clearly been the most popular choice for Third-Level, followed by Administration and Business. On average, 10.1% of first preference applications are for Science and Applied Science courses and 10% for Engineering and Technology courses. However, the first preferences for Engineering and Technology courses is in decline (13.1% in 2006 to just 8.8% in 2011) while the applications for the Science and Applied Science courses is increasing gradually (from 8.7% in 2007 to 11.2% in 2011).

Figure 2.10 shows the four most popular categories of Level 6 and 7 courses that were applied for over the past 6 years. Applications to the Arts and Social Sciences and the Engineering and Technology courses has remained consistent over recent years (averaging at 18.6%). However, there is a notable decline in the number of applications for Administration and Business courses (35.4% in 2006 to 26.1% in 2011) and a favourable increase in the
number of applications for Science and Applied Science courses (10.3% in 2006 to 17.1% in 2011).

Prior to 2007, the entry points for many Science courses were falling due to low demand and poor student intake (Childs 2006, McGinnty 2007). Low level entry requirements can act as a deterrent to those who could and perhaps should undertake degrees in Engineering and Science, as selecting these is considered to be ‘wasting’ points. Lower entry points, in turn results in a higher drop-out rate as a more mixed ability cohort of students are granted entry to the courses (e.g. without having studied Higher Level Leaving Certificate Mathematics or any physical science subject). In many cases Science subjects and Higher Level Mathematics are not specified as entry requirements. It is estimated that in 2008 across the seven Universities the dropout rate for Science Engineering and Technology courses was 20% (Engineers Ireland 2010).

Engineers Ireland (2010) welcomed this increase in applications to Science courses at levels 6, 7 and 8. This counteracted a decline in applications for Engineering and Technology courses, particularly at Level 8. These courses were among the worst affected due to the sudden downturn in the property and construction sectors of the economy.

Table 2.12 which follows shows that the entry points for some Level 8 Science courses has increased in more recent years due to an increasing demand and popularity of these courses.
The surge in the numbers seeking places on Science courses in 2011 was up 6% on 2010 and 14% since 2009 (Flynn 2011a). Flynn (2011b) recognised that part of the reason for increasing points for Science courses is due to the relatively small number of courses on offer in this area. This is a reflection of the many years of poor student interest.

While the results in Table 2.12 (indicating an increasing demand) and the percentage of first preferences (Figure 2.9) look promising for the future of Science and Technology at Third-Level, it is still important to recognise that Science and Technology account for only 21% of all higher-degree first-preference applications. More than 42% of applications are still for courses in Arts, Social Science or Business (Flynn 2011b).

*Table 2.12 Increasing CAO entry points for Level 8 Science courses from 2008-2011 (CAO 2011b)*

<table>
<thead>
<tr>
<th>University College Cork</th>
<th>Course</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>University College Cork</td>
<td>Biological and Chemical Sciences</td>
<td>365</td>
<td>350</td>
<td>375</td>
<td>400</td>
</tr>
<tr>
<td>University College Cork</td>
<td>Chemical Sciences</td>
<td>305</td>
<td>330</td>
<td>365</td>
<td>360</td>
</tr>
<tr>
<td>Dublin City University</td>
<td>Chemical and Pharmaceutical Science</td>
<td>360</td>
<td>370</td>
<td>380</td>
<td>425</td>
</tr>
<tr>
<td>Dublin Institute of Technology</td>
<td>Science with Nanotechnology</td>
<td>295</td>
<td>315</td>
<td>320</td>
<td>325</td>
</tr>
<tr>
<td>University College Dublin</td>
<td>Science</td>
<td>300</td>
<td>385</td>
<td>435</td>
<td>455</td>
</tr>
<tr>
<td>NUI Galway</td>
<td>Science</td>
<td>280</td>
<td>325</td>
<td>345</td>
<td>370</td>
</tr>
<tr>
<td>University of Limerick</td>
<td>Industrial Biochemistry</td>
<td>355</td>
<td>375</td>
<td>370</td>
<td>380</td>
</tr>
<tr>
<td>NUI Maynooth</td>
<td>Science</td>
<td>320</td>
<td>350</td>
<td>365</td>
<td>375</td>
</tr>
<tr>
<td>Sligo IT</td>
<td>Pharmaceutical Science</td>
<td>260</td>
<td>265</td>
<td>270</td>
<td>280</td>
</tr>
<tr>
<td>Trinity College Dublin</td>
<td>Science</td>
<td>415</td>
<td>440</td>
<td>455</td>
<td>475</td>
</tr>
</tbody>
</table>
2.3 – Organic Chemistry in Irish Education

2.3.1. Organic Chemistry in Junior Certificate Science

As outlined in Section 2.2.2 above, the Junior Certificate Science syllabus is composed of Biology, Physics and Chemistry. The learning objectives (188 in total) for the syllabus are divided according to each strand of Science. Biology has 67 learning objectives, while there are 60 learning objectives for Physics and 61 for Chemistry. Of these 61 learning objectives for Chemistry, nine are related in some way to Organic Chemistry. These objectives are listed here:

- Recall that fossil fuels are sources of hydrocarbons, and that they produce CO$_2$ and H$_2$O when burned.
- List two examples of fossil fuels.
- Describe the role of the combustion of fuels in the production of acid rain, with particular reference to SO$_2$; describe the effects of acid rain.
- Describe the effect of acid rain on limestone and on plants.
- Appreciate that natural gas is mainly methane.
- Identify everyday applications of plastics, and understand that crude oil products are the raw material for their production.
- Associate the properties of everyday plastics with their use.
- Describe and discuss the impact of non-biodegradable plastics on the environment.
- Appreciate that Chemistry has an important role in pharmacy, medicine.

(DES 2008)

As can be seen from the objectives listed, the focus is on the context of crude oil as a valuable resource as fuels and petrochemicals. The combustion of hydrocarbons is also studied. While this is a useful introduction of the topic to the pupils, this only accounts for less that 5% of the whole Junior Certificate Science syllabus. Organic Chemistry is only introduced at a surface and application-led level in this Junior Cycle curriculum, and is not mentioned explicitly as a topic.
2.3.2. Organic Chemistry in Leaving Certificate Chemistry

Participation and performance in Leaving Certificate Chemistry over the past 10 years has already been discussed in Section 2.2.3.1 above. This Section will focus on the Organic Chemistry content in the current Leaving Certificate Chemistry syllabus and the pupils’ attempts and performance in the relevant examination questions.

In the Leaving Certificate Chemistry syllabus (DES 1999a), Organic Chemistry (section 7 of the syllabus) is divided into five areas. These five topics are listed in Table 2.13 below with the recommended class time for each.

*Table 2.13 Leaving Certificate Organic Chemistry topics and recommended class periods for each (DES 1999a)*

<table>
<thead>
<tr>
<th>Organic Chemistry</th>
<th>Number of class periods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Higher Level</td>
</tr>
<tr>
<td>Tetrahedral Carbon</td>
<td>4</td>
</tr>
<tr>
<td>Planar Carbon</td>
<td>11</td>
</tr>
<tr>
<td>Organic Chemical Reaction types</td>
<td>21</td>
</tr>
<tr>
<td>Organic Natural Products</td>
<td>4</td>
</tr>
<tr>
<td>Chromatography and Instrumentation</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total number of class periods</strong></td>
<td><strong>43</strong></td>
</tr>
</tbody>
</table>

The DES (1999a) recommend 270 class periods (40 minutes) in total to teach and learn the whole Leaving Certificate Chemistry syllabus. Organic Chemistry requires 16% of this class time for the Higher Level course and 12% of class time in the Ordinary Level course. The Tetrahedral Carbon section includes saturated organic compounds: alkanes and alcohols. The Planar Carbon section includes unsaturated organic compounds: alkenes, carbonyl compounds, carboxylic acids, esters and aromatic compounds. The section of the Organic Chemistry course with the highest recommended class time is Organic Chemical Reaction types. The reaction types include addition, substitution, elimination, redox, reactions as acids and organic synthesis. Organic Natural Products includes extraction techniques. The instrumental methods listed in the syllabus include Mass spectroscopy, Gas chromatography, High-Performance Liquid Chromatography, as well as IR and UV absorption spectroscopy. The mandatory experiments in Organic Chemistry are common to both the Higher Level and Ordinary Level courses.
The following is the list of the mandatory experiments for Organic Chemistry:

7.1 Recrystallisation of benzoic acid and determination of its melting point.
7.2 Preparation of soap.
7.3 Preparation and properties of ethene.
7.4 Preparation and properties of ethanal.
7.5 Preparation and properties of ethanoic acid.
7.6 Extraction of clove oil from cloves by steam distillation.
7.7 Separation of a mixture of indicators using paper chromatography or thin-layer chromatography or column chromatography. (DES 1999a).

Fuels and Heats of Reactions is another section (section 5) in the Leaving Certificate Chemistry syllabus that contains some Organic Chemistry. The Introduction to Hydrocarbons, the Structure of Aliphatic and Aromatic compounds, as well as Oil refining, are useful introductory topics before teaching the Organic Chemistry section of the course as outlined above. Table 2.14 shows the breakdown of class periods required for the Fuels and Heats of Reaction section of the Leaving Certificate Chemistry course. In total this section requires 7% of the Higher Level class time and 6% of the Ordinary Level class time.

Table 2.14 Leaving Certificate Fuels and Heats of Reaction topics and recommended class periods for each(DES 1999a).

<table>
<thead>
<tr>
<th>Fuels and Heats of Reaction</th>
<th>Number of class periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources of Hydrocarbons</td>
<td>1 1</td>
</tr>
<tr>
<td>Structure of Aliphatic Hydrocarbons</td>
<td>5 5</td>
</tr>
<tr>
<td>Aromatic Hydrocarbons</td>
<td>1 1</td>
</tr>
<tr>
<td>Exothermic and Endothermic Reactions</td>
<td>9 5</td>
</tr>
<tr>
<td>Oil Refining and its products</td>
<td>4 4</td>
</tr>
<tr>
<td><strong>Total number of class periods</strong></td>
<td><strong>20 16</strong></td>
</tr>
</tbody>
</table>

The Aliphatic hydrocarbons include the naming, structural formulas, isomers and physical properties of the alkanes, alkenes and alkynes. The main aromatic hydrocarbon studied is benzene, and its derivatives. Exothermic and Endothermic reactions include the combustion of alkanes and other hydrocarbons as well as heats of reaction, bond energy, heat of combustion, heat of formation, law of conservation of energy and Hess’ law. Oil refining and products includes the formation of crude oil and the production of refined products. There is only one mandatory experiment in this section of the course; 5.2 Preparation and properties of ethyne (DES 1999a).
Since a proficiency in Organic Chemistry is not necessary for an understanding of exothermic and endothermic reactions, this part (section 5.4) of section 5, Fuels and Heats of Reaction has not been included in the Organic Chemistry part of the syllabus analysed as part of this study. Combining the remaining class periods with the class periods required for the Organic Chemistry course, Organic Chemistry requires a minimum of 20% of the class periods at Higher Level and 16% at Ordinary Level. Section 5 (with omission of section 5.4) and Section 7 of the current Leaving Certificate Chemistry syllabus are included in Appendix A. It should be noted that the Organic Chemistry terminology and definitions used throughout this thesis e.g. ‘ionic addition’ etc. are used with relevance to their meaning in the Leaving Certificate Chemistry syllabus. The author acknowledges that other terms e.g. ‘electrophilic addition’ in such case would more accurately describe the Organic Chemistry.

Organic Chemistry thus accounts for one fifth of the Higher Level Leaving Certificate Chemistry course. There are usually two full questions on the paper in Section B dedicated to Organic Chemistry. One of these questions concerns itself with fuels and thermochemistry, the other is usually based on reaction types and mechanism. In addition to this, at least one of the practical questions of Section A assesses an Organic Chemistry practical, giving a total of at minimum of three questions on Organic Chemistry out of a total of 11 questions, where eight have to be answered. Parts of questions 10 and 11 sometimes include Organic topics also. The 2011 Higher Level and Ordinary Level Leaving Certificate Chemistry Examination papers are included in Appendix B to illustrate the amount of Organic Chemistry content assessed in the Leaving Certificate curriculum.

In total Organic Chemistry accounts for almost one quarter of the Leaving Certificate examination paper. Therefore, it is necessary for Leaving Certificate candidates to gain a detailed understanding of this area of the course, together with the accompanying mandatory experiments. The Chief Examiner’s Reports published by the SEC every three years (SEC 2002, 2005, 2008) have recognised a tendency for Leaving Certificate candidates to avoid Organic Chemistry, even though this practice severely restricts their choice on the examination paper. In general, questions on Organic Chemistry are either well answered or poorly answered, with few candidates occupying a middle ground (SEC 2005). As Organic Chemistry is a significant element of the syllabus (~ 20%) and the examination (~25%), an appropriate amount of teaching time should be devoted to it. It is unwise for examination candidates to omit this area of the course as it minimises their choices on the examination
paper. Table 2.15 shows a summary of the Organic Chemistry questions asked in the Leaving Certificate Higher and Ordinary Level examination papers from 2002 to 2011.
Table 2.15 Summary of the Organic Chemistry questions in the Leaving Certificate Examination papers from 2011 to 2002.

<table>
<thead>
<tr>
<th>Year</th>
<th>Section A</th>
<th>Topic</th>
<th>Section B</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Higher Q2</td>
<td>Reflux technique</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions.</td>
</tr>
<tr>
<td></td>
<td>Q3</td>
<td>Steam distillation and recrystallisation</td>
<td>Q8</td>
<td>Substitution mechanism, preparation of ethene, benzene.</td>
</tr>
<tr>
<td></td>
<td>Ordinary Q1</td>
<td>Understanding distillation and reflux techniques</td>
<td>Q6</td>
<td>Fuels, oil refining, preparation of ethyne.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q8</td>
<td>Organic reaction types.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (b)</td>
<td>Chromatography.</td>
</tr>
<tr>
<td>2010</td>
<td>Higher Q2</td>
<td>Preparation of Soap</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q9</td>
<td>Organic Reaction Types</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (b)</td>
<td>Recrystallisation of benzoic acid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (c)</td>
<td>Ethanol and ethanal</td>
</tr>
<tr>
<td></td>
<td>Ordinary Q1</td>
<td>Preparation of ethene</td>
<td>Q6</td>
<td>Alkanes and fuels.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q7</td>
<td>Naming, ethene, reaction types.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (c)</td>
<td>Clove Oil Extraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q11 (a)</td>
<td>Aromatic compounds</td>
</tr>
<tr>
<td>2009</td>
<td>Higher Q2</td>
<td>Preparation of ethyne</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q8</td>
<td>Functional groups, Organic reactions.</td>
</tr>
<tr>
<td></td>
<td>Ordinary Q1</td>
<td>Preparation of ethyne</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q7</td>
<td>Reaction schemes, preparation of ethene.</td>
</tr>
<tr>
<td>2008</td>
<td>Higher Q2</td>
<td>Chromatography</td>
<td>Q6</td>
<td>Fuels and Heats of Reaction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clove Oil extraction</td>
<td>Q8</td>
<td>Alkenes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q11 (a)</td>
<td>Organic Reactions.</td>
</tr>
<tr>
<td></td>
<td>Ordinary Q1</td>
<td>Preparation of ethanoic acid</td>
<td>Q6</td>
<td>Fuels and Heats of Reaction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q9</td>
<td>Reaction schemes and preparation of ethene.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (b)</td>
<td>Instrumentation.</td>
</tr>
<tr>
<td>2007</td>
<td>Higher Q2</td>
<td>Preparation of ethanoic acid</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q8</td>
<td>Reaction schemes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q11 (b)</td>
<td>Chlorination of methane.</td>
</tr>
<tr>
<td></td>
<td>Ordinary Q1</td>
<td>Preparation of soap</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q8</td>
<td>Preparation of ethylene.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (b)</td>
<td>Chromatography.</td>
</tr>
<tr>
<td>2006</td>
<td>Higher Q2</td>
<td>Preparation of soap</td>
<td>Q6</td>
<td>Fuels and Heats of Reactions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q9</td>
<td>Alkenes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q10 (C)</td>
<td>Physical properties.</td>
</tr>
<tr>
<td>Year</td>
<td>Level</td>
<td>Question</td>
<td>Subtitle</td>
<td>2005</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>----------</td>
<td>----------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Higher Q2 Preparation of ethyne</td>
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<td></td>
<td></td>
<td></td>
<td>Preparation of ethene and ethyne</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Q1 Preparation of ethene and ethyne</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Q8 Reaction schemes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Q10 (b) Instrumentation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ordinary Q1 Preparation of ethene</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Q8 Reaction schemes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Q10 (a)</td>
</tr>
</tbody>
</table>
The examination papers were available at


<table>
<thead>
<tr>
<th></th>
<th>% Attempts</th>
<th>% Average Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section A</td>
<td>79.6%</td>
<td>63.5%</td>
</tr>
<tr>
<td>Section B</td>
<td>71.6%</td>
<td>64.9%</td>
</tr>
</tbody>
</table>

*Table 2.17 Summary of candidates’ performance in the Organic Chemistry questions in the Ordinary Level 2002, 2005 and 2008 examinations.*

<table>
<thead>
<tr>
<th></th>
<th>% Attempts</th>
<th>% Average Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section A</td>
<td>65.0%</td>
<td>49.4%</td>
</tr>
<tr>
<td>Section B</td>
<td>69.4%</td>
<td>60.2%</td>
</tr>
</tbody>
</table>

The percentage attempts included in Tables 2.16 and 2.17 are an average of the percentage attempts for each of the years listed above each table. The average percentage marks in both tables are also an average of the marks given for the Organic Chemistry questions in each of the sections of the respective examinations. The level of attempt and performance in the Organic Chemistry questions provides evidence that Organic Chemistry remains an unpopular topic among Leaving Certificate examination candidates. It also suggests that candidates present themselves for the examinations intending to avoid these questions, and attempting them only as a last resort (SEC 2002, Horgan and Regan 2004). Candidates’ misunderstandings of questions in section A in both Higher Level and Ordinary Level papers assessing the mandatory experiments raised doubts among the examiners as to whether all pupils are carrying out these experiments in school (S.E.C., 2002, 2005, 2008). This is a worrying issue as the practice of practical work would facilitate the pupils’ understanding and knowledge of Organic Chemistry when linked appropriately with the theory of the course.

It is important to note when interpreting the results in Tables 2.16 and 2.17 that these average percentage marks include questions (mostly question 6’s) that contained parts assessing Fuels and Heats of Reactions. Such questions are not directly assessing the candidates’ knowledge of Organic Chemistry, and these parts of the questions were usually answered well. The
performance in the 2005 Higher Level and Ordinary Level Organic Chemistry questions were the highest over the past eight years. The level of popularity and level of return in terms of marks for the Organic Chemistry questions was consistent with the assertion that those who study Organic Chemistry can get rewarded in the examination but that many Ordinary Level candidates choose to avoid the area altogether (SEC 2005).

Comparing the candidates’ performances at Higher and Ordinary Level in Tables 2.16 and 2.17 respectively, it is clear that the Higher Level candidates attempted more of and performed better in the Organic Chemistry questions than the Ordinary Level candidates. This observation supports the findings that Organic Chemistry requires a high level of cognitive ability and therefore is more approachable and accessible for Higher Level candidates.

2.3.3. Organic Chemistry in the proposed new Leaving Certificate Chemistry syllabus.

The current Leaving Certificate syllabus discussed in Section 2.3.2 above was first introduced to schools in September 2000 and first examined in June 2002. Under current Senior Cycle developments, this Chemistry syllabus is under review along with Leaving Certificate Physics and Biology also. The NCCA released a draft Leaving Certificate Chemistry syllabus in 2011 for consultation. This draft syllabus was made available to teachers and educators to read and review. It is available online at: http://www.ncca.ie/en/Consultations/Senior_Cycle_Science/CSLC.pdf. Many groups such as the Irish Science Teachers’ Association (ISTA) as well as individual teachers have had an opportunity to share their feedback as well as queries and concerns about the proposed syllabus with the NCCA. A report on the consultations of the proposed new syllabus will be published later in 2012.

The same time allocation (180 hours) is recommended for the revised syllabus. However, the syllabus overview does not provide recommended teaching times for each section of the syllabus as is the case with the current syllabus. The proposed new syllabus is divided into five units, while the current syllabus is divided into nine core areas along with two optional areas of study. Table 2.18 provides a summary of how the Chemistry topics in the current syllabus compare with those in the proposed new Leaving Certificate Chemistry syllabus. As is highlighted in bold in the table, Organic Chemistry is a prominent part of both syllabi. The
importance of Organic Chemistry (as 20% of the syllabus and 25% of the current Leaving Certificate examination paper) has been discussed (section 2.3.2).

Table 2.18 Comparison of current and proposed Leaving Certificate Chemistry topics.

<table>
<thead>
<tr>
<th>Current Syllabus (DES 1999a)</th>
<th>Proposed new syllabus (NCCA 2011b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Periodic Table and atomic structure.</td>
<td>• Scientific methods.</td>
</tr>
<tr>
<td>• Chemical bonding.</td>
<td>• Properties, structure and bonding.</td>
</tr>
<tr>
<td>• Stoichiometry, formulas and equations.</td>
<td>• Controlling using chemical change.</td>
</tr>
<tr>
<td>• Volumetric analysis.</td>
<td>• <strong>Organic Chemistry.</strong></td>
</tr>
<tr>
<td>• Fuels and heats of reaction.</td>
<td>• Environmental Chemistry.</td>
</tr>
<tr>
<td>• Rates of reaction.</td>
<td></td>
</tr>
<tr>
<td>• <strong>Organic Chemistry.</strong></td>
<td></td>
</tr>
<tr>
<td>• Chemical Equilibrium.</td>
<td></td>
</tr>
<tr>
<td>• Environmental Chemistry; Water.</td>
<td></td>
</tr>
<tr>
<td>• <strong>Option 1:</strong></td>
<td></td>
</tr>
<tr>
<td>o Additional Industrial chemistry</td>
<td></td>
</tr>
<tr>
<td>o Atmospheric Chemistry.</td>
<td></td>
</tr>
<tr>
<td>• <strong>Option 2:</strong></td>
<td></td>
</tr>
<tr>
<td>o Materials.</td>
<td></td>
</tr>
<tr>
<td>o Additional Electrochemistry and the extraction of metals.</td>
<td></td>
</tr>
</tbody>
</table>

This Section will compare the differences in the Organic Chemistry content of the current syllabus and the proposed new syllabus. The complete Organic Chemistry section of the proposed new syllabus is also included in Appendix A. It is important to note that sections 5.1, 5.2, 5.3, 5.5 and 5.6 of the current syllabus (although not labelled as Organic Chemistry) contain a lot of organic content. Similarly section 2.6 of the proposed new syllabus contains Organic Chemistry content also.

The Organic Chemistry topics of the current syllabus were listed in Table 2.13 and 2.14. The Organic Chemistry in the proposed new syllabus has been divided into seven categories; Carbon, Hydrocarbons and fuels, Homologous series and functional groups, Organic reactions, Common organic substances, Organic techniques and Forensic Chemistry. Nanoscience, Nanotechnology and Nanochemistry are included in unit 2.6 of the proposed new syllabus under the heading: Technological applications of Chemistry.
Much of the Organic Chemistry in the current syllabus is marked as Higher Level only. These topics include:

- Internal combustion engine in relation to auto-ignition.
- Relationship between octane number and chain length, branching and cyclic compounds.
- Adding oxygenates to increase the octane number.
- *Chloroalkanes: structure, nomenclature, physical properties.
- Ketones: structure, nomenclature and physical properties, redox reactions.
- Esters: structure, nomenclature, physical properties.
- Esterification reaction.
- *Base hydrolysis of esters.
- Sigma and pi bonding in benzene.
- Mechanism and evidence of mechanism for ionic addition to ethene.
- Mechanism and evidence of mechanism for free radical substitution of methane and ethane.
- Acidic nature of the carboxylic acid group.
- Infra-red spectrometry.
- *Ultraviolet absorption spectrometry.

Note: *Topics not included in the proposed new syllabus.

In comparison to the topics listed above, only one objective in the proposed new syllabus is marked as Higher Level only. This is ‘discuss the importance of organic synthesis with reference to a named pharmaceutical product’ (NCCA 2011b). The rest of the Organic Chemistry content in the proposed new syllabus is common to both Higher and Ordinary Level candidates. As is shown above, some of the Organic Chemistry topics from the current Leaving Certificate syllabus have not been included in the proposed new syllabus.

Table 2.19 lists the topics from the current syllabus that have not been included in the proposed new syllabus. It is important however, to recognise that all of the remaining topics from the current syllabus have been included in the proposed new syllabus.
Table 2.19 Organic Chemistry topics from the current syllabus (2000) but not included in the proposed new syllabus (2011).

<table>
<thead>
<tr>
<th>Section</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6 Other Chemical Fuels</td>
<td>Hydrogen: Manufacture by steam reforming</td>
</tr>
<tr>
<td>7.1 Tetrahedral carbon</td>
<td>Chloroalkanes: Structure and nomenclature up to C-4, physical properties.</td>
</tr>
<tr>
<td>7.5 Chromatography and instrumentation in Organic Chemistry</td>
<td>Ultraviolet absorption spectrometry as a quantitative technique involving the absorption of ultraviolet light.</td>
</tr>
</tbody>
</table>

Table 2.20 that also follows highlights the new topics that have been included in the proposed syllabus but are not in the current Leaving Certificate Chemistry syllabus.
Table 2.20 Organic Chemistry topics that have been introduced into the proposed new syllabus (2011) but were not in the current syllabus (2000).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Arenes</strong></td>
</tr>
<tr>
<td>2.6</td>
<td>Discuss how the advances in the hydrogen fuel cell have facilitated the development of electric cars.</td>
</tr>
<tr>
<td></td>
<td>Conduct a practical activity to demonstrate the use of fuel cells.</td>
</tr>
<tr>
<td></td>
<td>Discuss the terms: nanoscience, nanochemistry and nanotechnology.</td>
</tr>
<tr>
<td></td>
<td>Describe and discuss how incorporation of carbon nanotubes into polymer composites can alter the mechanical properties of these composites.</td>
</tr>
<tr>
<td></td>
<td>Describe/discuss the electronic properties and potential applications of carbon nanotubes.</td>
</tr>
<tr>
<td>4.1</td>
<td><strong>Carbon.</strong></td>
</tr>
<tr>
<td></td>
<td>Construct mechanically or use a software program to produce 3-D models to highlight the difference between (i) planar and tetrahedral carbon (ii) saturated and unsaturated hydrocarbons and (iii) aliphatic and aromatic compounds.</td>
</tr>
<tr>
<td></td>
<td>Differentiate between structural, and geometrical isomerism (apply cis and trans naming system).</td>
</tr>
<tr>
<td></td>
<td>Discuss the use of cis and trans fats in our diet.</td>
</tr>
<tr>
<td>4.2</td>
<td><strong>Hydrocarbons and fuels.</strong></td>
</tr>
<tr>
<td></td>
<td>Describe the use of rotary evaporation in the removal of a solvent from a mixture and give one example where this process is used.</td>
</tr>
<tr>
<td></td>
<td>Discuss the use of alcohols and biofuels as alternatives to petrol and diesel.</td>
</tr>
<tr>
<td>4.3</td>
<td><strong>Homologous series and functional groups.</strong></td>
</tr>
<tr>
<td></td>
<td>Construct mechanically or use a software program to produce 3-D models of a variety of organic compounds.</td>
</tr>
<tr>
<td></td>
<td>Identify a number of functional groups in a large molecule and predict the type of reactions that can occur.</td>
</tr>
<tr>
<td></td>
<td>Assess the likely chemical activity of a named biological molecule that is a protein, amino acid or lipid.</td>
</tr>
<tr>
<td>4.5</td>
<td><strong>Common organic substances.</strong></td>
</tr>
<tr>
<td></td>
<td>Discuss the importance of organic synthesis with reference to a named pharmaceutical product.</td>
</tr>
<tr>
<td></td>
<td>Differentiate between the action of soap and a detergent in aqueous solution.</td>
</tr>
<tr>
<td></td>
<td>Distinguish between addition and condensation polymerisation.</td>
</tr>
<tr>
<td></td>
<td>Discuss the reasons to develop waste management strategies to deal with non-biodegradable polymers (refer to both land fill and incineration).</td>
</tr>
<tr>
<td>4.6</td>
<td><strong>Organic techniques.</strong></td>
</tr>
<tr>
<td></td>
<td>Interpret mass spectrometry data of small organic compounds; demonstrate its use in determining the structure and molecular mass of a compound.</td>
</tr>
<tr>
<td></td>
<td>Identify the following peaks (stretching frequencies only) in given infra-red spectra (i) C-H (ii) C=O and (iii) O-H.</td>
</tr>
<tr>
<td>4.7:</td>
<td><strong>Forensic Chemistry</strong></td>
</tr>
<tr>
<td></td>
<td>Outline the role of forensic chemistry in criminal investigation.</td>
</tr>
<tr>
<td></td>
<td>Outline the use of thin layer, gas chromatography, high performance liquid chromatography, mass spectrometry and GC/MS in forensic science.</td>
</tr>
<tr>
<td></td>
<td>Explain the fate of alcohol in the body [principal metabolites only] and outline the principle of the modern breathalyser.</td>
</tr>
</tbody>
</table>
Looking at Tables 2.19 and 2.20, it appears that many more aspects of Organic Chemistry have been added to the proposed new syllabus. However, given this draft syllabus, it is difficult to infer the depth of treatment expected and required for each topic given in Table 2.20. The vocabulary used e.g. interpret, outline, discuss, distinguish etc. is very vague and does not specify the level of understanding and investigation required by the pupils. At a surface level, these objectives may offer very little opportunity to the learners to develop their higher order thinking. Many researchers have described this phenomenon as a ‘mile wide, inch think’ curriculum (Taagepera and Noori 2000, Bodner 1992, Millar 1991, Libby 1995, Anderson and Bodner 2008). While more and more topics are introduced and listed in the syllabi and curricula, this leaves less and less opportunity for the learners to develop a true understanding of the subject and relevant topics. It is apparent from the proposed new syllabus (Appendix A) that some effort has been made to include relevant applications of Organic Chemistry. While these may serve to make the subject more interesting and appealing for the pupils, if too many applications are included, it will not be possible for the learners to understand the process and principle of each application. Johnstone (2010) recommended that some content will have to be removed from Second-Level Chemistry, some reduced, and other topics to be rescheduled to accommodate for the what research has shown about how pupils and students learn. Chapter Three provides much detail about the Information Processing model and the challenges faced by learners.

In total, there are eight mandatory experiments in the Organic Chemistry sections of the current syllabus. However the practical work in the draft syllabus is not specifically classified as mandatory or not. It is categorised under three headings; prescribed activities, open-ended, investigative activities and research activities. Table 2.21 that follows provides a comparison of the Organic Chemistry practical experiments in both syllabi. The practical experiments in the current syllabus are taken from section 5 and section 7 of the syllabus. The organic practical experiments in the proposed syllabus are taken from unit 2 and unit 7.

As can be seen in Table 2.21, of the eight mandatory experiments in the current syllabus, only three of these are included in the proposed new syllabus. It should be noted that while the new syllabus has included the ‘reactions of carboxylic acids’ as an activity to be conducted, it does not include the preparation of the carboxylic acid. The preparation of the aldehyde (ethanal) has also been omitted. However, the half equations for the oxidation of an alcohol and aldehyde using potassium permanganate are included in the syllabus. The
preparations (using dichromate as the oxidising agent) have been removed due to the circular published in March 2011. This listed dichromate among other chemicals that are no longer allowed to be used in Second-Level schools due to concern over their safety (DES 2011a).

Even though these oxidation reactions can be carried out using an alternative oxidising agent (e.g. potassium permanganate or Fenton’s reagent), they have been omitted from the new syllabus. Paper, thin-layer and column chromatography practical experiments are not included in the new syllabus either. The materials and requirements for these activities are relatively inexpensive and would be more accessible in the Second-Level school laboratory, than some of the requirements for alternative experiments listed. The experiments numbered 2.4 and 2.6 are from unit 2 of the proposed new syllabus. Although these are not within the Organic Chemistry section (unit 4) of the syllabus, they are related to the Organic Chemistry topics that the pupils will be studying in unit 4.

Table 2.21 Comparison of Organic Chemistry practical experiments in the current (2000) and proposed new syllabus (2011).

<table>
<thead>
<tr>
<th>Current Syllabus (DES 1999a)</th>
<th>Proposed new syllabus (NCCA 2011b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2 Preparation and properties of ethyne.</td>
<td>2.4: Carry out a practical activity to investigate temperature loss during evaporation of a range of organic liquids.</td>
</tr>
<tr>
<td>7.1 Recrystallisation of benzoic acid and determination of its melting point.</td>
<td>2.6: Conduct a practical activity to demonstrate the use of fuel cells.</td>
</tr>
<tr>
<td>*7.2 Preparation of soap.</td>
<td>*4.2: Conduct a practical activity to extract a natural product by steam distillation e.g. clove oil.</td>
</tr>
<tr>
<td>7.3 Preparation and properties of ethene.</td>
<td>**4.3: Conduct a practical activity to demonstrate qualitatively, the reactions of carboxylic acid.</td>
</tr>
<tr>
<td>7.4 Preparation and properties of ethanol.</td>
<td>*4.5: Conduct an activity to prepare a sample of soap.</td>
</tr>
<tr>
<td>**7.5 Preparation and properties of ethanoic acid.</td>
<td>4.6: Conduct practical activities to distinguish (i) saturated compounds</td>
</tr>
<tr>
<td>*7.6 Extraction of clove oil from cloves by steam distillation.</td>
<td>(ii) aldehydes and ketones</td>
</tr>
<tr>
<td>7.7 Separation of a mixture of indicators using paper chromatography or thin-layer chromatography or column chromatography.</td>
<td>(iii) pure and impure solid compounds.</td>
</tr>
</tbody>
</table>

Note:
* These experiments are common to both syllabi.
** This experiment is common to both syllabi except the proposed new syllabus does not include the preparation of the ethanoic acid.
2.4- Summary

This chapter has looked at the current situation of Science and Mathematics education in Ireland, at Primary-Level, Second-Level and Third-Level. The context of Science at Second-Level in Ireland was outlined, with a particular focus on Senior Cycle Chemistry. The low participation in physical science subjects has been highlighted in comparison to the popularity of Biology. Much anecdotal and research-based evidence suggests that the perceived difficulty of the physical science subjects has contributed to their low popularity at both Second-Level and Third-Level education. Chapter Three will look at the reasons why Chemistry is perceived as a difficult subject by so many learners.

This chapter has summarised the participation by gender and performance in the Leaving Certificate Chemistry examinations over the past ten years. This project is focused on the Organic Chemistry section of the current Leaving Certificate course. The NCCA (2011) released a draft of the proposed new Leaving Certificate syllabus. In this chapter, the Organic Chemistry content of this proposed new syllabus has been compared with that from the current syllabus. The investigations carried out at Second-Level and the intervention programme developed in this research project are based on the current Leaving Certificate Chemistry syllabus.
Chapter 3
Teaching and Learning Chemistry
3.1 Introduction

The low popularity of the physical sciences at Second-Level and Third-Level has been discussed in Chapter Two. This chapter will look at the reasons why Chemistry is difficult to teach and learn as well as successful teaching strategies that have been implemented to teach Organic Chemistry.

Much anecdotal evidence suggests that these subjects are avoided by learners due to their ‘difficult’ nature. The poor uptake of the physical sciences at Senior Cycle was discussed in Section 2.2.3 of Chapter Two. In a survey of 334 teachers carried out by the ASTI (2009), 40% of teachers agreed that pupils’ negative attitudes to the physical sciences may be driven by a perception of the difficulty of the subject. This is seen to be the greatest barrier to the take up of Chemistry for the Leaving Certificate. 50% of teachers surveyed felt pupils perceived the subjects as too theoretical and removed from everyday life and 41% said pupils are unaware of career options that led on from studying Chemistry (ASTI 2009). Chemistry is often viewed as an unattractive and difficult subject for the Leaving Certificate in comparison to Geography, Biology, Business, Art and French. Anecdotal evidence suggests the latter subjects attract more numbers at Senior Cycle in Second-Level because pupils do not ‘fear’ them. It has also been suggested that these subjects are being delivered in a more attractive and context-based fashion, which interests pupils and facilitates understanding. In comparison to Chemistry, the curricula for these subjects are not as demanding in terms of pupil time and effort (Engineers Ireland 2012).

Given the perception of Chemistry and the Chemistry curriculum as explained in Chapter Two as difficult, it is important to recognise the efforts that are made by those teaching Chemistry at Second-Level and Third-Level. However, many researchers have recognised a mismatch between the enthusiasm of Chemistry lecturers and teachers and the interest levels of their learners (Johnstone 1991, Johnstone 1981, Johnstone 2010, Johnstone and El-Banna 1986, Millar 1991). A revolution in Science Education in the 1960’s saw the launch of initiatives to address learners’ deeper understanding of scientific concepts and theories. This meant that the security of ‘closed box’ Science was lost as learners were encouraged to explore, investigate and probe the scientific theories being taught (Johnstone 1991). However, such changes interrupted the security of Science as a concrete and tangible subject. Encouraging learners to think in an abstract manner and to apply learned theories and
formulae to new situations has proven too great an ambition for too many young people learning Science. Chemistry is a complex subject and demands a high level of cognitive ability.

The Chief Examiner for Leaving Certificate Chemistry has recognised the intellectual demands of Chemistry as a Second-Level school subject:

“There are certain inherent difficulties associated with the subject [Chemistry]… it is abstract, it requires logical thinking and dedication. It has some mathematical content, it has its own language and vocabulary. It requires clarity and accuracy of expression”.

(Desmond, 2008, p. 25)

Even though, Chemistry is most commonly regarded as the “Central Science” or the “Mother of all Science” owing to its confluence and influence (Jimoh 2005), Osborne and Dillon (2008) have recognised how school curricula have managed to transform what should be an engaging and interesting subject into one that many learners find alienating. Sections 3.2 and 3.3 of this chapter will provide a deeper insight into the reasons why Chemistry is a difficult subject to teach and learn.

Through reading and analysis of the literature and previous research relating to this topic, it is evident that there are many factors and conditions impacting the teachers’ and learners’ experience of Chemistry. Johnstone (1991) believed that the faults could lie in three places: the transmission system (teaching methods and facilities), the receivers (learner difficulties) or within the nature of the subject itself (its multidimensional nature).

Millar (1991) also divided the difficulties of learning Science into two categories:

**Extrinsic Difficulties:**
- The teacher’s choice of content and priorities need to identify the value of Science in the learners’ lives.
- Curriculum limitations.
- Science is an abstract subject

**Intrinsic Difficulties:**
- The cognitive ability of the learner.
- Science knowledge provides insufficient pay-off for the effort required in its understanding.
- Learning Science involves reconstruction of meaning.
• The tension between Science as an ‘agreed knowledge’ and as ‘enquiry’ is confusing.

The first Section (3.2) of this literature review discusses the extrinsic factors affecting the teaching and learning of Chemistry, while the second Section (3.3) will focus more closely on the intrinsic factors. Extrinsic factors refer to issues that are beyond the control of the learner. Intrinsic factors refer to difficulties faced by the individual learners. In Section 3.4 the particular difficulties of Organic Chemistry will be discussed in order to understand why so many learners find this area of Chemistry so challenging to understand. Particular misconceptions relating to the Leaving Certificate Organic Chemistry content will be identified and discussed. Section 3.5 will look at some solutions to the challenges when teaching Organic Chemistry, with reference to initiatives that have been successful elsewhere at Second-Level and Third-Level.

3.2 – Extrinsic Difficulties of Teaching and Learning Chemistry

While Chemistry is often described as difficult and boring, it is possible to consider, that it may perhaps be the manner in which the subject is taught that is ‘dull’ (Bodner 1992). Bodner (1992) recognised that many teachers are so conscientious that they take the responsibility of learning from the learner. The structure of many courses reflects that if a lecturer or teacher does not specifically mention a topic in a lecture or in class, the learners are not expected to know it. While attention is focused on the learners’ development of an individual skill at any one point in a course, very often no effort is made to provide an overview of how the topics in the course fit together or relate to the learners’ own lives. As a consequence of such a disjointed curriculum, the learners become detached from the topics. An example of such poor understanding of topics is evident where learners may often explain that the value or answer simply comes from a given table or ‘from the back of the book’ (Bodner 1992).

While teachers can influence the learners’ approach to learning, they cannot assume responsibility for the learners’ own learning. Essentially, active learners will learn more and better than passive learners. This suggests that the responsibility lies with the teachers’ ability to involve the learners in the class and maximise their level of participation (Bodner 1992). This can be done by group-work, discussions, debates etc. Dialogue between the learner and teacher needs to begin with a concept or topic that makes sense to the learner. Understanding
can then be built up from the learners’ level. This approach allows the learner to see that chemical knowledge is a product of rational thought allowing for the development of meaningful ideas and clear frameworks of understanding. Bodner (1992) again advocated ‘teaching by listening’. By knowing what level of understanding the learners are at, and by listening to their explanations and questions, the teacher may also become more familiar and aware of misconceptions and difficulties that the learners have, and hence work on addressing these.

Figure 3.1 provides an overview of the extrinsic factors that have been discussed that contribute to the difficulties and challenges for learners and teachers in Chemistry Education. Each of these factors will be defined, explained and discussed in detail in this Section (3.2).
3.2.1. The Multidimensional Nature of Chemistry

The main reason that Chemistry is perceived as difficult by many learners and by those teaching it is due to the abstract nature of the subject.

“This is at once the strength of our subject as an intellectual pursuit, and the weakness of our subject when we try to teach it, or more importantly when beginners try to learn it”

(Johnstone, 2000a, p. 35)

The nature of Chemistry itself makes it a difficult subject to teach, learn and understand. The abstract concepts of Chemistry require multi-level thought. This multi-level thought was first represented by Johnstone (1991) as the ‘Triangle of Chemistry’. This triangle is represented in Figure 3.2 with the use of pictures to signify each conceptual level of understanding. Johnstone’s planar triangular representation of Chemistry depicted three levels of thought that are presented to the learner.

![Figure 3.2. Three conceptual levels of Chemistry (adapted from Johnstone, 1991)](image)

These three levels are the Macroscopic, Sub-microscopic and Symbolic. The ‘macro’ level refers to what is tangible and visible e.g. a beaker of ethanol as a clear colourless liquid. The
‘sub-micro’ level refers to what is molecular and invisible e.g. the molecules (atoms and bonds) that make up the ethanol. The third level is ‘symbolic’: this refers to the chemical symbols and equations that represent the molecules and atoms etc. e.g. C₂H₅OH. While a teacher, lecturer or professional chemist may be able to easily move between these levels of thought without hesitation, the combination of just any two of these levels, or even the comprehension of an individual level can be demanding for a learner who has a limited or no prior knowledge and understanding of Chemistry. Johnstone (2000b) described it as ‘psychological folly’ to introduce learners to all three levels of thought simultaneously. Most Chemistry teaching operates at the macro (or laboratory) level and the symbolic (representational) level. Many misconceptions in Chemistry stem from an inability to visualise structures and processes at the sub-microscopic (or molecular) level (Tasker and Dalton 2006).

Mahaffy (2005) introduced a fourth vertex to Johnstone’s triangle, creating a ‘Learning Tetrahedron’ as shown in Figure 3.3.

Mahaffy (2005) recognised that Chemistry, like other branches of Science ‘is a quintessential human activity, shaped by our creative yet fallible human beings’ (Mahaffy, 2005, p. 65). Bodner (1992) also recognised that learners are trying to work and learn in a real world that, in their eyes, has no relationship to what they learn in the Chemistry class. This is because the learners are not able to recognise the Chemistry in the world around them. By including this
human dimension when addressing the difficulties of Chemistry, we may be better able to teach the subject. This in turn could maximise the learners’ level of understanding and satisfaction. The fourth vertex introduced by Mahaffy (2005) is the human context. This accounts for the economic, political, social, environmental, historical and philosophical aspects of Chemistry, which are too often ignored. The Salter’s Chemistry course in the UK and Chemie in Kontext in Germany are examples of some initiatives that have attempted to introduce this fourth dimension to Chemistry. (These and further initiatives will be discussed in greater detail in Section 3.5). Efforts have also been made in revising the Junior Certificate Science (DES 2008) and Leaving Certificate Chemistry (DES 1999a) curricula to make more relevant links with the learners’ lives.

Due to the abstract nature of Chemistry, it is important to plan appropriate teaching approaches. In the revision of many curricula and syllabi, the standard of what is being taught is often lowered instead of improving how it is taught. Such difficult Chemistry topics need be tailored to meet the psychological needs of the learners. The process of how we learn will be discussed in detail in Section 3.3.

### 3.2.2 Use of Complex Language

Another factor contributing to the complexity of Science is the intricacy of the language used in the subject. Schmidt (1992) acknowledged that ‘we cannot expect chemists to modify the just-described terms simply because students are misguided. What we can do is discuss the development of chemical terms in the course of the history of Chemistry’ (Schmidt, 1992, p. 134). As well as the introduction of new vocabulary to the learner e.g. molarity, electronegativity etc., the dual use of words which pupils have already developed an understanding of outside of Science often creates further confusion (Nakhleh 1992) e.g. solution, equilibrium. The Information Processing Model, Short Term Memory and Long Term Memory will be explained and discussed with reference to how we learn in Section 3.3. The perception of language and the meaning of words stored in the Long Term Memory can be a cause of learner difficulty and misunderstandings (Selepeng and Johnstone 2001). In a study carried out by Cassels (1985), over 100 words used in school Science were identified as troublesome and often the cause of misconceptions among learners. Problems arise in the Long Term Memory when a familiar word changes its meaning. It is difficult for the learner to develop a clear conceptual understanding of the scientific meaning of words which they
have previously learned outside Science e.g. neutral, theory. Such prior knowledge and alternative conceptions are often the cause of learner difficulties in Chemistry. Johnstone (2010) recognised how complex language can lead to problems in the Long Term Memory when a word which was familiar then changes meaning.

Research has found that learners have more difficulty correctly applying and interpreting familiar words correctly, than in their perception of new unfamiliar technical words (Cassels and Johnstone 1983). Johnstone (1991) used the example that a pipette is just a pipette in the eyes and mind of the novice learner, while a ‘volatile compound’ can mean at least four different things. Research on young learners in Britain has found that many novice learners confuse words, and understand them to mean their opposite e.g. understanding abundance to mean ‘scarce’ (Johnstone 1991).

Childs (2006) highlighted literacy and numeracy as two ‘essential pre-requisites’ for Science education. Chemistry in particular, requires the learner to essentially learn a new language. The Periodic Table is like the ‘alphabet’ of Chemistry. This must first be taught and understood before the learner can make ‘words’ (chemical formulae). After learning how to write individual chemical formulae, the learner can then be introduced to form whole ‘sentences’ (equations). Correct grammar and punctuation needs to be learned to balance and interpret these equations. An example of such includes a clear understanding of the International Union of Pure and Applied Chemistry (IUPAC) nomenclature rules. If a learner understands these rules, they will be able systematically recognise, classify and name a compound from a given structural representation or alternatively identify and draw a compound (with appropriate functionality) from a given IUPAC name. Learners need to be able to understand the names of functional groups and substituents in order to proceed to understand how compounds will react with each other.

Since whole-class teaching rather than group work is the norm in Irish classrooms, it is easy to understand how the weaker learners may have more difficulty grasping this new language, while the higher ability pupils may lose interest if the movement of the lesson is too slow. Adding to this complication for the teacher is the increasing number of pupils in Irish classrooms whose first language is not English (Childs and O’Farrell 2003). Working Memory Space refers to Short Term Memory storage and processing of new information. This will be discussed in greater detail in Section 3.3. Selepeng and Johnstone (2001) found that those learning Science through a second language (not their native language) had less
working space available to them as some of the working space was occupied by translation. This is illustrated in Figure 3.4.

![Figure 3.4 Reduction of available working space due to a second language (Selepeng and Johnstone 2001)](image)

### 3.2.3 Relationship with Mathematics

Numeracy is integral to learning and understanding Chemistry. Mathematical ability is closely associated with cognitive ability of the learner, and cognitive ability also affects the learners’ understanding of Chemistry. Mathematics and Chemistry both have a high cognitive demand as they rely on the learner’s understanding of the concept of proportionality (Goodstein 1983). The cognitive ability of the learner will be explained and discussed in Section 3.3.1.

Numeracy is often developed in the Mathematics class and then applied in the Science laboratory. Science and Mathematics are often taught in mixed ability classes. This complication makes it more challenging for the teachers to accommodate the learners at the higher and lower ends of this spectrum. Science and Mathematics are very closely linked and dependent on each other. Childs (2006) used the analogy that they ‘sink or swim together’. Very often, learners that excel in one, excel in the other. However, unfortunately, the contrary is more often true. One benefit of the Irish schooling system is that all pupils continue to learn Mathematics until the end of their Second-Level education. The uptake of Higher Level Mathematics and the pupils’ performance at Junior and Senior cycle Mathematics in Second-Level was discussed in Chapter Two (Section 2.2.4).
Childs and Sheehan (2009) have identified the Mathematics ability of the learners at Second-Level and Third-Level education in Ireland as a contributing factor to difficulties experienced in Chemistry. As well as sharing symbols, numbers and equations, Science and Mathematics also use visualisation to represent data. A firm understanding of either subject facilitates the learner’s ability to interpret graphs and diagrams. An understanding of Mathematics contributes to the learners’ ability to understand Chemistry (Coll et al. 2006). Research carried out by Coll et al., (2006) has found that learners who struggle with Science often also have difficulty with Mathematics.

Figure 3.5 shows the Mathematics requirements that are necessary for study of Leaving Certificate Chemistry (Higher Level and Ordinary Level). These requirements are listed in the Leaving Certificate Chemistry syllabus (DES, 1999a, p. 73). From these requirements, it is clear that Chemistry pupils need to have an understanding of arithmetic, algebra and graphs for their study of Chemistry. It easy therefore to understand why learners who ‘sink’ in one subject can begin to ‘sink’ in the other. While both subjects (Mathematics and Chemistry) are inter-linked, the current disjointed curricula do not facilitate the integration of both subjects. An area of cognitive confusion for the learners is when teachers of different subjects present the same material but in different ways, using different terminology or symbols (Childs 2006). This can often be the case in the transition between Science and Mathematics. Further to this, many teachers may avoid teaching the same material, assuming that the teacher of the other subject has done so. This is more often the case at Third-Level than at Second-Level.
CHAPTER THREE   TEACHING AND LEARNING CHEMISTRY

Figure 3.5 Mathematics Requirement for Leaving Certificate Chemistry reproduced from (DES 1999a)
3.2.4 Laboratory Work

Practical work is undoubtedly an important part of Chemistry Education, and is an integral part of Chemistry curricula at Second-Level and Third-Level. It provides the teacher with a method of demonstration and avenues for investigation, as well as opportunities to probe the learners’ thinking and interest in lessons. While studies have shown that learners enjoy laboratory work (Reid 2009), most of the CER is pessimistic when discussing the learning value of this valuable opportunity available to those teaching Chemistry (Johnstone 1991, Letton and Johnstone 1991, Wham and Johnstone 1982).

With the ‘Tetrahedron of Chemistry’ in mind (Figure 3.3), it is easy to understand how practical work may add to the complexity of Chemistry for many learners, rather than facilitating their understanding. All levels of thought are present in practical work (Johnstone 1997), even though most learners may only be aware of and able to comprehend the macroscopic level i.e. setting up the apparatus for reflux, without an understanding of the process itself. The laboratory environment is often full of activity and busy-work e.g. clamping the round-bottomed flask securely and safely, finding apparatus which fits etc. without the learner recognising what the aim of the experiment actually is. While the manipulation of laboratory apparatus (macroscopic) is a necessary skill to be learned in practical sessions, caution has to be taken to ensure the other dimensions of Chemistry are not ignored. Johnstone (1991) acknowledged the difficulty that novice learners experience in distinguishing the ‘signal’ from the ‘noise’ in the laboratory. The ‘signal’ here refers to the aim of the practical investigation e.g. the oxidation of ethanol to ethanal, while the ‘noise’ relates to the numerous other observations that the learners will make during the course of the experiment. There is often very little cognitive gain in formal laboratory work as instructions, manipulation of equipment, recording of observations etc. can occupy most of the learners’ Working Memory Space, therefore limiting the space available for cognitive processing. Working Memory Space and cognitive processing will be discussed in detail in Section 3.3.2.

Writing an equation for the reaction happening in a flask while observing and explaining what is happening, requires higher level thinking and the capacity of the learner to think abstractly. This places a high cognitive demand on the learner and requires the learner to be at the formal operational stage of cognitive development. The stages of Cognitive Development will be discussed in Section 3.3.1. There is a lack of evidence supporting the idea that traditional laboratories are effective in promoting meaningful learning. Simply
replicating what chemists do in laboratories will not enhance the learners’ understanding of Chemistry. (Greenbowe and Schroeder 2008).

Johnstone (1981) outlined how the “phethora of instructions in a laboratory manual far exceed what he [the learners] can hold in his [their] short term memory” (Johnstone, 1981, p. 132). Johnstone (1981) explained this phenomenon as being similar to a young child who can read every word in a sentence correctly but has no idea of its total meaning. Laboratory work should be more focused on incorporating an element of discovery and interpretation rather than making representative compounds and learning techniques. An example of one way of improving the effectiveness of practical work in Chemistry is through the Science Writing Heuristic (SWH). Other initiatives will also be discussed in Section 3.5. SWH has been designed with reference to the learning cycle and understanding how learners think (Schroeder and Greenbowe 2008). It focuses on exploration, term introduction and concept application. The learners generate their own questions at the beginning of the lab and can only answer these by carrying out the experiment. In practice however, learner-led laboratory sessions are somewhat idealistic and not always feasible due to curriculum and examination restrictions.

3.2.5. Chemistry Curricula

The Chemistry curriculum is one of the most restricting extrinsic factors contributing to the difficulties of teaching and learning Chemistry. The curriculum guidelines outline the topics to be taught, the practical activities that need to be carried out and the learning outcomes to be achieved. However, even if the curriculum is well balanced, how it is taught is more than often determined by how it will be assessed. Second-Level teachers in particular, have little input into the closely-defined curricula that they have to teach. In some cases, Third-Level lecturers can have more autonomy in how their courses are taught as well as the content. Poorly designed Chemistry courses offer no relationship with the real world (Bodner 1992). However, Bodner (1992) acknowledged that “it’s not the topics that are being taught that makes Chemistry dull, but the way that they are taught” (Bodner, 1992, p. 187).

Most changes in curricula are additions to what is already listed to be learned. Even the suggestions made about contextual and application-led aspects in revised curricula are adding more to already crowded courses. Instead of trying to fit more topics and new approaches into our syllabi, should we not consider what is reasonable for the pupils and students to learn
within the limited amount of time given (Leaving Certificate – 180 hours, one Third-Level semester – 32-34 hours)? When refining old curricula, some of the basic and fundamental topics are often compressed or summarised in an effort to make space for ‘novel’ aspects of the new curriculum. While it is important and necessary to include interesting, contextual and relevant applications in the syllabi, Ellis (1994) highlighted the danger of these ‘improvements’. What may no longer seem necessary to be taught by the teacher, may yet be a vital link in the learning chain for the learners. If Chemistry courses do not change for the better, learners may lose interest due to the lack of demonstrations, innovations or experimentation which should be part of Chemistry Education, in order to facilitate fundamental understanding. Bodner (1992) advised that doing less in class, but doing it better may have a more beneficial effect for the learners.

Chemistry needs to be taught in a way that allows learners to construct their own knowledge rather than simply memorising unrelated facts. “The sequencing of topics that makes sense to us [experts] is not necessarily the sequence of topics that will produce the optimum learning in an individual encountering a course for the first time” (Bodner, 1992, p. 190). However, if the hierarchy and order of teaching Organic Chemistry is developed and planned by the teacher or other experts, it is necessary to acknowledge the difference in thinking patterns between novice learners and experts (Taagepera and Noori 2000). What is logical to a teacher may not seem at all logical to the learner (Johnstone 2000a). Teachers assessing the learners’ knowledge must consider the amount of information which is rote learned for examinations, as well as the methodical prediction of examination questions and topics in the Leaving Certificate examination, and in Third-Level examinations. The ‘points-race’ in Ireland due to competition for places in Third-Level education has resulted in the evolution of a grinds school culture, where the whole focus of teaching is on passing the Leaving Certificate examinations and attaining as many points as possible. In some schools, very little practical work is carried out, and learners are often provided with summary notes of ‘what they need to know for the examination’. Examinations need to be more diverse and include more ‘why’ questions rather than assessment based on the learners’ ability to recall and memorise material without a true understanding. The inclusion of some higher order examination questions are necessary to assess the learners’ understanding of the topic and ability to apply learned knowledge to new situations, but state examinations are dominated by lower order questions (McCrudden 2009).
The teaching of Organic Chemistry needs to include the revision of many General Chemistry topics: electron configuration, bonding, structure, shapes etc. (Ellis 1994). Instead of following the teaching order in the syllabus or text-book, teachers need to adapt their approach to accommodate the learners’ level of ability.

“Something is wrong with the way Science is taught and we need to reconstruct Science education”. (Bodner, 1992, p. 186)

“[College Chemistry courses do not have] enough relevant or new Chemistry, not enough emphasis on method, not enough involvement of the students and not enough experimentation in the laboratories” (Ellis, 1994, p. 399)

“We have chosen to teach fundamentals that are of little value to the student while neglecting fundamentals of greater value” (Reid, 2000, p. 382)

“Syllabus construction, whether in the context of courses for all pupils or for future specialists needs to take the question of justification of content much more seriously than has previously been the case if we are to reduce the difficulty which many associate with Science” (Lazonby, 1988, cited in Millar, 1991, p. 73).

The quotes above echo the opinions of many Chemistry Education researchers and teachers in their recognition of the restrictions and defects of the current Second-Level and Third-Level Chemistry curricula.

Many school curricula fail because of the disconnection between the dimensions (Johnstone’s Triangle of Chemistry) and the full-bodied reality of Chemistry in the pupils’ lives (Mahaffy 2005) (Figure 3.2 and Figure 3.3). The revolution of Chemistry teaching essentially needs to begin with the teachers in the classrooms. This idealisation is, however, restricted by limited laboratory facilities, poor resources, and lack of teaching support, as well as by strict examination guidelines. The textbooks used by teachers and pupils often interpret the curricula for the teacher. Such textbooks if used dependently can dictate how a subject is taught. Essentially, the curricula, examinations and textbooks can dictate what and how Chemistry (or any other subject) is taught. Sadly, the teacher has limited or no input into the development of any of these three determining factors.

The repeating failure of revised curricula over the past fifty years or so, has shown that these approaches alone will not suffice. The real need is in re-thinking how the curriculum is
delivered. Bodner (1992) described the present teaching of Science in Third-Level as similar to the ‘linear descendant of a system introduced in medieval Universities’ (Bodner, 1992, p. 186). The lecturer is still seen as the source of knowledge and information. Even though abundant resources (library, books, articles, journals etc.) are available to Third-Level students today, many don’t recognise any need to look at textbooks themselves, as the lecturer will have the information sourced for them. As a consequence of this provision of information by the lecturer, students will not expect to see anything different in their examinations than was presented in the lectures. The ability of these students to succeed in their examinations without further study, is a poor reflection on the quality of the examination questions. Repeating or using similar questions from previous examinations, allows the students to easily predict the types of questions that will be asked. These students will have developed some scientific knowledge from this type of learning, but are still without a clear understanding of how to apply their chemical knowledge to a different situation or to the real world.

The cause of much of the misunderstandings in Chemistry is due to rote learning in order to pass predictable examinations. This results in essential concepts not being correctly attached to the established frameworks in the Long Term Memory. The Information Processing Model will be discussed in greater detail in Section 3.3. However, we must recognise that it is the crammed and complex curricula that often force teachers to teach without sufficient time to develop concepts, and force learners to rote learn equations, mechanisms, formulae etc. without any clear understanding of their purpose.

It is clear that there is a need for curriculum ‘change’ rather than ‘reform’. Change, here refers to changes in the teaching and implementation of the curriculum proposed and implemented by the teachers and instructors themselves. In comparison, curriculum reform refers to ‘top-down’ instructional changes from external parties not directly involved in the teaching and learning.

Figures 3.6 and 3.7 provide an insight into the proposed reform of curricula at Junior and Senior Cycles in Second-Level education. While the proposed key skills for development and vision for learning are desirable in Second-Level education, it is important that teachers (who will be implementing these proposals) understand clearly how these aims can be achieved.
Figure 3.6 Proposed Key Skills for the development of the Junior Cycle reproduced from (NCCA 2011a)

Figure 3.7 Vision of Learning for the proposed new Senior Cycle learning experience reproduced from (NCCA 2011b)
The challenges presented in the development and revisions of curricula are evident at the moment in Ireland. The NCCA (2011) have published a draft syllabus of proposed changes to the Leaving Certificate Chemistry syllabus. This draft syllabus has been met with some antagonism and concern by practicing Second-Level teachers. The NCCA is currently reviewing the proposed draft following recommendations from practising teachers. This is a necessary and integral part of curriculum reform if the curriculum is expected to be effectively implemented. As well as concerns about the availability of laboratory resources to implement the proposed curriculum, teachers are also concerned about the mode of assessment as ‘assessment is the tail that wags the curriculum dog’. Essentially, unless the mode of assessment (currently 100% written examination) is changed, it will be difficult to change how the content is taught. The current 100% terminal written examination can simply be a test of the learners’ ability to memorise. The draft proposal includes a laboratory notebook (worth 5%) and a practical assessment (worth 15%) for the pupils as well as the terminal written assessment (worth 80%), and a greater focus on learning outcomes.

As was shown in Table 2.20 of Chapter Two a lot of additional content has been added to the Organic Chemistry section of the proposed new Leaving Certificate Chemistry syllabus. An over-loaded curriculum may result in many pupils resorting to outright memorisation of the material rather than learning the material for understanding (Grove et al. 2008). For example the extended inclusion of instrumentation techniques in the proposed syllabus presents a challenge for many teachers. Second-Level schools do not have access to rotary evaporators, mass spectrometers, IR spectrometers etc. Therefore it is rather difficult and challenging for the pupils to learn to understand how these apparatus operate and their use in analytical techniques. However, some of the other new inclusions to the proposed syllabus such as the use of three-dimensional models to facilitate understanding of the molecular shape and bonding may be more accessible for schools to implement. Chemistry is the Science which relies most heavily on visual modes (Rowe 1983), hence the use of molecular modelling can be effective in facilitating cognitive development as well as reducing the possibility of learners developing misconceptions about molecular shape and bond angles. However, it should be noted that models should already be used in teaching the current syllabus.

Because not all of the Leaving Certificate Chemistry pupils continue to study Chemistry at Third-Level, there is no reason why the Second-Level syllabi need to cover the same content as is necessary for entry into Third Level. The type of Chemistry to be learned at Second-
Level does not necessarily need to prepare pupils for Third-Level Chemistry or work in industry, as only a minority of the pupils that study Science and Chemistry in school, progress in that manner. Reid (2000) suggested a better way whereby each educational level uses the Chemistry learned in the previous level rather than determining what is to be taught in the previous level. This is a ‘bottom-up’ approach to curriculum design rather than the traditional ‘top-down’.

Throughout the 20th century and into the 21st century, efforts have been made to change and improve how Science and Chemistry are taught in an effort to increase the numbers taking the subjects and to increase the level of understanding. However, the result has always been the same – something is wrong with the way Science is being taught, and thus we need to restructure Science Education (Bodner 1992). The response to this crisis has typically taken the three approaches listed by Bodner (1992): restructuring of the curriculum; increasing the efforts to attract young people to Science; and convincing teachers to change the way in which Science is taught. Johnstone (2006) outlined five key lines of research that should be considered in curriculum planning and teaching: the function of language in Science; the problems of learning in a laboratory; multi-level learning; the assessment of Science learning and problem solving. Reid (2008) made suggestions such as using the application-led approach and being aware of the working memory capacity of learners to facilitate the development of positive attitudes towards Science. If understanding is possible, the learners’ attitudes will be more positive. The Information Processing Model will be discussed in detail in Section 3.3.2.

Johnstone (2010) outlined how to teach by “Diminishing Deceptions”:

1. Start with the tangible.
2. Build the triangle gradually (over a number of lessons).
3. Teach nothing that has to be abolished later.
4. Over-simplification may cause future trouble. (Johnstone, 2010, p. 27)

There are some examples of Chemistry curricula that have been effective in facilitating learners’ interests and understanding of Chemistry. Successful examples from the UK include the Salters’ Advanced Chemistry (Bennett and Lubben 2006) and the CASE (Cognitive Acceleration through Science Education) (Adey 1999) programmes. Examples from Germany include Chemie in Kontext (Parchmann et al. 2006) and the PIN-Concept
(Phenomena-orientated and Inquiry-based Network Concept) (Barke et al. 2012). The ITS Chemistry (Increasing Thinking Skills in Chemistry) (Sheehan 2010) is a programme developed for teaching the concepts of the mole and particulate nature of matter within the context of the current Leaving Certificate Chemistry syllabus.

Reid and Mbajiorgu (2006) proposed the following recommendations for planning an effective Chemistry curriculum:

1. Meet the needs of all learners.
2. Relate to life.
3. Reveal Chemistry’s role in society.
4. Have a low content base.
5. Be within information processing capacity.
6. Take account of language and communication.
7. Aim at conceptual understanding.
8. Offer genuine problem solving experience.
9. Use laboratory work appropriately.
10. Involve appropriate assessment. (Mbajiorgu and Reid 2006)

To conclude, five of the factors that can contribute to the extrinsic difficulties of Chemistry have been discussed above. Extrinsic difficulties refer to the difficulties beyond the control of the learner. It is important to consider these complications with the teaching of Chemistry before continuing to discuss the challenges that individual learners face in their perception of Chemistry.

“[Teaching Science well], involves a more broadly based model for the matching of ideas and learners and an awareness of the epistemological difficulties which the communication of Science involves, as well as the more obvious factor of teachers’ basic classroom skills” (Millar, 1991, p. 73)
3.3 – Intrinsic Difficulties with Teaching and Learning Chemistry

For many learners, it is difficult to recognise the value of developing scientific knowledge. Many of the abstract concepts in Chemistry can confuse and alienate learners rather than entice them to further learning. Learning and understanding Science can often be a daunting task, as it involves the establishment of new concepts as well as the reconstruction of prior knowledge, and a deluge of new information. This is particularly difficult due to the abstract nature of the subject which requires the learner to accept agreed knowledge and facts, while also encouraging an enquiry-based approach to the subject. Many models of learning need to be considered when addressing the difficulties of learning Chemistry. These include the stages of cognitive development outlined by Piaget (Piaget 1964), Ausubel’s inadequacy of previous knowledge and Pascual-Leone’s limited working space related to age (Johnstone and El-Banna 1989, Pascual-Leone 1970), as well the Information Processing Model (Johnstone 1997). These learning models and theories will be explained in this Section and discussed with reference to Chemistry Education. In a study carried out by Childs and Sheehan (2010) across Irish Second-Level pupils and Third-Level students, the cognitive development of the pupil and thus their information processing ability were identified as reasons for finding Chemistry difficult. The other two main findings of the same study highlighted the mathematical ability of the learner and the learner’s misconceptions as contributing factors in their perception of the difficulty of Chemistry.

Figure 3.8 summarises the numerous factors that have been identified in the literature as contributing to the intrinsic difficulties experienced by those learning Chemistry. Each of these factors will be discussed in this Section.
Before beginning to look at the difficulties involved in learning, it is important to understand what is meant by cognition and how people learn. Cognitive theorists acknowledge the importance of reinforcement. They also view learning as involving the acquisition or re-organisation of the cognitive structures through which humans process and store information (Good and Brophy 1990).

Mergel (1998) outlined the key concepts of the cognitive theory of learning:

- **Schema** - An internal knowledge structure. New information is compared to existing cognitive structures called "schema". Schema may be combined, extended or altered to accommodate new information.

- **Information Processing Model** - Input first enters a sensory register, then is processed in Short Term Memory, and then is transferred to Long Term Memory for storage and retrieval.

- **Meaningful Effects** - Meaningful information is easier to learn and remember. Also, if a learner links relatively meaningless information with prior schema it will be easier to retain.
• **Serial Position Effects** - It is easier to remember items from the beginning or end of a list rather than those in the middle of the list, unless that item is distinctly different.

• **Practice Effects** - Practicing or rehearsing improves retention especially when it is distributed practice. By distributing practices the learner associates the material with many different contexts rather than the one context afforded by mass practice.

• **Transfer Effects** - The effects of prior learning on learning new tasks or material.

• **Interference Effects** - Occurs when prior learning interferes with the learning of new material.

• **Organisation Effects** - When a learner categorises input such as a shopping list, it is easier to remember.

• **Levels of Processing Effects** - Words may be processed at a low-level sensory analysis of their physical characteristics to high-level semantic analysis of their meaning. The more deeply a word is processed, the easier it will be to remember.

• **State Dependent Effects** - If learning takes place within a certain context it will be easier to remember within that context rather than in a new context.

• **Mnemonic Effects** - Mnemonics are strategies used by learners to organise relatively meaningless input into more meaningful images or semantic contexts.

• **Schema Effects** - If information does not fit a person’s schema it may be more difficult for them to remember and what they remember or how they conceive of it may also be affected by their prior schema.

• **Advance Organisers** – Ausubel’s (Ausubel 1968) advance organisers prepare the learner for the material they are about to learn. They are not simply outlines of the material, but are material that will enable the student to make sense out of the lesson.

(Mergel 1998)

We will most likely never "see" an atom; likewise, we will never "see" learning either. Mergel (1998) used this analogy to describe how learning theories have developed over time just as the model of the atom has also developed from Dalton’s atomic theory to the orbital model. This analogy is illustrated in Figure 3.9.
The behaviourist learning theory centred on what is observable, not considering that there was anything occurring inside the mind. Behaviourism can be compared to Dalton's atom, which was simply a solid particle. Experimentation by Crookes, Thompson, Rutherford and Bohr found that there was something occurring within the atom causing its behaviour. This model of the atom can be compared with the cognitive model of learning. Further experimentation found that Bohr’s model of the atom was not correct. Likewise the constructivist learning theory proposes that each learner is constantly changing, and although the old models work to a certain degree, other factors must also be considered.

These factors that need to be considered are outlined and discussed in the following Sections of this chapter: 3.3.1 to 3.3.4.

### 3.3.1. Cognitive Ability of the Learner

#### 3.3.1.1. Cognitive Development

Having discussed the multidimensional nature of Chemistry (Section 3.2.1), it is easy to understand that if the learner does not have the cognitive ability to address the abstract and complex aspects of the subject, then this leads to many complications, misunderstandings and
Jean Piaget (Piaget 1964) outlined a sequence of operational stages of cognitive development. Piaget (1964) predicted that progression between these stages of cognitive development was dependent on the age of the learner. The main periods of development are shown in Figure 3.10 below; from sensorimotor (first 18 months of life) to preoperational (from 2-6 years) to concrete operational (7-11 years) to the final stage of formal operational development (which begins at 12 years to full development by 15 years). (Beard 1969).

![Figure 3.10 Piaget’s Stages of Cognitive Development (adapted from Piaget, 1964).](image)

The concrete and formal operational stages are highlighted in Figure 3.10 as these are the stages of cognitive development relevant to most Second-Level and Third-Level learners.

Concrete operational thinkers usually treat all associations as ‘equivalence relations’ (Shayer and Adey 1981). This means that they understand that if A happens with B, then in the same way B will happen with A. If a third variable is included in the situation i.e. C, the concrete thinker will not know how to deduce what would happen. The formal thinker however, is capable of this further investigation and abstract thought. ‘Concrete operational thinking involves putting considerable structure on reality, and most of us conduct our everyday business using concrete thinking only’ (Shayer and Adey, 1981, p. 27). Concrete thinking is sufficient when rules can adequately be applied to a situation. However, if a set of rules
cannot be directly applied to solve a problem, this then requires formal thinking. Shayer and Adey (1981) explained that formal operations involve the ability to go from a bi-variate reality to a multi-variate reality, while concrete operations involve the ability to cope with just a uni-variate reality. Chemistry curricula commonly incorporate many abstract concepts, which are central to further learning in both Chemistry and other Sciences (Taber 2002). These abstract concepts are important because further Chemistry and Science concepts or theories cannot be easily understood if these underpinning concepts are not sufficiently grasped by the student (Zoller 1990, Nakhleh 1992).

Figure 3.11 shows the stages of cognitive development required to understand and learn the different dimensions of Chemistry as illustrated in Johnstone’s (1991) Triangle of Chemistry. The three dimensions and levels of thought required to understand Chemistry have already been explained (Figure 3.2).

Learners can understand the macroscopic (visible and tangible) content of Chemistry when operating at the concrete stage of cognitive development. However, to understand the sub-microscopic and symbolic nature of Chemistry, learners need to be at the formal stage of cognitive development. Problem solving in Mathematics and Chemistry requires formal operations (Boujaoude et al. 2004, Lewis and Lewis 2007).

If learners are not at the required stage of cognitive development, it is not surprising that Chemistry is perceived as a difficult subject for them and as a result many resort to
memorisation rather than true understanding (Hassan et al. 2004, Bryan 2007). To understand Chemistry, learners need to have a true understanding of what is meant by a compound and a molecule. To understand this, pupils need to be at the early formal stage of cognitive development (Shayer and Adey 1981). Since these concepts are fundamental concepts in the learning of Chemistry, Shayer and Adey (1981) describe Chemistry as having a ‘high entrance fee’ in comparison to the other two Science subjects; Biology and Physics. However, a considerable amount of Chemistry can still be learned without any higher cognitive demand.

Shayer and Adey (1981) found that while Piaget’s sequencing of the stages of cognitive development was accurate, the corresponding age groups were not. Research carried out by Shayer and Adey (1981) in the U.K. and Childs and Sheehan (2010) in Ireland have shown that the majority of the pupils at Second-Level and students at Third-Level have not reached the ‘expected level’ of cognitive development as previously predicted by Piaget. Piaget’s age predictions for learners in the formal operational and concrete operational stages of development are widely optimistic for the diverse Second-Level and Third-Level populations in today’s classrooms and lecture theatres. It is evident that Piaget’s findings were based on an elite cohort of learners, and thus over-estimated the ability of Second-Level pupils. Most Third-Level students may still be operating at the concrete stage of cognitive development. A number of factors may be contributing to fewer pupils at Second-Level operating at the formal operational stage. One simple explanation may be due to the increase in video and computer games rather than ‘free play’. Free play gives children a greater opportunity to explore and navigate their environment helping them to discover and appreciate concepts such as depth, height and rotation etc. (Shayer et al. 2007).

3.3.1.2. How to facilitate Cognitive Development

“Piaget believed that knowledge is acquired as the result of a life-long constructive process in which we try to organise, structure and restructure our experiences in light of existing schemes of thought, and thereby gradually modify and expand these schemes”

(Bodner, 1986, p. 874)

Many researchers have proposed ways for teachers and educators to facilitate the cognitive development of learners. Collins et al. (1987) described what they considered an ideal learning environment to facilitate the cognitive development of learners. This is shown in
Table 3.1 below with reference to the content, teaching methods, sequence of teaching and sociology.

**Table 3.1 Characteristics of Ideal Learning Environments to facilitate cognitive development as suggested by Collins et al. (1987)**

<table>
<thead>
<tr>
<th>Content</th>
<th>Methods</th>
<th>Sequence</th>
<th>Sociology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td>Modelling</td>
<td>Increase complexity</td>
<td>Situated learning</td>
</tr>
<tr>
<td>Heuristic strategies</td>
<td>Coaching</td>
<td>Increase diversity</td>
<td>Culture of expert practice</td>
</tr>
<tr>
<td>Control strategies</td>
<td>Scaffolding and fading</td>
<td>Global before local skills</td>
<td>Intrinsic motivation</td>
</tr>
<tr>
<td>Learning strategies</td>
<td>Articulation</td>
<td></td>
<td>Exploiting co-operation</td>
</tr>
<tr>
<td></td>
<td>Reflection</td>
<td></td>
<td>Exploiting competition</td>
</tr>
<tr>
<td></td>
<td>Exploration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1 summarises many of the characteristics necessary to nurture the learners’ cognitive development. As well as being aware of the different cognitive abilities in their classroom, the teacher should also differentiate between Chemistry topics that require formal operational thinking and those that require concrete operational thinking. This is an important consideration when teachers are planning the sequence of topics for a class, as the concrete operations should precede the formal operations (Shayer and Adey 1981). As discussed in Section 3.2.1, much of Chemistry requires abstract thought and formal thinking. It is important therefore that the teacher is aware of ways of teaching and presenting these higher order topics in a concrete manner. This approach of teaching Chemistry would help to make the subject more available and easier to understand for learners at both higher and lower cognitive levels.
Further ideas from research (Chiappetta 1976, Lawson and Renner 1975, Bearison 1975, Palinscar and Brown 1984, Scardamalia et al. 1984, Schoenfeld 1983) on how to develop learners’ cognitive ability are listed in Figure 3.12 below, along with some strategies that have been successful in facilitating cognitive development.

**Figure 3.12 Ideas of how to facilitate cognitive development in the classroom.**

As well as facilitating the learners’ perception of new information and content, investigative studies have shown that the learners’ rate of cognitive development can be increased through
targeted and specific teaching methods (Adey 1999). The Cognitive Acceleration through Science Education (CASE) project was established in London in the 1970's. The aim of the project was to increase learners’ thinking skills to facilitate their understanding of their Science curriculum. The short and long term effects of this two-year intervention programme have proven to be very successful.

Figure 3.13 shows the structure of a CASE lesson. This project was carried out as a stand-alone programme and not infused into any existing curricula. Concrete preparation was a necessary part of every lesson, as this is the stage of cognitive development that many of the learners were at. Cognitive conflict is a central process to allow for the development of cognitive acceleration and development. Metacognition gave the learners an opportunity to reflect on how they solve problems. Bridging allowed for the new learning to be linked with previous learning and concepts or to lead onto further lessons. These stages in the lesson allow the learner to construct their own reasoning process and understanding of the topic.

![Figure 3.13 Structure of a CASE lesson reproduced from (Adey 1999).](image)

Evaluation of the CASE intervention found that pupils made cognitive gains throughout the period of the implementation. The pupils continued to have cognitive gains in delayed tests after the experimentation phase as well as in other subjects (Adey 1999). This strategy of teaching to accelerate cognitive development was implemented and successful in Australia also (Endler and Bond 2000). Maume and Mathews (2000) implemented the CASE programme with Irish Second-Level (first year) pupils. The increase in cognitive ability of the pupils who undertook the programme was one standard deviation greater than pupils not involved in the programme (Maume and Matthews 2000). A similar programme was also
developed and proven to be successful for Mathematics; Cognitive Acceleration in Maths Education (CAME). Sheehan (2010) adapted a similar approach in designing the ‘ITS Chemistry’ teaching materials which addressed the teaching of the particulate nature of matter and the mole concept within the Irish Junior Certificate Science and Leaving Certificate Chemistry syllabi. ‘ITS was an acronym meaning Increasing Thinking Skills. The findings from this study again reported cognitive gains in the participating pupils as well as a reduction in the number of misconceptions held by these pupils.

3.3.2. The Information Processing Model

“All humans learn in essentially the same way. Through our senses we take in information from our environment, we select what is relevant to use in a particular moment, we process it in some way and then, perhaps, we store what we have found” (Reid, 2008, p. 54).

The Information Processing Model shown below provides a clear insight into how learners perceive, understand and learn information. This model (Figure 3.14) presented by Johnstone was originally proposed by Greene and Hicks (1984). It is particularly useful in our investigation into the difficulties that learners experience in their learning of Chemistry.

![Information Processing Model](image)

*Figure 3.14 The Information Processing Model reproduced from (Johnstone 1997)*
The learner selects some of the information presented to them, and where possible, links are made with prior learning as the learner works to solve or understand the problem, applying what they already know. This cognitive model also acknowledges the affective factors of learning.

Even though all learners essentially learn in the same way, if the learning situations are not consistent with how the learner can understand new material, then true learning and understanding cannot happen (Reid 2008). Each stage of the model will now be discussed individually, in order to understand how each stage is linked to each other. Johnstone (2000b) highlighted the importance for teachers and lecturers to understand the processes of learning, metacognition, rather than the development of more programmes and courses to teach Chemistry. Johnstone (1997) described learning as the reconstruction of material from the teacher to the learner: an ‘idiosyncratic reconstruction’ of what the learner understands of the new material, taking into consideration their existing knowledge, beliefs and misunderstandings.

Figure 3.15 Factors affecting the smooth operation of the Information Processing Model.
Figure 3.15 summarises many of the complications that inhibit and hinder the normal operation of the Information Processing Model as illustrated in Figure 3.14. These factors will be discussed in the following sections with reference to each stage of model: Perception Filter, Working Memory Space and Long Term Memory.

3.3.2.1. Perception Filter

To understand how pupils (Second-Level) and students (Third-Level) learn Chemistry, it is important to look at the age and profile of the learners. Teenagers by their nature are not as interested in their environment or as receptive to new theories and laws as younger children are (Millar 1991). Unlike a young child who may ask questions such as ‘Why is the grass green?’ such observations are accepted and unquestioned by adolescents. Johnstone (1991) suggested the need for Science to address the larger issues such as Global Warming, Nuclear power etc. Twenty First Century Science (21CS) is a curriculum initiative introduced in the U.K. by the Nuffield Foundation in 2006, which has addressed this issue. The aim of this curriculum is to provide learners with an understanding of the Science they experience in everyday life with additional courses for those contemplating further academic study. The success of this programme has been evaluated in the University of York (Millar 2009). Millar (2009) found a striking increase in the numbers of pupils choosing to continue the study of Science at AS-level in schools and colleges using the 21CS programme. The success of this initiative is encouraging. More Chemistry curricula initiatives will be discussed in greater detail in Section 3.5 of this chapter. The inclusion of issues broadcast by the media provides an alternative approach to Science in comparison to mundane day-to-day applications from everyday life which many teenagers do not find interesting. It is difficult to relate many of the abstract and scientific concepts on our curricula and syllabi to the learners’ own lives. Linking new information to the learners’ previous experience and knowledge involves approaching a new topic from an angle where it can be perceived by the learner so that some association can be made with an established framework in their Long Term Memory. According to the Information Processing Model, (Johnstone 1997), the learner’s mind will only perceive new concepts, which can in some manner be linked to previous conceptual frameworks.

In one sense, the Perception Filter is the fundamental component of the Information Processing Model. Since the learner can only perceive what is familiar to them, if a new
concept is rejected at this stage, it may never pass through the Working Space to Long Term Memory and understanding. The perception of new information is dependent on what the learner already knows (Ausubel 1968). Even though the teacher can provide stimuli for the learner, the learner’s previously developed knowledge and concepts are used to activate and control their perceptual filter (Johnstone 1997). When there is no attachment to established frameworks in the Long Term Memory, this often forces the learner to adopt rote learning. The efficient use of the Perception Filter reduces the risk of overload in the Working Memory Space. Overload, Working Memory Space and the Long Term Memory will each be discussed in detail later.

The three main factors contributing to a learner’s perception of a problem are concept understanding, information content and perceived difficulty (Johnstone 1981). These three factors are interdependent as illustrated in Figure 3.16. The most and least ideal conditions for learners to perceive a problem are mapped. Problems are most likely interpreted by the learner as difficult due to high information load.

![Figure 3.16 The most likely combinations of understanding and content for high or low perceived difficulty of a concept adapted from (Johnstone, 1981).](image)
The Perception Filter is controlled by the Long Term Memory. Ausubel (1968) explained how our prior knowledge and experiences depict what we can learn in the future. Pre-learning exercises such as pre-lectures and pre-laboratory sessions are of greatest benefit to learners with no previous Chemistry knowledge (Reid 2008, Seery 2009, Seery and Donnelly 2011). This pre-learning enables the Perception Filter to work more efficiently, as it provides the learner with a related concept to link with from the Long Term Memory. This means that information can be easily retrieved if it has been stored in a linked and orderly fashion. Visual or symbolic storage of information can often facilitate their retrieval (Reid 2008). However, it is important to consider the effectiveness of the graphical representations used and the possibility that these may not be perceived correctly by the learner. Johnstone (1997) used the example of conveying a three-dimensional molecular representation on a flat computer screen. Many learners may not have the cognitive ability or familiarity to effectively interconvert between two-dimensional and three-dimensional representations.

Many pupils and students learning Chemistry cannot see any relevance between what they learn in the classroom or the investigations carried out in the laboratory with their everyday lives and the world that they live in. Learners are often better able to see the relevance of Biology to their own lives in learning how their bodies work. It is often more challenging for teachers to make this same link with Chemistry. While in fact, there are many examples (foods, clothes, materials etc.) of organic compounds in every aspect of the learners’ lives, the challenge for the teacher is making the learners aware of these. Effective teaching needs to be able to activate and stimulate the learners’ perceptual filter.

Applications-led and context-based curricula base their content and in particular their introduction of new topics on real examples and situations relevant to the learners’ lives. In a context-led approach, learners are introduced to Chemistry through learning how experts, chemists and industrialists use Chemistry in today’s world. In an applications-led approach, a problem depending on the application of Chemistry can be the starting point. Reid (2000) stressed the importance that the problem used is relevant to the learners. This ‘real-life’ problem e.g. development of an aesthetic compounds used in surgery can define the Chemistry topic to be explored and thus, provide the framework for the more traditional teaching that follows. Chemistry taught in this manner is determined by life and the psychology of the learner, rather than the traditional logic of the discipline of the subject. Previously revised Chemistry syllabi and even recent syllabi continue to teach the
fundamentals that have little relevance to the lives of the learners. Typical traditional syllabi include applications of the Chemistry towards the end of a topic or as optional further reading. However, Reid (2000) outlined how it is possible to approach a topic from its application, leading to an explanation, and then working backwards towards the fundamental scientific concept. Introducing content that has social meaning and value to the learners assists their appreciation of the wonder and excitement of Science. Reid (2000) has specified five dimensions that can improve the learners’ attitudes to studying Chemistry if incorporated in the teaching. These included the historical dimension, social impact, industrial implications, economic implications and socio-moral implications. The approach to teaching Chemistry advocated by Reid (2000) involves the presentation of a problem, discussing the problem and then unfolding the necessary Chemistry as it makes sense in the context of the application. Such problems can include the depletion of the ozone layer, development of anaesthetics, chemical pollutants, energy of fuels etc. This approach has been used successfully in the Salters’ context-based Science courses in the U.K.(University of York 2010), which was first developed in the 1980’s.

Perceiving information which is familiar or known to the learner facilitates their understanding. If the Perception Filter works efficiently, Information Overload is less likely (Reid 2008). Information Overload will be defined and discussed in more detail with reference to Working Memory Space later. Beginning with a topic that the learners already perceive as interesting ensures the existence of an anchor in the learners’ Long Term Memory to attach this new knowledge to. Pupils need to be able to make a connection with the new information being presented and with their prior knowledge. Organic Chemistry is a useful section of the Chemistry curriculum to use as an introduction to other topics (Johnstone 2000b). Gas, food, fuels, clothing and plastics etc. are all part of the learners’ everyday lives. If the Long Term Memory has anchors of familiarity for such topics, the Working Memory Space is less likely to become overloaded when such topics are used as introductions to a lesson. Such a psychological organisation of the curriculum may facilitate the learners’ understanding better than the traditional logical approach. This applications-led approach rather than a conceptual approach makes it easier for learners to perceive new topics and make links with their previous knowledge and information.
3.3.2.2. Working Memory Space

Figure 3.14 illustrated the Working Memory Space within the Information Processing Model. Interpreting, re-arranging, comparing and preparing all happen within the Working Memory Space. Not only do learners filter what they can learn, but there is also a limit to the quantity of information that they can process and this also has a time factor (Johnstone 1997). It is important to clarify at this point the Working Memory Space has two functions; temporary storage (Short Term Memory) for incoming information, as well as processing and making sense of the perceived information. The Short Term Memory relates to the storage capacity within the Working Memory Space. It is easy to understand how a problem or new information presented to the learner can limit their Working Memory Space available if the information is not presented in an approachable manner. If the Working Memory Space is overloaded, learning will cease. Memory Overload can happen for two reasons: the Working Memory Space is shared (processing and short term storage and sometimes translation) and also new ideas coming in can displace old ideas if they are not organised (Johnstone and El-Banna 1986). When discussing Memory Overload, we must also consider the multidimensional nature of Chemistry in order to estimate the load being placed on the learner (Figure 3.2). Miller (1956) identified the average number of pieces of information that one can hold within the Short Term Memory as seven. The Short Term Memory grows by one unit for every two years of age, up to sixteen years (Pascual-Leone 1970). Miller (1956) used the word ‘chunk’ to describe each piece or unit of information that can be held in the Short Term Memory. The size of this chunk depends on the learners’ previous knowledge and related content in the Long Term Memory.

The Digit Backwards Test (DBT) (Miller 1956) and Figure Intersection Test (FIT) (Pascual-Leone 1970) were both used to measure the Short Term Memory capacity. However, it is important to acknowledge that the capacity of seven chunks is only true when no processing is required. Recall that the Working Memory Space is shared between the holding and processing of information. If there is too much of either one, the other is restricted. Working Memory Space increases with age reaching a maximum of seven at an average age of 16. Following the findings of Miller (1956) and Pascual-Leone (1970), Johnstone and El-Banna (1986) assessed learners’ Chemistry alongside the measure of Working Memory capacity. Due to the nature of the difficulty of Science and the method by which it is taught, the
average number of pieces of information that can be stored in the Short Term Memory is just five (Johnstone and El-Banna 1989).

It was found that subjects (e.g. Science) which are perceived as difficult by learners have many topics where a high number of pieces of information are presented to the learner at one time (Kellet and Johnstone 1980). This has been described as the Information Load. Information Load is the number of pieces of information that the non-expert learner has to hold at the same time to perform a task successfully (Reid 2008). While an expert may only use a small amount of their Working Memory Space to solve a problem, a novice may become over-loaded by the information to hold, organise, sequence and solve. Johnstone and El-Banna (1986) found that the relationship between Working Memory Space and performance was not linear. An increase in Working Memory Space (according to age) does not necessarily mean an increase in performance. However, performance is dependent on the Working Memory Space available. When a task exceeds Working memory Space, performance collapses. Figure 3.17 below shows that learners with a higher Working Memory Space are more successful in questions and tasks with a greater Information Load. However, irrespective of the Working Memory Space available, performance collapses once that capacity is overloaded.

![Figure 3.17 Performance collapses as Information Load increases reproduced from (Reid 2008).](image)

An expert (teacher or lecturer) can look at a problem, ignore the ‘noise’ (irrelevant details) and retrieve the associated concept from the Long Term Memory to further develop the new concept or create a link to the established framework. However, none of this is as easy for the
novice learner. Witkin and Goodenough (1981) identified the importance of selecting what is important in a particular task from all of the information given. This is called Field Independence. Learners who are Field Independent are less distracted by irrelevant material and can focus sharply on the ‘signal’, the message being taught. If this Field Independence is coupled with a high Working Memory Space, through the development and use of learning strategies such as chunking, the learner can perform to their greatest ability (Johnstone 2006). (Chunking will be explained when discussing Memory Overload later). Conversely, a learner who is highly Field Dependent and has a low Working Memory Space will have a lower performance level. This inter-relationship between Field Independence and Working Memory Space is illustrated in Figure 3.18. Learners’ performance improves at the level at which Working Memory Space increases and the learners become more Field Independent (Danili and Reid 2004).

![Figure 3.18 Effect of Working Memory Space and Field Independence on Chemistry performance reproduced from (Johnstone 2006).](image)

Material needs to be presented to the learner and assessed in a simple and clear manner to reduce the risk of overloading the Working Memory Space (Reid 2008). Learners with low Working Memory Space but who are field independent can perform as well as learners with a high Working Memory capacity but who are field dependent. The pattern observed in Figure 3.18 above illustrates this. Teachers should control the amount of useful information (the
signal) which the learner has to process and limit the distractions (noise) in the learning situation to maximise learner performance.

It has been found that the reason for much of the difficulty in Science and Chemistry is due to Information Overload and the learners’ limited Working Memory Space (Johnstone 1991). Reid (2008) highlighted the importance of setting questions for learners in a manner that the question itself will not overload the Working Memory Space even before the learner can begin to perceive what is being asked and to answer the question. Learners with less Working Memory Space should not be at a disadvantage from learners with normal or above average Working Memory Space. Examinations should be a test of content knowledge rather than intelligence and memory capacity. If neither the presentation nor type of assessment requires the learner to hold more information than the capacity of their Working Memory Space, then their performance will relate to their knowledge of the topic and not Working Memory Space. It is possible for learners with smaller Working Memory Spaces to learn and understand difficult topics through use of appropriate strategies (Danili and Reid 2004). In a school-based study by Danili and Reid (2004) several topics of Chemistry were re-organised and their presentation was modified to reduce the Information Load. It was found that the experimental group had a significantly greater (9%) improvement in their performance than learners from the control group, who were taught conventionally. The teaching materials used with this pilot group were specifically designed to minimise working memory overload, use relevant applications, and encourage understanding rather than memorisation and also to link new material in a meaningful way.

Unless there is systematic organisation of information from the Working Memory Space to Long Term Memory, any new ideas can displace older ideas. This can lead to confusion and Memory Overload. Johnstone and El-Banna (1986) examined questions given to learners by the demand (Z) involved in answering the question. The information given in the question needs to be processed, stored information in the Long Term Memory may need to be recalled and learned strategies for answering the question need to be activated.

Figure 3.19 shows the three factors contributing to our use of the Working Memory. To avoid overloading of the Working Memory and a decline in performance, the difficulty of the task (Z) cannot exceed the Working Space capacity (X) (Johnstone and El-Banna, 1986).
Figure 3.19 Simplified Model of Working Memory Space adapted from (Johnstone and El-Banna 1986).

When $Z \leq X$, this allows a fair assessment of the learner’s knowledge, and performance will therefore relate to the learner’s knowledge and skill, irrespective of their Working Memory Space. A beginner needs tasks to be set below their capacity ($Z < X$). However if $Z > X$, the learner’s performance is limited by their Working Memory Space. When Working Memory is overloaded, meaningful learning ceases (Johnstone 1997). This is where the use of strategies ($Y$) are constructive. These strategies included pre-learned concepts. The appropriate application of learned strategies such as formulae, definitions, mnemonics etc. can reduce the task demand and so enable the learner to answer the question. As strategies are developed, tasks can be set with a higher demand ($Z$). It has been found that when learners’ capacities are exceeded, about 10% can continue to work successfully through the use of strategies (Johnstone and El-Banna 1989).

Our Working Memory Space cannot expand beyond its limit ($X$). The Working Memory Space was correlated to the learners’ achievement scores in organic-synthesis problem solving (Stamovlasis and Tsaparlis 2000). However, we can train the Working Memory Space so that we can use it more efficiently. If the overall demand of the question exceeds the capacity of the Working Memory Space, this leads to Memory Overload and performance fails. This hypothesis presented by Johnstone and El-Banna (1986) and reviewed by Johnstone (2006) proposes that strategies can be developed and learned to overcome the limitations of Working Memory Space capacity. Successful chemists can handle tasks of high complexity because they are able to apply highly developed strategies ($Y$). The teacher should think more closely about how a question is asked as well as limiting and excluding the noise in the teaching situation, in order to facilitate the learners’ recognition of the signal. If the demand of the task is greater than the working space available ($Z > X$), this is not a fair
assessment of the learners’ Chemistry knowledge. It is important for teachers to realise that they often don’t ‘hear the noise’ because they are used to it, and know what needs to be focused on, but their learners do not.

Most introductory Chemistry textbooks introduce, on average 15 new concepts, symbols and terms per page (Rowe 1983). It is no surprise then, that the learners’ Short Term Memory can easily become overloaded when attempting to study Chemistry. Organic Chemistry textbooks have grown in size over recent years, as the number and coverage of topics has increased steadily. ‘Compretention’, a one-word philosophy combining comprehension and retention, may be used as a simple ideology for teachers and lecturers to follow in their striving for understanding amongst their learners (Ellis 1994). Johnstone and Kellet (1980) identified Information Load as the number of pieces of information that a non-expert learner can hold while performing a task successfully at the same time. The complex nature of Chemistry, which requires multi-level thought, is another contributing factor leading to overload of the Working Memory Space.

In many cases, teachers incorrectly estimate learners’ level of ability and prior knowledge. This, as well as the complex nature of Chemistry, contributes to Memory Overload for the learner. Johnstone (1981) suggested the use of ‘crutches’ such as rules and mnemonics to allow the learner to build confidence in the topic. These can be removed later when the concept is more clearly developed. E.g. the use of the \( \frac{M_1V_1}{N_1} = \frac{M_2V_2}{N_2} \) formula for the titration calculations, which is a concrete and solid method for beginners to learn and use before a more developed understanding of molarity is gained. However, there is a danger of becoming dependent on the crutches so that learners do not learn to walk unaided.

‘Chunking’ information is a strategy used to maximise the space available in the Short Term Memory. Chunking depends on the ability of the learner to draw on and use old material or else systemise new material (Johnstone 1997). For example, the letters FBI, CSI, ISPCC etc. are easily chunked and stored as one piece of information rather than three or five separate pieces. However, each of these acronyms are easily recalled because they are familiar. Learners are unable to chunk information which is unfamiliar to them, and as a consequence this limits the Working Memory Space available to them. \( \text{CH}_3\text{COOC}_2\text{H}_5 \) may be interpreted as fourteen pieces of information (individual atoms) rather than three (the \(-\text{C(O)O}-\) functional group, and two alkyl parts) or as one (ethyl ethanoate). As learners develop their own strategies, the appropriate application of these devices will allow them to exceed their
Working Memory Space capacity. As learners develop their knowledge of Chemistry, what constitutes a unit or chunk of knowledge (e.g. a functional group, an alkyl group etc.) expands (e.g. whole compounds or families of compounds) as concepts are developed. However, this does require a good inter-linked framework where new information is incorporated.

Nash et al. (2000) described the use of the ‘ordered tree technique’ in Organic Chemistry. This technique is based on the fact that learners have a tendency to remember one chunk of information before proceeding to the next chunk. It was found that the learners’ knowledge structures (trees) showed more depth at the end of their study of Organic Chemistry than at the beginning. Figure 3.20 illustrates the significant change observed by Nash et al. (2000) in their study of Organic Chemistry. The learners’ knowledge trees have developed more hierarchical depth and share more common chunks and related concepts. Also, similarity between the learners’ and lecturer’s ordered trees increased significantly during the term of study.

Figure 3.20 Cognitive structure representation of a learner at the beginning (A) and end (B) of their study of Organic Chemistry reproduced from (Nash et. al, 2000)
The time needed to chunk information is generally between 5-10 seconds per chunk. However, the pace of a general lecture is usually much quicker than this (Rowe 1983). This explains how many learners may feel lost and thus disinterested in Chemistry lectures. The time taken to chunk information also depends on how familiar the information is to the learner. Since beginners have fewer relevant concepts in Chemistry, which help them to ‘file’ their information efficiently, they may experience an overload of the Short Term Memory sooner than a more experienced learner in the subject. The rate at which information can move through the Short Term Memory depends on the familiarity of the new information and degree of connectedness among the incoming ideas and previous knowledge. Mental lapses happen sooner when the information that has to be learned seems to form no pattern. Rowe (1983) described four types of mental lapses that can happen: short-term memory overloads, the use of symbols which are not familiar to the learners, momentary confusion (as the learner tries to make sense of new information before processing to the Long Term Memory) and when something the lecturer says initiates a complementary chain of thought. All four of these mental lapses result in the learner missing out on the continuing lecture.

3.3.2.3. Long Term Memory

As was shown in Figure 3.14, there are arrows from the Long Term Memory to the Perception Filter (the perception of new information relative to previous knowledge), and also to the Short Term Memory (recalling and retrieving previous knowledge) as well as from the Short Term Memory to the Long Term Memory (for storage). The Perception Filter has already been discussed earlier with reference to the significance of previous knowledge in new learning and the value of introducing new topics in a context-based and recognisable manner to learners.

The feedback loop from the Long Term Memory to the Perception Filter provides an insight into the work of Ausubel (1968). Previous knowledge directly influences the learners’ perception of new material and their ability to understand and store it. The operations of the Working Memory Space (short term storage and processing) have already been discussed. The efficient operation of the Working Memory Space is dependent on an organised Long Term Memory. The Long Term Memory may be described, using the analogy of a ‘filing cabinet’ of information. The ability to recall and retrieve information from the Long Term Memory depends on how this knowledge has been stored. If stored in an orderly and organised manner, material will easily be retrieved, but if stored without order and
understanding, information will not be retrieved or recalled as easily. Very often the learner cannot make sense of processed material in the Working Memory Space because they cannot link it to anything in their Long Term Memory. If knowledge is stored in a linked fashion, it will be more easily recalled (Reid 2008). The accuracy of how prior knowledge is stored and understood can affect how we learn. The quality of the new information which is constructed is dependent on precise links with previously developed frameworks. The way in which information is stored in the Long Term Memory has consequences for future learning. It is important to acknowledge that this ‘filing system’ is not the same for all learners. What may appear as logical to one person may not be logical for the next. It is important to appreciate that each individual builds their own knowledge from what is presented to them. Johnstone (1997) described learning as a ‘reconstruction of material in the mind of the learner’ (Johnstone, 1997, p. 264). Johnstone (1997) also referred to Ausubel’s (1968) Spectrum of Learning. This spectrum is illustrated in Figure 3.21. The spectrum ranges from meaningful learning to rote learning.

Figure 3.21 Ausubel’s Spectrum of Learning adapted from (Johnstone, 1997)

Figure 3.21 clearly illustrates the different ways in which information can be stored the Long Term Memory (Johnstone 1997). New information can be merged with other information, which allows for meaningful learning. Alternative frameworks lead to the development of
misconceptions which are difficult to undo. The existence of such misconceptions in Organic Chemistry will be discussed later in this chapter (Section 3.4.3). Information which is rote learned is mostly unattached and therefore difficult to recall later (Johnstone 2006). When some information is unattached to previous knowledge, this may also be as a result of no pre-existing knowledge. Incorrectly linked knowledge or separate fragments of knowledge in the Long Term Memory are stored by memorisation without any clear understanding. This can lead to a lack of intrinsic satisfaction for the learner, and so cause a negative attitude towards learning Chemistry (Reid 2008). Learners’ attitudes and ability to learn will be discussed in more detail later (Section 3.3.3). Chemical misconceptions will persist when the cognitive organisation of the knowledge is weak (Taagepera and Noori 2000). Teachers need to present material in a manner to prevent overload and to optimise the processing stage to facilitate long term storage (Johnstone 2006). Ausubel’s (1968) spectrum can be applied to validate the practice of priming and preparing the Long Term Memory through pre-laboratory and pre-lecture sessions. Pre-learning problems activate the Long Term Memory to facilitate the solving of new problems later. This model of learning also highlights the negative consequence of misconceptions stored in the Long Term Memory, and the snowball effect of mismatched conceptual frameworks.

3.3.2.4. Using the Information Processing Model to enhance Learning

Reid (2009) summarised five predictions that have been developed from the Information Processing Model and have been tested and demonstrated in many of the research studies referred to above:

- When the Perception Filter works well, working Memory Overload is less likely: better performance.
- When the Perception Filter is well informed by pre-learning, working Memory Overload is less likely: better performance.
- Chunking skills enable the Working Memory Space to be used more efficiently: better performance.
- Working Memory Overload can force the learner to memorise: attitudes deteriorate.
- Ideas linked together extensively in Long Term Memory enable better recall: problem solving skills enhanced.

(Reid 2009)
Having looked at how the Information Processing Model works and the different stages involved in learning, it is also important to consider the most ‘ideal learning environment’ that teachers should aim to create in order to facilitate learning.

As well as teaching strategies (Y) so that tasks of higher demand (Z) can be kept within the learners’ capacity (X) (Figure 3.19), it is important for the teacher to encourage the learner to develop their own strategies to allow the individual to exceed their own limitations (Johnstone and El-Banna 1986). Reid (2008) outlined ways of increasing learners’ levels of understanding in Chemistry: Pre-learning helps to improve the selection process of the Perception Filter as learners become more field independent; presenting a problem in a way which is clear to the learner can facilitate linkages with prior learning e.g. the use of a picture from a laboratory experiment may trigger a concept previously developed in the Long Term Memory; deliberately linking new material to old material increases learner understanding.

Understanding how learners process information, Johnstone (1997) listed Ten ‘Educational Commandments’ to enable learning:

1. What you learn is controlled by what you already know and understand.
2. How you learn is controlled by how you have learned successfully in the past.
3. If learning is to be meaningful, it has to link onto existing knowledge and skills, enriching and extending both.
4. The amount of material to be processed in unit time is limited.
5. Feedback and reassurance are necessary for comfortable learning, and assessment should be humane.
6. Cognisance should be taken of learning styles and motivation.
7. Students should consolidate their understanding by asking themselves about what is going on in their own heads.
8. There should be room for problem solving in its fullest sense to exercise and strengthen linkages.
9. There should be room to create, defend, try out, and hypothesise.
10. There should be opportunity given to teach (you don’t really learn until you teach).

(Johnstone 1997)
3.3.3. Learners’ Attitudes

Much of the negativity and pessimism that surrounds Chemistry as a subject is related to the bad experiences learners have had with the subject (Johnstone 2006). The combination of abstraction, symbolism and practical work has turned many learners off the subject. Learners’ motivation to learn is important but does not necessarily determine whether they employ a deep or a surface approach. Aspects of learners’ motivation to learn can be classified as either intrinsic (e.g. wanting to know) or extrinsic (e.g. wanting to learn for the examination) (Sirhan 2007). As well as the perception, processing and storage of new information, it is important also to consider how the learners’ attitudes can influence their learning. Many people may believe that most of the learners’ difficulty with Chemistry is due to their poor and negative attitudes towards the subject, which in turn lead to low success rates in the subject. However, the contrary may also be true – poor attitudes are held towards Chemistry due to the low success rate in examinations. It has been found that learners who have less success have poorer attitudes (Reid 2009), but there is no research to prove that success rates directly influence attitudes. A study carried out by Hussein (2006) in the Emirates looked at the learners’ attitudes relating to studies in Chemistry. New teaching materials were designed to specifically reduce the demand on the limited Working Memory Space of the learners. These teaching materials were trialled with a group of learners, while a parallel group were taught the same content in the traditional manner. The experimental group reported an increased positive attitude to Chemistry in comparison to the control group (Hussein 2006).

The natural way of learning Chemistry through the operations of the Working Memory is to try to interpret and understand the information. However, when the Working Memory Space is overloaded, learners often resort to memorisation to gain success in examinations. When understanding is too demanding and time consuming, memorisation offers an easy way out. There is much anecdotal evidence that learners at Second-Level and Third-Level resort to this alternative when facing critical examinations with limited study time.

It is important when discussing the attitudes of learners to realise that learners don’t simply have a negative attitude to difficult material and a positive attitude to easy material. For many learners difficult tasks are more enjoyable than easier tasks (Reid 2009). Essentially, enjoyment comes when the learner is successful in their effort to gain understanding. If a true understanding of a chemical concept is not possible, due to limitations in the Working Memory, learner satisfaction decreases and their attitudes towards Chemistry deteriorate. The relationship between Working Memory Space and the learners’ attitudes is summarised...
in Figure 3.22. This highlights how the learners’ Working Memory Space can influence their attitudes towards a topic or subject. It is important that the teacher understands, recognises and accommodates for their learners’ level of Working Memory Space and cognitive development. These factors may be inhibiting the learning and in turn leading to negative attitudes towards Chemistry.

As well as the learner’s attitude to learning, understanding and motivation for learning is also dependent on the emotions of the learner. “The emotions generated in the learning process can either siphon off energy or energise the student” (Katz, 1996, p. 441). Katz (1996) described a productive cycle and a futile cycle of learning. In the futile learning cycle, negative emotions (e.g. frustration, stress, anger) preoccupy the learner and consume energy (i.e., through confusion, disappointment, loss of confidence etc.). In comparison, the productive learning cycle is the result of positive emotions (e.g. satisfaction, excitement) that provide energy to complete the task successfully (i.e. anticipation, curiosity, confidence).

3.3.4. Conceptions and Misconceptions

3.3.4.1. Developing a Concept

The world itself is complex, and as a child grows, they have to learn to make sense of everything. In the same way as a child develops the simple concept of a ‘tree’ for example, learners of Chemistry have to develop their own chemical concepts. Understanding what a ‘tree’ is, a child is then able to clearly distinguish what is a tree and what is not a tree. From
this understanding, a child can then continue to learn about the different types of trees e.g. sycamore, ash etc.

The literature provides many definitions of schema. Axelrod (1973) described a schema as a *pre-existing assumption about the way the world is organised* (Axelrod, 1973, p. 1248). However, McVee *et al.* (2005) referred to Rumelhart’s (1984) summary of the main features of schemas:

- Schemas have variables.
- Schemas can be embedded, one within another.
- Schemas represent knowledge at all levels of abstraction.
- Schemas represent *knowledge* rather than definitions [italics in the original].
- Schemas are active processes.
- Schemas are recognition devices whose processing is aimed at the evaluation of their goodness of fit to the data being processed. 

   (McVee *et al.* 2005)

Before discussing misconceptions, it is important to clarify what is meant by a concept, a misconception and an alternative conception. Taber (2002) described a concept as *‘a way of breaking up the world into bits that we can recognise and think about’* (Taber, 2002, p. 11). When new information is presented to a learner, he or she must try to fit this new information into their schema and pattern of understanding that they have used in the past. If new information does not fit well, something will have to give and essentially this is where many of the learning difficulties and misunderstandings are developed. The importance of linking new information to previous schemas is evident through the discussion in the previous Section regarding the links between the Perception Filter and Long Term Memory in the Information Processing Model.

Taber (2002) has provided a theoretical background about the prevention, diagnosis and cure of chemical misconceptions. He explained how unlike other concepts developed through development, Science is largely dealing with rule-governed concepts rather than natural concepts. New concepts are often introduced as definitions, which are in many cases inconsistent with the natural concepts. A person is said to have acquired a concept once they are able to identify examples and non-examples. Taber (2002) used a method of noticing similarities and differences as way to identify if learners have understood a concept. For example a learner may recognise the structures of ethene and ethanoic acid as molecules, as organic molecules or as an alkene and carboxylic acid etc. Acquiring and using concepts
requires the learner to look for and to recognise the similarities and differences in the structures. This elicits the features they bring to mind when thinking about the structures of the two molecules. In Chemistry, it is important that if concepts are introduced by a definition, that the definition is clear. For example the definition of an alcohol as ‘a compound with a –OH group’ may be understandable to teachers and chemists. However, to the novice learner, this could also apply to a carboxylic acid (-COOH) or even sulphuric acid or water! The definition needs to be precise: an alcohol is ‘an organic compound and the –OH group is not part of a larger functional group’. Taber (2002) warned that formal definitions are not always helpful for the learner. They may be incomplete, have limited capacity and application and often require prerequisite knowledge of equally difficult concepts. The use of concept maps, spider diagrams and mind maps are useful for the teacher to identify the learners’ difficulties and possible misconceptions after introducing a new topic (Novak 1990).

3.3.4.2. Development of Misconceptions

Many learners have difficulty with Chemistry because they are trying to construct appropriate understandings of fundamental chemical concepts from the beginning of their study of the subject. Learning is a cyclic process, meaning that new information presented to the learner is firstly compared with prior knowledge and if an appropriate association can be made, the new information is fed back into the same knowledge base. How learners develop their own understanding of new phenomena is dependent on their previous understanding of a related topic. Concepts are essentially a set of propositions that the learner uses to infer meaning for a particular topic. It is important to be aware that learners construct these concepts using information from two sources: what is formally taught to them by the teacher or lecturer and also their informal prior knowledge from everyday experiences. In their own framework, the learner can connect new information to previously developed knowledge. This essentially means that even though teachers try to teach theories and new ideas, the learner will in fact build their own concepts, which are often somewhat different from what was intended. When false concepts and frameworks are developed by the pupils, new information cannot be connected appropriately. This leads to the development of alternative frameworks or conceptions and misconceptions. Alternative conceptions are not always derived from the learners’ unschooled experience of Chemistry, but from the confusion and misleading linguistic cues in the formal learning environment (Rushton et al. 2008). This weak
understanding of a topic is often due to rote learning (Figure 3.21) as no connection can be made with any previous knowledge and as a result, this information is difficult to retrieve and can easily be lost. Inaccurate recording of material in lessons and lectures without independent checking can also leave learners with incorrect facts and concepts.

Understanding the difficult nature of the subject and the limitations and complications of the Information Processing Model, it is easy to understand why so many chemical misconceptions are developed by new learners. In their effort to make sense of new information, many learners often form mismatched or no linkages at all with previous knowledge in their Long Term Memory. Nakhleh (1992) outlined many of the chemical misconceptions that students develop through their misunderstandings of many Chemistry topics. These misconceptions are related to atoms and molecules, intermolecular forces, phase changes and gases.

“Creating a cognitive structure of a complex body of knowledge such as Chemistry is not easy, and it is a small wonder that students find the subject difficult. Students don’t know how to approach the material in a suitable manner”. (Nakhleh, 1992, p. 195)

As discussed above in this Section (3.3.4), as well as through discussion of the Information Processing Model (Section 3.3.2), how the learner perceives and understands new knowledge is dependent on their level of prior knowledge and how it is stored in the Long Term Memory. Johnstone (2006) outlined the need to help learners to make the correct linkages of new information with previous knowledge in the Long Term Memory. The presentation of material should avoid overload, to optimise processing and facilitate effective and logical storage (Johnstone 2006). The misconceptions present in Organic Chemistry will be discussed in Section 3.4.3 that follows. Taber (2002) made some recommendations for the teacher on how to construct correct chemical conceptions: never assume prior knowledge, make the unfamiliar familiar and use analogies. These and other effective teaching strategies will be discussed in Section 3.5.1 of this chapter.
3.4 - Organic Chemistry as an area of Conceptual Difficulty

Sections 3.2 and 3.3 of this chapter have taken a close look at the external and internal factors contributing to the difficulties in teaching and learning Chemistry. All of these factors contribute to the challenges faced by learners who are introduced to Organic Chemistry for the first time. This Section (3.4) will review previous research that has identified Organic Chemistry as a particularly difficult area of Chemistry, investigate what makes Organic Chemistry difficult and then discuss the most difficult topics and common misconceptions that have been identified in Organic Chemistry.

“Organic Chemistry touches our daily lives. We are made of and surrounded by organic compounds. Almost all the reactions in living matter involve organic compounds, and it is impossible to understand life, at least from the physical point of view, without knowing some organic chemistry”

(Hart et al., 1998, p. 3)

“Organic chemistry nowadays almost drives me mad; to me it appears like a primeval tropical forest full of the most remarkable things, a dreadful, endless jungle into which one does not dare to enter for there seems no way out”

(Freidrich Wohler, 1838)

Both quotes above present two different attitudes towards Organic Chemistry. There are three main difficulties in Organic Chemistry (Ellis 1994): there are no algorithms for solving problems, it requires three-dimensional thinking and the new vocabulary to be learned is very intensive. It is no wonder that learners need help in learning how to study Organic Chemistry. Organic Chemistry deals with all aspects of the chemistry of carbon compounds, which are the building blocks for all living organisms. Organic Chemistry is vibrant and diverse, but also complex and vast in size. As a subject it has a difficult reputation, as much of the vitality is stripped away in its transition from the real world to the typical Leaving Certificate or Third-Level course. There is also a long learning curve before the beginner can appreciate the beauty and structure of Organic Chemistry, and distinguish the beauty of the forest from the confusion of the trees.

“Among students, the Organic Chemistry course has a bad reputation of mythic proportions. From their viewpoint Organic Chemistry is a dreaded ‘wash-out’ course”

(Katz, 1996, p.44)
The contributing factors (column on the left) listed in Table 3.2 include most of those presented in Figures 3.1 and 3.8, and discussed in Sections 3.2 and 3.3 respectively. The resultant problem areas in Organic Chemistry (column on the right) will be discussed below.

**Table 3.2 Contributing factors and resultant difficulties in teaching and learning Organic Chemistry.**

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>Resultant Problem areas in Organic Chemistry</th>
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</thead>
<tbody>
<tr>
<td><strong>Multi-dimensional Nature of Chemistry</strong></td>
<td>Understanding reaction equations and mechanisms (symbolism).</td>
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<td></td>
<td>Understanding structures (sub-microscopic).</td>
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<tr>
<td></td>
<td>Understanding properties and physical characteristics (macroscopic).</td>
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<tr>
<td><strong>Complex language</strong></td>
<td>Misconceptions and alternative conceptions for word meanings e.g. radicals, electrophile, carbonyl etc.</td>
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<tr>
<td><strong>Laboratory Work</strong></td>
<td>Cannot recognise the linking between the theoretical and practical work (distracted by the 'noise').</td>
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<tr>
<td><strong>Chemistry Curricula</strong></td>
<td>Organic formulae, structures and reactions are limited to the boundary of the Chemistry class, without real-life applications.</td>
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<td></td>
<td>Content is not perceived in a psychological order.</td>
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<tr>
<td><strong>Cognitive ability of the learner</strong></td>
<td>High cognitive demand in order to understand abstract concepts without any concrete representations e.g. reaction mechanisms.</td>
</tr>
<tr>
<td><strong>Information Processing Model</strong></td>
<td>Different representations of organic formulae, rules of IUPAC nomenclature can cause memory overload, lack of prior knowledge affects the Perception Filter.</td>
</tr>
<tr>
<td><strong>Pupil Misconceptions</strong></td>
<td>Without time for understanding, mechanisms and reactions may be rote learned without any real appreciation for their meaning.</td>
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<tr>
<td></td>
<td>Misconceptions of prior areas of Chemistry e.g. electronegativity, bonding, molecular shapes etc. can lead to further difficulties in Organic Chemistry.</td>
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</table>
3.4.1. Previous Research

Many studies have been carried out over the past 30 or 40 years highlighting the difficulties with Chemistry at both Second-Level and Third-Level. Table 3.3 below provides an overview of some of the difficulties relating to Organic Chemistry persistently identified in these studies. While each of the studies investigated the difficulties of Chemistry in general, only the Organic topics are listed here. It should be noted that Table 3.3 essentially lists almost all topics in Organic Chemistry. The findings of Childs and Sheehan (2009) are highlighted in particular since this study was carried out in Ireland.

Table 3.3 Organic Chemistry topics that have persistently been identified as difficult.

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<tbody>
<tr>
<td>Third Level &amp; Third Level Ireland</td>
<td>- Hydrocarbons; aliphatic and aromatic.</td>
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<tr>
<td>U.K.</td>
<td>- Organic synthesis involving aromatic compounds.</td>
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<tr>
<td>- Organic Synthetic Reactions involving:</td>
<td>- Preparation of Organic compounds.</td>
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<tr>
<td>*Carbonyl compounds (Aldehydes and Ketones)</td>
<td>- Reactions and Reaction Mechanisms.</td>
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<tr>
<td>*Carboxylic acids and their derivatives</td>
<td>- Organic Instrumentation (NMR Spectroscopy)</td>
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<td>- Amines</td>
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<td>- Protein</td>
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<tr>
<td>Chemistry</td>
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</table>
Many other studies, not included in Table 3.3, have also identified Organic Chemistry as one of the most difficult Chemistry courses (Gravert 2006, Schroeder and Greenbowe 2008). Jimoh (2005) also identified Organic Chemistry as an area of difficulty for A-Level Chemistry pupils in Nigeria.
The studies referred to in Table 3.3 identified difficult areas of Organic Chemistry. Sections 3.4.3 and 3.4.4 which follow will take a closer look at the specific areas of Organic Chemistry where pupil misconceptions have been identified. Firstly, section 3.4.2 looks at the reasons why Organic Chemistry is perceived as difficult by so many.

3.4.2. Cognitive Demand of Organic Chemistry

It is clear from the findings of previous research that Organic Chemistry is a difficult topic. The Information Processing Model discussed in section 3.3.2 provides an insight into the complications and challenges facing the learner. Piaget’s model of Cognitive Development indicates that the cognitive ability and development of the learner is age-dependent. Reaching the formal operational stage of development at 11 or 12 years should mean that these learners can then handle abstract ideas and think logically. However, Piaget’s findings were based on a small and elite sample and so resulted in an over-estimation of the pupils’ level of ability. More recent research has in some part contradicted this theory (Shayer et al. 2007, Childs and Sheehan 2010, Ingle and Shayer 1971).

Ingle and Shayer (1971) analysed the O-Level Nuffield Chemistry syllabus in England and decided that as many of the topics required formal operational cognitive ability, they were not suitable for pupils in Second-Level education. It was proposed that such topics be postponed until the learners reach the formal stage of cognitive development (Ingle and Shayer 1971).

Further work carried out by Shayer and Adey in the U.K. in 1981, (Shayer and Adey 1981) and in 2007 (Shayer et al. 2007) showed that the percentage of pupils at age 16 reaching formal operational level was much lower than previously thought. Piaget’s ideas do not reflect the reality of mixed ability classrooms and the diversity of learners at both Second-Level and Third-Level education in Ireland, and presumably in other countries. Through the preceding decades of the last century, performance on intelligence tests (I.Q. Tests) had been rising substantially. This phenomenon was termed the ‘Flynn Effect’. However, Shayer et al. (2007) showed that in contrast, the cognitive ability of learners has decreased over the past 23 years (Figure 3.23). This is described as the ‘Anti-Flynn’ effect because the decrease in cognitive ability has occurred despite a year-on-year improvement in examination grades.
Figure 3.23 shows the proportion of learners (boys and girls) at each stage of cognitive development in 1976 and in 2003. On both graphs, the proportion of learners at the early concrete level of cognitive ability has increased, while the proportion at the early formal level has decreased significantly. Shayer and Adey (1981) found that less than 30% of the learners at age 16 were at the formal stage of cognitive development. In the Irish educational system, the average age of the pupils beginning the Senior Cycle and the Leaving Certificate Chemistry course is 16 years. Only 30% of these pupils are at or above the early formal stage of development and only 10% are at or above the late formal development stage (Shayer and Adey 1981). This means that many of these pupils are then beginning a Leaving Certificate course without the ability to think in an abstract and conceptual manner. More recent work carried out by Childs and Sheehan (2010) show that the percentage of Irish learners operating at the formal operational level is lower than in the U.K. Less than 10% of Junior Certificate pupils, less that 20% of Leaving Certificate pupils and less than 40% of Third-Level students are operating at the formal stage of cognitive development. As discussed earlier, learners need to be at the formal stage of cognitive development to approach and understand the sub-microscopic and symbolic levels of Chemistry.

Shayer and Adey (1981) valued the benefit of streaming learners to facilitate cognitive development. When classes were streamed, the higher streams developed sooner and had a higher percentage of learners in the formal stage of cognitive development. However, this is not always the case at Second-Level and Third-Level education in Ireland. In the reality that is mixed-ability classes; the slightly below average do better and the above-average do less well. Shayer and Adey (1981) highlighted that this problem is even more acute in the
teaching and learning of Science. It is important for teachers and lecturers to realise that the percentage of learners reaching the formal operational stage of cognitive development by the end of Second-Level or in the early years of Third-Level education is much lower than many assume. In teaching Chemistry, it is critical that educators are aware of the cognitive level and ability of their learners. Otherwise, they will become swamped within the multi-level thought of Chemistry as well as the other scientific and mathematical demands of the domain.

Shayer and Adey (1981) devised a Curriculum Analysis Taxonomy (CAT) to analyse the cognitive demand of school Chemistry. This CAT was designed using the structure of Piaget’s work to classify curriculum objectives according to the schema and reasoning patterns employed as well as the stage of cognitive development at which they are characteristic. This was done by using two taxonomies. The first taxonomy looked at the different aspects of the development of the child’s interaction with the world. The five functions that were used were: Interest and investigation style, Reasons for events, Relationships, Use of models, Type of categorisation and Depth of Interpretation. The second taxonomy looked at different schema required for the understanding of the Sciences. The nine functions investigated in this taxonomy included Conservation, Proportionality, Equilibria of systems, Mathematical operations, Control of variables, Exclusion of variables, Problematic thinking, Correlational reasoning and Measurement skills.

Using these taxonomies, Shayer and Adey (1981) analysed the curriculum content of the O-Level Chemistry syllabus. Table 3.4 shows the analysis of the Organic Chemistry content in the O-Level syllabus. The properties of organic compounds according to their functionality, organic reactions and integration between organic families require the highest level of abstract thought (late formal) and intellectual ability.

<table>
<thead>
<tr>
<th>Late Concrete</th>
<th>Early Formal</th>
<th>Late Formal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Names of simple compounds.</td>
<td>Classification of a few simple families in terms of their common functional group. Absence of the simpler ‘rules’ of ionic chemistry (e.g. Redox reactions) gives rise to confusion.</td>
<td>Reactions between compounds, and deductive / explanatory model of the properties of compounds in terms of their functional groups and 3-D structure. Appreciates that there is a system of possible integration between different families of compounds and can begin to store knowledge of system.</td>
</tr>
</tbody>
</table>
Many of the Organic Chemistry topics on the O-Level syllabus are the same as those included in the current Irish Leaving Certificate Chemistry syllabus (DES 1999a). Table 3.5 which follows shows the proposed stages of cognitive development that Irish Second-Level pupils need to be at in order to learn and understand the complex nature of Organic Chemistry in the Leaving Certificate syllabus. These stages were categorised given the stages of cognitive development required for the main topics (highlighted in bold) listed from the O-Level Chemistry course in Table 3.4.

It can be seen from Table 3.5 that much of the Organic Chemistry in the current Leaving Certificate syllabus requires pupils to operate at the early and late formal stages of cognitive development. The topics listed in *italics* in Table 3.5 are Higher Level content only. The other topics are common to Ordinary Level and Higher Level. While much of the Higher Level material requires learners to operate at the late formal stage of development, most of the Ordinary Level content also requires formal operational thinking. From Table 3.5, it is easy to understand how and why Chemistry is often described as an elitist subject. Due to this high cognitive demand, the subject is correctly perceived as too difficult and avoided by many learners. Most of the topics in Chemistry courses are developed on an abstract, conceptual level even though most to the learners are only operating at a lower cognitive level (Goodstein and Howe 1978). If the majority of Second-Level pupils and Third-Level students in Ireland have not yet reached this stage of cognitive development, it is not surprising that these topics are difficult for them. When the learners lack the cognitive ability necessary to learn and understand the topics on their courses, alternative approaches may be taken by the learners e.g. rote learning to prepare for and pass the necessary examinations. This rote learning results in the formation of Organic Chemistry misconceptions leading to difficulties with the topics listed in Table 3.5.
Table 3.5 Curriculum Analysis Taxonomy of Organic Chemistry current Leaving Certificate Chemistry syllabus.

<table>
<thead>
<tr>
<th>Organic Chemistry (DES, 1999)</th>
<th>Late Concrete</th>
<th>Early Formal</th>
<th>Late Formal</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2 Structure of Aliphatic Hydrocarbons</td>
<td>Nomenclature and physical properties of alkanes, alkenes, alkynes.</td>
<td>Recognition of alkanes, alkenes, alkynes as homologous series</td>
<td>How the functional group and structure affects the physical state of aliphatic hydrocarbons and their solubility in water and non-polar solvents.</td>
</tr>
<tr>
<td>5.3 Aromatic Hydrocarbons</td>
<td>Nomenclature of benzene and examples of aromatic compounds. Physical properties of benzene</td>
<td>Recognition of examples of aromatic compounds.</td>
<td>How the functional group and structure affects the physical state of aromatic hydrocarbons and their solubility in water and non-polar solvents.</td>
</tr>
<tr>
<td>7.1 Tetrahedral Carbon</td>
<td>Nomenclature and physical properties of alkanes, chloroalkanes, alcohols.</td>
<td>Recognition of alcohols as a family due to the functional group.</td>
<td>How the functional group and tetrahedral shape affect the physical state of aliphatic hydrocarbons and their solubility in water and non-polar solvents.</td>
</tr>
<tr>
<td>7.2 Planar Carbon</td>
<td>Nomenclature and physical properties of alkenes, ketones, aldehydes, carboxylic acids, esters.</td>
<td>Recognition of benzaldehyde, alkenes, ketones, aldehydes, carboxylic acids and esters as families of compounds due to their functional groups.</td>
<td>How the functional group and planar shape affect the physical state of benzene, alkenes, aldehydes, ketones, carboxylic acids and esters and their solubility in water and non-polar solvents.</td>
</tr>
</tbody>
</table>

Notes:
Table 3.5 was constructed through adaptation of the O-Level curriculum analysis carried out by Shayer and Adey, (1981). Only topics that had been previously analysed and categorised by Shayer and Adey (1981) are included in Table 3.5. This does not include the complete Leaving Certificate Organic Chemistry syllabus. Topics listed in italics in Table 3.5 are topics on the Higher Level Leaving Certificate Chemistry syllabus.
The Leaving Certificate Organic Chemistry topics omitted from Table 3.5 include those from sections 5.1 (Sources of Hydrocarbons), 5.5 (Oil refining and its products), 5.6 (Other chemical fuels) of Section 5 of the syllabus and sections 7.4 (Organic Natural Products) and 7.5 (Chromatography and Instrumentation) from Section 7 of the syllabus. These topics omitted from Table 3.5 do not specifically require an understanding of Organic Chemistry. The topics listed in Table 3.5 are fundamental for an understanding of organic compounds, families and properties. To understand organic reactions, pupils need to be at the late formal stage of cognitive development. Organic mechanisms are only on the Higher Level Leaving Certificate Chemistry course. The understanding of reaction mechanism has been identified as a particular area of difficulty by many (Rushton et al. 2008).

“Students who might be aware of the need to connect the curved arrows with chemical concepts cannot achieve this goal because their knowledge of the principles of Organic Chemistry is not at an operation stage where they can apply it to problem solving’

(Bhattacharyya and Bodner, 2005, p. 1407).

Reaction mechanisms and other precise areas of difficulty in Organic Chemistry will be discussed in Section 3.4.4. However, it is important to first look at the misconceptions that can lead to difficulties with Organic Chemistry topics.

3.4.3. Organic Chemistry Misconceptions

What is meant by a concept and a misconception has already been defined and discussed in Section 3.3.4. Misconceptions can also be referred to as alternative conceptions or alternative frameworks. Both terms refer to a concept which has been misunderstood by the learner. Most misconceptions in Chemistry do not derive from the learner’s unschooled experience of the world, but instead as a result of confusion within the formal learning environment (Taber 2000). As already discussed (Section 3.3.1), many learning Organic Chemistry have not yet reached the formal operational stage of cognitive ability. This cognitive limitation impedes the learners’ ability to evaluate and assimilate an abstract and complex system. Improper assimilation of fundamental concepts such as functional groups, stereochemistry and equatorial or axial designations, lead to the development of misconceptions in the Long Term Memory, in turn resulting in misapplication of the theories. Learners do not consider any complications in the transfer of ideas between the sub-disciplines of Chemistry, when
attempting to apply what they have learned in General Chemistry in an Organic Chemistry context (Taagepera and Noori 2000, Hassan et al. 2004).

Schmidt (1997) has reported the many ways in which misconceptions have been identified in previous studies: through interviews, as well as paper-and-pencil tests including multiple choice, free response and concept maps. Rushton et al. (2008) also described a ‘think aloud’ approach was also recommended to allow learners to ‘explain verbally’ their thought processes to written prompts.

The misconceptions listed and outlined in Table 3.6 have been identified in a number of research studies. The reference given directly across from the explanation of the misconception refers to its source in the literature although these misconceptions may also have been identified by other research studies. Even though none of these studies specifically looked at the misconceptions identified in relation to Leaving Certificate Chemistry in Ireland, Table 3.6 presents the possible misconceptions when learning the topics in the Irish Leaving Certificate Chemistry syllabus. The misconceptions are presented in the subject areas as they are listed in the Leaving Certificate Organic Chemistry syllabus. This table does not include misconceptions in other areas of Chemistry e.g. particular mature of matter, which can also affect the understanding of Organic Chemistry.
Table 3.6 Possible misconceptions in Leaving Certificate Organic Chemistry.

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Related topic</th>
<th>Specific Misconceptions</th>
<th>Literature references</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aliphatic and Aromatic Hydrocarbons</strong></td>
<td>Isomerism</td>
<td>The term isomerism is limited to compounds of the same class. Isomers have the same shape in their representations.</td>
<td>Schmidt (1992) Taagepera and Noori (2000) Schmidt (1992)</td>
</tr>
<tr>
<td></td>
<td>Aromaticity</td>
<td>Incorrectly cite aromaticity when evaluating a resonance-stabilised non-aromatic molecule. Describe cyclohexane or cyclohexene as aromatic. Regarded as a structural rather than a functional attribute. How does the delocalisation of π electrons in the benzene ring make it more stable?</td>
<td>Rushton et al. (2008)</td>
</tr>
<tr>
<td></td>
<td>Combustion of hydrocarbons</td>
<td>Role of oxygen in combustion is poorly understood. Fuels change state and do not burn. Fuels are destroyed in burning or changed into something else.</td>
<td>Kind (2004)</td>
</tr>
</tbody>
</table>
**CHAPTER THREE TEACHING AND LEARNING CHEMISTRY**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polarity</strong></td>
<td>All of the organic compounds are neutral.</td>
<td>Chiu (2007)</td>
</tr>
<tr>
<td></td>
<td>Unable to identify the positive and negative ends of a polar bond.</td>
<td>Hassan <em>et al.</em> (2004)</td>
</tr>
<tr>
<td></td>
<td>Bond polarities depend on absolute electronegativities of atoms only.</td>
<td>Taagepera and Noori (2000)</td>
</tr>
<tr>
<td></td>
<td>Bond polarities in organic molecules depends only on atom electronegativities, whether they are connected or not.</td>
<td></td>
</tr>
<tr>
<td><strong>Stereochemistry</strong></td>
<td>Confusion between equatorial and axial positions</td>
<td>Rushton <em>et al.</em> (2008)</td>
</tr>
<tr>
<td><strong>Functionality</strong></td>
<td>Confusion between aldehyde, ketone and ester functional groups</td>
<td>Hassan <em>et al.</em> (2004)</td>
</tr>
<tr>
<td><strong>Organic Chemical Reactions</strong></td>
<td>Why are alkenes more reactive than alkanes, in spite of the fact that double bonds are “stronger” than single bonds? An ion is more stable than a neutral atom. Least hindered reactant identified as the most reactive.</td>
<td>Zoller (1990)</td>
</tr>
<tr>
<td></td>
<td>Inability to recognise reaction types.</td>
<td>Taagepera and Noori (2000)</td>
</tr>
<tr>
<td></td>
<td>Confusion between reactions that look similar on the surface and reaction names that sound similar.</td>
<td>Ferguson and Bodner (2008)</td>
</tr>
<tr>
<td><strong>Addition reactions</strong></td>
<td>Alkenes can only decolourise bromine in the presence of light.</td>
<td>Huat Bryan (2007)</td>
</tr>
<tr>
<td><strong>Esterification reactions</strong></td>
<td>During esterification, condensation occurs as water is produced. An –OH group is lost from the alcohol, while –H is lost from the carboxylic acid.</td>
<td>Huat Bryan (2007)</td>
</tr>
<tr>
<td><strong>Organic Synthesis</strong></td>
<td>Covalent bonds in organic molecules are broken on boiling</td>
<td>Taagepera and Noori 2000</td>
</tr>
<tr>
<td><strong>Organic Mechanisms</strong></td>
<td>Arrow pushing as meaningless method of getting to the product - pushing electrons wherever they may be needed. Using a mapping process to determine reaction mechanisms. Reproduction of memorised steps of reaction mechanism without understanding. Curved arrows were purely mechanical. Symbols in mechanisms are meaningless. Electron flow starting with a proton.</td>
<td>Bhattacharyya and Bodner (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rushton <em>et al.</em> (2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ferguson and Bodner (2008)</td>
</tr>
<tr>
<td>Focus on Reactants and Products</td>
<td>Evaluating stability of products instead of feasibility of the reaction mechanism Focus on the starting materials and products while disregarding the ‘whys’ and ‘hows’. Over-reliance on resonance structures for reaction mechanisms</td>
<td>Rushton et al. (2008) Ferguson and Bodner (2008)</td>
</tr>
<tr>
<td>Ionic addition mechanism</td>
<td>In the reaction of bromine and ethene, the carbocation is the same carbon that the first bromine atom joined to.</td>
<td>Taber (2002)</td>
</tr>
<tr>
<td>Free radical substitution mechanism</td>
<td>The chlorine bond breaks, forming HCl with a hydrogen from the methane (without any electron mapping / arrows).</td>
<td>Taber (2002)</td>
</tr>
<tr>
<td>Dynamic reaction pathway</td>
<td>Learners had more correct answers when evaluating a static image e.g. the axial / equatorial orientation of a molecule than when evaluating a dynamic system. Learners view starting materials and target molecules as static.</td>
<td>Rushton et al. (2008) Bhattacharyya and Bodner (2005)</td>
</tr>
</tbody>
</table>
It is important to understand that the misconceptions listed in Table 3.6 could also persist for those studying Organic Chemistry at Third-Level. Table 3.7 which follows outlines some further Organic Chemistry misconceptions that have been identified, but which are beyond the scope of the Leaving Certificate Chemistry syllabus.

**Table 3.7 Additional possible misconceptions beyond the scope of Leaving Certificate Organic Chemistry.**

<table>
<thead>
<tr>
<th>Related topic</th>
<th>Specific Misconception</th>
<th>Literature references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confusion between reaction types</td>
<td>Inability to recognise reaction types (tending to do nucleophilic addition reactions to carbonyl groups with strong acids, not recognising a simple proton transfer reaction)</td>
<td>Taagepera and Noori (2000)</td>
</tr>
<tr>
<td>Organic synthesis</td>
<td>Use of incorrect algorithms to solve synthesis problems</td>
<td>Bowen and Bodner 1991</td>
</tr>
<tr>
<td>Hydroxyl compounds</td>
<td>Phenols do not show any visible reaction with carboxylic acids because both are acids, and acids do not react with each other.</td>
<td>Huat Bryan (2007)</td>
</tr>
<tr>
<td>Carboxylic acid derivatives</td>
<td>All molecules that contain C=O group should undergo nucleophilic addition reactions, as it is unsaturated. Then why don’t acid chlorides and carboxylic acid undergo nucleophilic addition reactions?</td>
<td>Huat Bryan (2007)</td>
</tr>
<tr>
<td>Optical activity in substituted cyclic compounds</td>
<td>Why is 1,2-trans-dichlorocyclobutane optically active, whereas 1,3-trans-dichlorocyclobutane is not?</td>
<td>Zoller (1990)</td>
</tr>
</tbody>
</table>

The possible misconceptions listed in Tables 3.6 and 3.7 contribute to the difficulty of Organic Chemistry for the learner both at Second-Level and Third-Level. The next Section (3.4.4) will look at the resultant topics of most difficulty in Organic Chemistry as a result of these misconceptions that have been identified.
3.4.4. Difficult topics in Organic Chemistry

When looking at the areas of most difficulty in Organic Chemistry, it is important also to consider the topics learned in General Chemistry that contribute to the learner’s understanding of Organic Chemistry concepts. Ferguson and Bodner (2008) acknowledged the application of General Chemistry topics in Organic Chemistry and the effect that a prior correct conception or misconception of these topics can have on the learner e.g. understanding acids and bases or oxidation and reduction to recognise and classify organic reactions. The learner’s spatial reasoning abilities will also impede their efforts to understand reactions and reaction mechanisms. Figure 3.24 below illustrates many of the prior misconceptions learned in Chemistry, as well as the misconceptions specifically related to Organic Chemistry that contribute to many topics of difficulty in Organic Chemistry.

Figure 3.24 Misconceptions from General Chemistry and Organic Chemistry contributing to areas of difficulty in Organic Chemistry.
Anderson and Bodner (2008) highlighted the importance of the learners’ ability to transfer knowledge from General Chemistry to Organic Chemistry accurately. Very often even if the concepts have been perceived accurately in the study of General Chemistry, they may be applied and used inaccurately in the Organic Chemistry context. “It is possible that the reasoning process students develop in General Chemistry might even hinder their performance in Organic Chemistry” (Anderson and Bodner, 2008, p.100). Even though Hassan et al. (2004) referred to Organic Chemistry as a foreign language for first year student at Third-Level, the same may be said about second year Third-Level students as well as Second-Level Leaving Certificate pupils.

The learner experiences many difficulties in their attempt to formulate a clear understanding of Organic Chemistry. Some of these difficulties will now be discussed in this section. Anderson and Bodner (2008) summarised the main difficulties:

- Deriving the connectivity of atoms from a line structure.
- Translating the two-dimensional structure in an exam question into a three-dimensional image.
- Visualising the structure and properties of the entire molecule rather than focusing on the individual atoms or elements.
- Interpretation of chemical reactions as represented by the curved-arrow electron-pushing formalism. (Anderson and Bodner 2008)

These structural, holistic and abstract concepts require a high level of cognitive ability as they involve integration between the three levels of Chemistry (Figure 3.2). The difficulties with representation of organic compounds, isomerism, and families of organic compounds, organic reactions and mechanisms, as well as the challenges in the Organic Chemistry laboratory, will now be discussed.
CHAPTER THREE

TEACHING AND LEARNING CHEMISTRY

Representation of Organic compounds

“Students who do poorly in Organic Chemistry have shown that they often have difficulty escaping verbal/linguistic representation systems. They tend to handle chemical formulas and equations that involve these formulas in terms of letters and lines and numbers that cannot correctly be called symbols because they do represent or symbolise anything that has physical reality”.

(Bodner and Domin, 2000, p. 27)

The different methods of representing organic formulae are illustrated in Table 3.8. It should be noted that some textbooks may differ in how they refer to condensed structural formulae and structural formulae. Extended structural formulae are also sometimes referred to as expanded structural formulae. The manner in which the structures are named in Table 3.8 will be used throughout this thesis.

Table 3.8 Structural formulae used to represent compounds in Organic Chemistry.

<table>
<thead>
<tr>
<th>IUPAC Name</th>
<th>Structural Formula</th>
<th>Condensed Structural Formula</th>
<th>Extended Structural Formula</th>
<th>Skeletal structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane</td>
<td>CH₃-CH₂-CH₂-CH₃</td>
<td>H₃C(CH₂)₂CH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or CH₃CH₂CH₂CH₃</td>
<td>or CH₃(CH₂)₂CH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethyl ethanoate</td>
<td>CH₃-COO-CH₂-CH₃</td>
<td>H₃CCOOCH₂H₅</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or CH₃COOCH₂CH₃</td>
<td>or CH₃COOC₂H₅</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is easy to understand how learners meeting organic compounds for the first time can be confused if the types of representation are used interchangeably and inconsistently by the teacher. Some of the formulae can be represented in more than one way, which may add to the learners’ confusion.
Taber (2002) explained that each type of representation emphasizes different aspects of the molecule. It may be easier to recognize the functional group in the skeletal representations. Johnstone (2006) explained how the presentation of organic formulae can cause complications for the learner in Organic Chemistry. Johnstone (2006) presented pictures of organic formulae in different forms and the learners were asked to recall and re-write these. Since most of the learners’ mistakes were at the right hand side of the formulae, the conclusion was reached that as the learners read the formulae from left to right (as they read ordinary text). They also attempted to memorize them in the same way. It was also found that condensed formulae were easier to recall than extended formulae. This finding concurs with the previous research about the value of chunking information to prevent overloading in the Working Memory Space (Johnstone 1981, Johnstone and El-Banna 1989, Reid 2008). These have already been discussed in Section 3.3.2 above.

Johnstone (1981) had previously recognized the tendency of learners to rotate formulae in an equation to facilitate their understanding of the reaction. Orientation of the formula was seen as important to the learners. For example, many learners presented the acid or alcohol formula ‘backwards’ to facilitate the ‘lasso operation’ for the elimination of water in an esterification reaction. Such rotation of an organic formula signifies the learners’ perception of the organic structural formulae. Anderson and Bodner (2000) recommended the use of extended structures rather than condensed structures by instructors. Extended structures showing the atoms, bonds and non-bonding electrons make more space available to the learner in the Working Memory to learn the more important conceptual aspects of Organic Chemistry.

It has been found that the learners’ ability to solve chemical problems is often related to their ability to interpret the types of chemical representations used (Taber 2002). Understanding structural representations of organic compounds is fundamental to recognizing functional groups, classifying reaction types, writing reaction mechanisms etc. However, many learners develop a false perception of the meaning of the line bonds (Harrison and Treagust 2000, Hassan et al. 2004). The compounds are often falsely perceived as flat two-dimensional molecules as the extended structural formula can imply this for the novice learner.

The skeletal formulae represent the most advanced and cut-down representation. For this reason, these are usually not used at Second-Level, but are common in advanced Chemistry.
courses. Rushton et al. (2008) recognised the difficulty that learners have with understanding the three-dimensional molecular shape and bonding angles of the organic compounds.

As well as the structural formulae used to represent organic compounds, learners also need to be able to recognise and draw organic compounds through use of their IUPAC nomenclature. If understood correctly, the IUPAC nomenclature system should enable the learner to recognise, name and draw even unfamiliar compounds. The representation of the compound (skeletal, condensed or extended) can affect the learner’s ability to recognise functional groups, substituents, the longest continuous chain etc. The paper representations of compounds all depict the structures as flat two-dimensional molecules. This false perception contributes to further difficulties in stereochemistry, recognition of isomers and predicting how compounds will react.

Anderson and Bodner (2008) summarised some contexts that learners have difficulty understanding with relation to molecular representation in Organic Chemistry:

- deriving the connectivity of atoms from a line structure;
- translating the two-dimensional structure into a three-dimensional image;
- visualising the structure and properties of the entire molecule rather than focusing on the individual atoms and elements. (Anderson and Bodner 2008)

It takes some time before line structures become true symbols for learners (Bodner and Domin 2000), as this requires formal understanding at the three levels of Johnstone’s triangle (Figure 3.2).

**Isomerism**

Difficulties recognising isomers of organic compounds are closely related to the difficulties and misconceptions related to the representation of organic compounds. If learners cannot recognise substituents or carbon chains, or understand the three-dimensional nature of organic compounds, it is easy to understand how they have difficulty in identifying isomers of compounds. Without an understanding of the structural representations of organic compounds, learners find it difficult to recognise isomers, and resort to selecting compounds that have the same shape (branched or straight) as isomers (Schmidt 1992). Learners also often incorrectly restrict isomeric relationships to compounds from the same family (Schmidt 1992). While this illustrates difficulty with isomerism, it does suggest that the learners have
the ability to recognise common functional groups within compounds. However, the recognition of functional groups as a method of classifying organic compounds is also another area of difficulty for learners.

**Classification of Organic compounds**

Categorisation and classification is a systematic and higher order cognitive process. It evokes prior knowledge to infer new knowledge (Domin et al. 2008). Domin et al. (2008) outlined two methods of categorisation that may be used in Organic Chemistry: rule-based and similarity-based. The rule-based method is rigid, and involves procedural knowledge to make a clear yes or no decision. In comparison the similarity-based method is dependent on the learners’ own perception of a common attribute. Many salient features are presented to the learner when asked to categorise a given organic compound. Domin et al. (2008) listed seven of these attributes:

1. Number of carbon atoms.
2. Type of heteroatoms present.
3. Connectivity of parent compound.
4. Presence of multiple bonds between atoms.
5. Presence of chiral centres.
7. Different types of functional groups. (Domin et al. 2008)

This list provides an insight into the complex and intricate process of categorisation. With so many attributes, each providing a possible correct categorisation, it is difficult for the learner to identify the most prominent attribute for the given situation. Domin et al. (2008) found that the critical attribute by which learners categorise compounds changes as they progress through the Organic Chemistry course. Overall, functionality was found to be the predominant attribute for both higher and lower ability learners (Domin et al. 2008, Hassan et al. 2004). The higher ability learners tend to be more influenced by the current instructional topic when categorising compounds. The second most commonly used attribute by the higher ability learners was stereochemistry, while structural commonalities was the second chosen attribute for the lower ability learners. The process of categorisation is methodical and dynamic as the learners consciously devote their attention to different features in the organic compound.
Categorisation according to functionality does pose a lot of difficulty for some learners. Strickland et al. (2010) reported that many learners of Organic Chemistry were unable to explain or define clearly what a functional group was. For the novice learner, all organic compounds may appear similar, as a molecule made up of a combination of carbons, hydrogens and oxygens in most cases. The most common functional groups that are included in Second-Level syllabi and at introductory level Organic Chemistry at Third-Level are alcohols (-OH), aldehydes (-CHO), ketones (C=O), carboxylic acids (-COOH), esters (-C(O)O), as well as aliphatic and aromatic hydrocarbons. The presence of oxygen, carbon and hydrogen atoms in each of the functional groups can make it very difficult for the learner to differentiate between these families of organic compounds (Hassan et al. 2004). In particular aldehydes and ketones both contain the carbonyl (C=O) group and only differ in the internal (ketone) or terminal (aldehyde) position of this group.

As discussed already, the type of structure used to represent the organic compounds can affect the learner’s ability to classify organic compounds and identify the functional groups. Larger compounds are often more complex problems for the novice learner. Field dependency and independency (Witkin and Goodenough 1981) were discussed in Section 3.3.2. Johnstone (1991) explained the challenges faced by the novice learner to recognise the ‘signal from the noise’. Although much of Johnstone’s discussion was in relation to laboratory work, this factor is also relevant to the learner’s ability to recognise functional groups. Even if learners are familiar with the functional group of compounds, their difficulty in classifying compounds and identifying members of organic families of compounds is due to their inability to identify the complete functional group (signal) as part of the whole larger molecule (noise).

**Organic Reactions:**
The classification of organic reactions is difficult because learners do not have the same background knowledge as experts. Classification of a reaction “adds an additional cognitive demand, which does not automatically bring the benefits that accrue to the expert” (Taber, 2002, p. 142). Many learners have difficulty recognising that the many chemical reactions learned in Organic Chemistry are limited to number of common types. Learners need to be able to ‘construct reaction type mental slots into which they can drop reactions’ (Taber, 2002, p. 142).
A source of confusion for many learners is between reactions that look similar on the surface, reaction names that sound similar and poor differentiation between a nucleophile and a base (Ferguson and Bodner 2008). As illustrated in Figure 3.24, misconceptions and difficulties from learners’ prior experience of General Chemistry contribute to further difficulties when trying to understand Organic Chemistry. Misunderstandings related to reactivity of compounds and the stability of products due to bonding and electron density etc. make organic reactions difficult for novice learners (Taber 2000, Zoller 1990, Rushton et al. 2008). Understanding organic reactions requires a high level of cognitive ability. Learners need to be able to relate effectively the macroscopic reaction (evident in the laboratory) to the submicroscopic (molecular level) in order to be able to represent the reaction using the appropriate reaction equation (symbolic). Combining these three levels of thought is only possible for the formal operational thinker. Huat Bryan (2007) provided many examples of how learners don’t understand why reactions happen and what exactly is happening at the molecular level.

**Reaction Mechanisms**

Reaction mechanisms could be described as the ‘crescendo’ of understanding Organic Chemistry. Hassan et al. (2004) compared learning Organic Chemistry to learning a foreign language:

“Students must learn the vocabulary (names, functional group) and the grammar (reactions, mechanisms) in order ultimately to develop a rudimentary style of composition (mechanistic explanations, evidence of structures)”.

(Hassan, et al., 2004, p. 40).

‘Curly arrows’, ‘electron pushing’, ‘arrow-pushing’, ‘curved arrows’ are all names used to describe the methods of electron book-keeping used to keep track of electron pairs, or single electrons in chemical reactions. Mechanisms essentially track the movement of electrons from an electron rich ‘source’ to an electron deficient ‘sink’ (Ferguson and Bodner 2008). Unlike many other purely algorithmic exercises that learners practice, mechanisms are a valuable tool used by practising chemists. Mechanisms explain reactions, facilitate the understanding of new and unseen reactions and break the reaction into clearly-defined steps. A clear understanding of mechanisms can help to explain why a reaction takes place at a certain site and why an attack takes place on one side of the plane and not the other.
While practising chemists frequently use mechanisms for the above reasons, there are a number of conditions impeding the learners’ ability to do the same.

To draw a correct mechanism, the learner must be able to:

- Understand chemical principles.
- Apply complex and abstract theories and facts.
- Look at the problem from different perspectives.
- Selectively apply chemical and physical concepts.
- Correctly draw starting, intermediate and existing materials.

(Ferguson and Bodner 2008).

To understand why learners have persistent problems writing reaction mechanisms, one may refer to the relevance of the ‘Constructivist Theory’ (Bodner 1986). Ferguson and Bodner (2008) used this theory to again highlight the importance of the learner’s prior knowledge and Organic Chemistry experience, as deriving mechanisms essentially requires a holistic and accurate application of previously developed concepts and theories.

The factors limiting learners’ ability to make sense of mechanisms include:

1. Inability to recall – (Learners’ poor understanding of the rules, concepts and theories and only applying them sparingly. Too much reliance on memorisation, ‘tricks’ or ‘magic’ to problem solve).
2. Inability to apply or understand – (Confusion of reactions that look similar on the surface. Learners fail to make the link between what happens in the laboratory and drawing curly arrows on paper).
3. Poorly understood content – (For learners, the process of drawing curved arrows was purely mechanical and poor application and linking of General Chemistry concepts with Organic Chemistry).
4. Non-content-specific barriers – (Spatial reasoning abilities e.g. linear reactants and cyclical product. Such barriers arose when students could not see the connection between a reactant drawn in a linear structure and a subsequent cyclic product).

(Ferguson and Bodner 2008)

It was found that the process of drawing curved arrows was purely mechanical for learners (Anderson and Bodner 2008). The learners view mechanisms as an academic exercise to produce a scheme on a page. This may be because the learners are only able to comprehend
one side of the ‘Chemistry Triangle’ (Figure 3.2) at any time, and are unable to see the connection between the reaction in the laboratory (macroscale) and the paper exercise of drawing mechanisms (symbolic).

Bhattacharya and Bodner (2005) used a ‘think aloud’ protocol when conducting interviews to assess the learners’ predictions of mechanisms in a study carried out at Third-Level. It was found that the curved arrows used in electron pushing formalisms held no physical meaning for the learners involved. The learners did not understand the function of the mechanism in explaining the ‘how’ and ‘why’ of the reaction. The learners’ focus were more on the starting materials, intermediates and products rather than the physical process involved. Many learners evaluate the suitability of the products rather than the feasibility of the process. For these learners, the arrows are physically meaningless (Rushton et al. 2008, Bhattacharyya and Bodner 2005). Bhattacharyya and Bodner (2005) explained the ‘Connect the Dots’ strategy: for some learners, the curved arrows simply join the intermediates on the path to the target molecule. The most difficult part of the mechanism for many is the beginning; learning to determine the first intermediate. Some learners firstly identify the reaction type and then used the curved arrows to go to the next step of the reaction. Since the arrows were useless, the justification for their use was simply ‘to get to the product’. This meant that many learners were forcing reactions to fit using nonsense steps, resulting in the creation of unlikely intermediates. These learners illustrated a naïve mapping strategy where the starting materials and target molecules were static in comparison to the dynamic minds of expert organic chemists. When asked to explain each step, it became clear that the participants had simply reproduced a memorised sequence of events. The learners are able to produce correct answers without understanding the concepts on which their solutions are based. “Rather than solving chemical problems, they [the learners] were essentially playing with puzzles” (Bhattacharyya and Bodner, 2005, p. 1406). It takes a significant amount of time before line structures and mechanisms truly become symbols for learners (Bodner and Domin 2000). Hessley (2000) reported on the learners’ use of flash cards to facilitate their rote learning of reaction mechanisms, as an alternative when understanding seems to be beyond the scope of the learners’ abilities.

Bhattacharyya and Bodner (2005) concluded the reason that learners cannot understand curved arrows is because their knowledge and cognitive understanding of Organic Chemistry is not yet at a formal operational stage. The theory of mechanisms needs to be incorporated
into the Organic Chemistry course to give learners more of an insight into the rationale behind their use. If the learners are more aware that arrow-pushing serves a function, they may be better able to understand and draw mechanisms, without recalling and memorising previous mechanisms. Later recommendations by Ferguson and Bodner (2008) reiterated the need to focus class time on the recognition of the main themes and core concepts of mechanisms, rather than concentrating on the minute detail of functional groups. However, such minute details about structure and functional groups are paramount to the learners’ understanding of reactivity and mechanisms of reactions. Taber (2002) also acknowledged that the understanding of how and why reactions occur is dependent on a complete background knowledge. If learners do not have a strong foundational understanding of Organic Chemistry, they will not be able to understand, predict and classify reactions and mechanisms.

More frequent and distinctive connections need to be made between the representational, submicro-scale and macro-scale levels of Organic Chemistry to make symbols more meaningful for learners. Exercises such as explaining the mechanism of a reaction in the laboratory report may facilitate this. Misapplication of discipline-specific concepts, as well as previously learned concepts from other Chemistry disciplines is a major source of confusion and error for learners (Anderson and Bodner 2008, Ferguson and Bodner 2008, Rushton et al. 2008). To alleviate misapplications and misunderstandings from General Chemistry impeding the learners’ comprehension of Organic Chemistry, the approach to chemical concepts will need to be addressed and reinforced within the context of new reactions and functional groups.

**Practical Work**

The importance and necessity of practical work has already been outlined in Section 3.2.4. The short-comings of practical and laboratory work were also discussed earlier with reference to Johnstone’s Triangle (Figure 3.2). Successful understanding of and effective practical work requires the ability of the learner to interpret what is happening at the macroscopic, submicroscopic and symbolic levels of Chemistry. As already discussed, due to the limited cognitive development of many learners, this can lead to Memory Overload and result in a poor understanding of what their practical experiment is demonstrating or investigating. Greenbowe and Schroeder (2008) and others have criticised the instructional ‘recipe-type’
procedures that are often given to learners in laboratory classes. In these cases, the learners become focused on the macroscopic set-up, preparation and manipulation of apparatus, without considering the submicroscopic reaction. Johnstone (1991) described this as the learners’ inability to recognise the ‘signal from the noise’. Following a set procedure to find predetermined results does not envoke any sense of scientific inquiry for the learner. Hume and Coll (2008) investigated the learners’ perceptions of practical Science at Second-Level in New Zealand. It was found that much practical work is ineffective, and the learners acquire a narrow view of scientific inquiry without any higher-level thinking (Hume and Coll 2008).

“[Such two-dimensional laboratory settings] reduce student learning about experimental design to an exercise in “following the rules” as they engaged in closed rather than open investigations. Thus, the resulting student learning was mechanistic and superficial rather than creative and critical, counter to the aims of the national curriculum policy that is intent on promoting students’ knowledge and capabilities in authentic scientific inquiry”.

(Hume and Coll, 2008, p. 1201)

Although this investigation was carried out in New Zealand, anecdotal evidence suggests that the same findings could be true for practical work at Second-Level and Third-Level in Ireland.

Although many experts hold the view that practical work has the potential of making a difference in terms of learners’ interests and views of Science, the matter of how effective practical work could be and what learners should learn from in the laboratory is still an open discussion (Gomes et al. 2008). There is a lack of evidence that traditional laboratories promote meaningful learning (Schroeder and Greenbowe 2008, Zoller and Pushkin 2007). Practical work, according to Abrahams and Millar (2008) is “generally effective in getting students to do what is intended with physical objects, but much less effective in getting them to use the intended scientific ideas to guide their actions and reflect upon the data they collect” (Abrahams and Millar, 2008, p. 1945). There is little evidence the learners effectively link their learned theory with the practical activities in Science lessons (Abrahams and Millar 2008). Many learners see no connection between the reaction as it occurred in the laboratory and how arrows depict the mechanism on a page (Ferguson and Bodner 2008).

Abrahams and Millar (2008) explained that practical work links two domains: observables (objects, materials) and ideas. As illustrated in Figure 3.25, each of these domains can be
effective at two levels: Level 1 and Level 2. At Level 1, the learners work with the objects and materials provided as the teacher intended them to do, and generate the kind of data the teacher intended. At level 2, the learners think about their actions and observations using the ideas that the teacher intended them to use. Level 1 is referred to as the ‘doing level’, and Level 2 is referred to as the ‘learning’ level (Abrahams and Millar 2008). At Level 2, learners can recall the materials and procedure used and features of the data collected in a practical activity. They are also capable of demonstrating an understanding of the purpose of the practical activity and what it demonstrated and helped them learn.

Through observation of 25 practical lessons, Abrahams and Millar (2008) found that the tasks were ineffective in facilitating the learners’ scientific understanding. While emphasis was placed in the teachers’ presentation of the task and the learners’ discussion, little emphasis was given to the learners’ understanding of aspects of the experimental design, analysis and interpretation of the results.

Practical work should help to bridge the gap between a macroscopic understanding and the sub-microscopic and symbolic levels. Learners need to be made more aware of the observations and ideas present in a practical activity.

“If teachers could be helped to differentiate more clearly between tasks of relatively low learning demand and those where the learning demand is much higher, this would then allow them to identify those tasks where students might require greater levels of support in order that the intended learning might occur” (Abraham and Millar, 2008, p. 1967).
3.5 – How to Improve Teaching and Learning of Organic Chemistry

Chemistry needs to be taught in a way that allows learners to construct their own knowledge, rather than simply memorising unrelated facts. However, if the hierarchy and order of teaching Organic Chemistry is developed and planned by the teacher or other experts, it is necessary to acknowledge the difference in thinking patterns between novice learners and experts (Taagepera and Noori 2000). What is logical to an expert may not seem at all logical to the learner (Johnstone 2000a). The results of many examinations and tests given regularly to Second-Level and Third-Level indicate deceptively high levels of understanding of Organic Chemistry. Teachers and lecturers assessing learners’ knowledge must consider the amount of information which is rote learned for these examinations; as well as the methodical prediction of examination questions and topics in both the Leaving Certificate and Third-Level examinations. The pupils’ plea for model answers and written explanations that can be learned, to be later regurgitated in an examination situation was recognised in a study of A-Level Chemistry pupils (Ratcliffe 2002). The ‘points-race’ in Ireland due to competition for places in Third-Level education has resulted in the evolution of a grinds school culture, where the whole focus of teaching is on successfully passing the Leaving Certificate examinations. Examinations need to be more diverse and include more “why” questions i.e. higher order questions. These are necessary to assess the learners’ understanding of the topic and ability to apply learned knowledge to new situations.

The teaching of Organic Chemistry in the first or second year of a Third-Level programme (where it is usually first introduced) needs to include the revision of many of the topics from General Chemistry: electron configuration, bonding, structure, shapes, formal charge and resonance (Ellis 1994). A short introductory Organic Chemistry course doesn’t need to cover all types of reactions. Certain reaction types may be selected to demonstrate synthesis etc. The complexity of the volume of material can be reduced to facilitate what may be the learner’s first introduction to Organic Chemistry, and focus on essential ideas.

Difficulties at Second-Level underpin learner difficulties at Third-Level (Hassan et al. 2004). This explains why it is important address to these misconceptions and difficulties at both Second-Level and introductory courses at Third-Level. To teach effectively, the teacher has to be able to draw upon three distinct domains of knowledge: an understanding of their learners’ cognitive ability (as discussed earlier), content knowledge and pedagogical
knowledge (Taber 2002). Childs (2009) highlighted the importance of selecting and training the best people for Science teaching and to continue their training during their teaching. Childs (2009) also acknowledged the importance of involving practitioners in the design, preparation and evaluation of teaching materials and methods. If practising teachers are involved in active research, they will then become more aware of the difficulties and misconceptions that their learners may have, and so, attempt to address these in their teaching.

Suggestions made by Rushton et al. (2008) to reduce the misconceptions in Organic Chemistry include increasing active learning in the classroom and increasing the use of visualisations and animations to facilitate the learners in developing a comprehensible and holistic understanding of the organic molecules as three dimensional compounds.

Ferguson and Bodner (2008) made the following recommendations to facilitate the learner’s understanding of electron mapping arrows and mechanisms: focus class time on core concepts that run through Organic Chemistry, rather than specific detail of functional groups; increase the frequency of connections between the symbolic world with the atomic and macroscopic levels of laboratory work. This study also sought feedback from the learners directly on how they think Organic Chemistry could be taught better to facilitate their understanding: ‘Students recognised that they would benefit from a discussion of basic themes, rather than the details of reactions of which they were exposed that can be learned by reading the textbook’ (Ferguson and Bodner, 2008, p. 111). It is interesting that none of the learners involved in their study wanted to ‘water-down’ the Organic Chemistry syllabus, but instead wanted the core concepts to be made more explicit.

Bodner (1986) has proposed a constructivist model for the teaching of Chemistry: “Social knowledge such as ...the symbols for the elements can be taught by direct instruction. ...But physical and logico-mathematical knowledge cannot be transferred intact from the mind of the teacher to the mind of the learner” (Bodner, 1986, p. 876). He explained that the constructivist model requires a shift in the position of the teacher from “teaching by imposition to teaching by negotiation” (Bodner, 1986, p.876). This emphasises the importance of a two-way dialogue between teachers and learners.
3.5.1. Evidence of Successful Approaches for Teaching Organic Chemistry

Improved teaching and learning strategies should be research-led, with regard to both Chemistry research and Educational research (Childs 2009). Chemistry Education Research is underway in many countries (DeJong 2007). In this Section a number of trialled and successful teaching strategies for Organic Chemistry will be outlined. The strategies are categorised with relation to the teaching approaches adopted: visualisation of the sub-microscopic; understanding of symbolic representations; context-based; meaningful practical work; facilitation of cognitive development; sequencing of topics; variable teaching styles; and accommodating for misconceptions.

1. Bridging from Macroscopic to Sub-microscopic and Symbolic:

Models are used in all levels of Science to explain a number of different concepts (Harrison and Treagust 2000). Models are a particularly useful resource in the teaching of Organic Chemistry. Johnston's Triangle (Figure 3.2) illustrated the three dimensions of Chemistry. Many learner difficulties and misconceptions in Chemistry result from inadequate or inaccurate mental models at the molecular level (Tasker and Dalton 2006). The concept of representation is one of the cornerstones of scientific practice (Strickland et al. 2010).

“Professional chemists tend to have detailed microscopic representations of matter. They can draw microscopic representations, use 3-D models of molecules, and illustrate molecular interaction using animations. This may help them translate between the microscopic and macroscopic worlds. In contrast, numerous studies have highlighted students’ difficulties grasping the particulate nature of matter” (Nicoll, 2003, p. 203).

Molecular modelling representations can be compelling and effective learning resources (Tasker and Dalton 2006). However, they must be designed and presented with great care to encourage learners to focus on the intended ‘key features’, and to avoid generating or reinforcing misconceptions (Tasker and Dalton 2006). Taber (2002) also highlighted the importance of allowing the learners time to become familiar with whatever type of molecular models are being used. There is much evidence that learners are not able to interpret scientific models as they were intended (Harrison and Treagust 2000). In a study carried out by Nicoll (2003), undergraduate students were asked to represent the Lewis structure of methanal (which was a compound they were familiar with) and a molecular model of the aldehyde. Different coloured clay and different sized sticks were available to the students. Even though
the symbolic and sub-microscopic representations were not shown correctly or accurately by all of the students, in all cases, the way students drew their Lewis dot structures were identical to the way they built their models (Nicoll 2003). This does suggest a good understanding and translation between the two types of representation. Most students correctly identified the carbon as the central atom, however, there was some confusion about the size of the atoms: some made the carbon the largest, while others incorrectly made the oxygen the largest using the explanation, ‘it has more electrons’. Almost all of the students used different coloured clay to represent the different atoms. The most common mistakes made related to bond angles, bond lengths and incorrect use of double and single bonds. Given the misconceptions and alternative structures of methanal represented in this study, this highlights that learners do not hold the same sub-microscopic representations as experts. It is essential that teachers do not make the assumption that they do. This study highlighted the advantages of using alternative materials (e.g. clay and sticks) instead of conventional molecular modelling kits:

- Some learners try to bring more to their models than are traditionally included in model kits.
- Conventional model kits tend to lead learners towards the correct answer, with a fixed number of holes and a fixed geometry inherent in each piece of the kit.
- Conventional model kits do not allow learners the freedom they may desire to represent different types of models.
- Learners can still build their own, potentially unconventional, representations of molecules.
- Not all learners are positively affected by the use of the conventional modelling kits.

(Nicoll 2003)

Some educators desire learners to have a common sub-microscopic representation of molecules, which may be achieved by molecular model kits. However, the findings from Nicoll (2003) tend to indicate that “while some students produced something that represented traditional model kits, there were those students who had perfectly correct representations, [that] appear to have exceeded the expectations of the model kit and built more creative and potentially useful representations” (Nicoll, 2003, p. 212). Learners need to move backwards and forwards between two-dimensional and three-dimensional representations using physical models and paper representations (Hassan et al. 2004). Teaching strategies using visual aids
can help to explain the concepts to the learners. This can help to increase the learner’s understanding and retention of the topic by enabling them to picture the Chemistry as it happens (Smith and Metz 1996).

In contrast to textbook illustrations, animations can show the dynamic, interactive, and multi-particulate nature of chemical reactions explicitly (Tasker and Dalton 2006). Computer modelling makes three-dimensional molecular structures visual and mobile in a manner that hand-held models cannot (Hessley 2000), and they provide “a greater potential to achieve deeper and more lasting understanding” (Hessley, 2000, p. 797). Learners benefit from the three-dimensional computer representations of chemical events and gain a better mental image of the course of a reaction (Fleming et al. 2000). Computerised representations and animations are dynamic; often highly interactive; can scaffold inquiry; and also provide multiple representations (Lindgren and Schwartz 2009).

Fleming et al. (2000) looked in particular at how computerised models can be useful in facilitating the learners’ understanding of chemical reactions and mechanisms, which are often the most difficult aspects of Organic Chemistry for the novice. Fleming et al. (2000) felt that the traditional Lewis structures (and curly arrows) used in written mechanisms do not provide a realistic picture of electron flow between molecular orbitals, and so designed computerised representations that showed a ball and stick perspective and the space-filling representation. The animations “facilitate visualisation and understanding [of] …electronegativity differences, bond polarisation, delocalisation of charges and partial charges through resonance and hyper conjunction, steric environments, and electron distribution within molecules” (Fleming et al., 2000, p. 790). Being able to see molecular orbital interactions helps in understanding how electrons flow in a reaction and why certain molecules react in the way they do (Fleming et al. 2000). Computer-based molecular modelling with predictive Valence Shell Electron Pair Repulsion (VSEPR) theory and hybridisation is helpful for learners to bridge the gap between macroscopic and sub-microscopic levels of understanding (Jones 2001). Jones (2001) discussed the value of allowing the learner to be able to measure the bond angle in alkanes and alkenes, and measure bond length etc. to gain a better understanding of the structure of molecules. This understanding will facilitate the learners when they progress to predicting the stability and reactivity of the molecules.
Fleming *et al.* (2000) has explained how the use of computerised molecular modelling has learning benefits for both the beginning Organic Chemistry learner “seeing the molecules undergoing the reactions in the ball and stick movie” (Fleming *et al.*, 2000, p. 792) and the advanced undergraduate to “observe stereo-electronic effect, π complex formation, reaction reversibility and the role of orbital symmetry” (Fleming *et. al.*, 2000, p. 792).

Tasker and Dalton (2006) gave specific benefits of computerised animations of molecules for learners:

- Animations encourage a learner with low prior knowledge to develop new ideas in Long Term Memory to create their mental models.
- High prior knowledge in the Long Term Memory allows a learner to perceive subtle but relevant features in an animation enabling development of more sophisticated mental models.
- High prior knowledge also enables comparison of an image created in Working Memory from viewing an animation, with an existing mental model in in Long Term Memory, leading to confirmation or modification of the existing mental model.
- High dis-embedding ability allows a learner to perceive the desired key features in a ‘busy’ animation.
- High Working Memory Space ensures a learner is able to manage the information from complex animations effectively, and construct and manipulate mental models of the phenomena.
- Adoption of deep-learning strategies and not surface learning approaches enables a learner to relate ‘key features’ in animations to models in the in Long Term Memory for deep understanding.  
  
  (Tasker and Dalton, 2006, p. 150)

The work of Tasker and Dalton (2006) in the VisChem project indicates that animations and simulations can communicate many key features about the molecular level effectively, and these ideas can link the laboratory level to the symbolic level. However, they did also acknowledge that molecular modelling can create new misconceptions, and the teacher needs to be aware of these. The teacher needs to learn how to integrate molecular modelling (using model kits, computerised models or animations) into their lessons in a manner that will not overload the Working Memory Space of the learner. Spending one laboratory class teaching the learners how to use and become familiar and interpret the software will enable the learner
to gain more from this approach to learning (Hessley 2000). ChemTube3D, developed in the University of Liverpool is an example of another resource for interactive animations and structures for undergraduate Chemistry (Greeves 2012).

Harsch and Heinmann developed a *Phenomena-orientated and Inquiry-based Network Concept (PIN-Concept)* for teaching Organic Chemistry in universities and Second-Level grammar schools in Germany (Barke et al. 2012). The ‘criterion of concreteness’ is one of the seven principles of this programme. The approach used in their programme echoes the focus on the macroscopic before sub-microscopic as outlined above and in Johnstone’s (1991) work.

> “The transition to an abstract level of understanding should not be expected by the teacher before the students have become acquainted with a sufficient broad basis of phenomena and concretely ordered perceptions, which require explanation, generalisation, and abstraction by the students themselves”.  

(Barke et al., 2012, p. 245-246)

2. **Context-based Learning**

> “Science, after all, is a process for interrogating nature, not simply a compendium of facts”

(Schwartz, 2006, p. 983)

A ‘context-based’ approach to teaching Chemistry is where a topic is introduced by showing the learner how the Chemistry is relevant to today’s world in research and industry etc. For example, specific case studies relating to bromine compounds and fertilisers were part of an ‘Industrial Chemistry-School Chemistry’ programme in Israel (Hofstein and Kesner 2006). Learning Chemistry through context and applications helps the learner to make sense of the world around them. Some Chemistry curricula only ‘tag on’ applications of Chemistry and contextual examples of the use of the Chemistry at the end of a chapter or topic, “*with applications of Chemistry only added as a footnote*” (Reid, 2000, p. 381). Knowledge must be based on the learners’ perceptions of the real world for understanding to be constructive (Bodner 1986). Chemistry should be taught by applications. Reid (2000) suggested many possible application areas: clothes, washing and dyeing, food and drink, cooking and cleaning, cosmetics and cleanliness, drugs and medicine, colour etc. Different applications will be more appropriate for different societies and cultures. However, the case is more that many curricula teach the fundamentals and neglect the greater value that could be taught. Reid (2000) cited Fensham (1985) in explaining that the boring fundamental concepts can
take up so much time, very little is left for the excitement of contemporary Science. In applications-led Chemistry, a real-life problem could be the starting point. This makes for a very interesting set induction to a lesson. The traditional teaching of the chemical concepts can then follow through a guided inquiry approach. (More teaching approaches and styles will be discussed below).

De Jong (2007) outlined four possible domains of origin of contexts for teaching Chemistry. These are illustrated with examples in Table 3.9 below.

Table 3.9 Four origins of context reproduced from (De Jong 2007)

<table>
<thead>
<tr>
<th>Origin of a context</th>
<th>Example of a context</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Personal domain</td>
<td>* Personal health care</td>
</tr>
<tr>
<td>* Social and society domain</td>
<td>* Acid rain effects on the environment</td>
</tr>
<tr>
<td>* Professional practice domain</td>
<td>* Practices of chemical engineers</td>
</tr>
<tr>
<td>* Scientific and technological domain</td>
<td>* Historical models and theories</td>
</tr>
</tbody>
</table>

International research projects such as Trends in International Maths and Science Study (TIMMS) and PISA have found that every learner constructs their own knowledge. Knowledge is situated, and so should be acquired in that manner (International Centre for Educational Statistics, 2010a, 2010b).

The Salters’ Institute was developed in 1918, as part of the Salters’ Company in the U.K. (The Salters’ Company 2009). The Institute aims to promote the appreciation of Chemistry and related Sciences among the young, and to encourage careers in the teaching of Chemistry and in the UK chemical industries. The Institute’s three core activities are Salters’ Chemistry Camps, Salters’ Festivals of Chemistry and Curriculum Development. The curriculum development is undertaken by the Education Group in the University of York. This curriculum development includes Salters Advanced Chemistry (SAC), Salters Horners Advanced Physics, Salters-Nuffield Advanced Biology and Twenty First Century Science. The SAC course is a two-year course which leads to the A-Level (Advanced Level) examination (aged 18) in the UK. This course and examination has been nationally validated and qualifies candidates for Third-Level courses. The examination incorporates a combination of written and practical assessments. It is also used as a one-year course leading to an AS-Level (Advanced Subsidiary Level) qualification. The two-year course is divided into 14 teaching units, the first 6 comprising the one-year AS course. Each unit focuses on
modern applications of Chemistry and important chemical principles are only introduced when they help students understand the application. Each unit is made up of three parts: story, chemical concepts and activities (Burton et al. 2000). This SAC Chemistry course offers an exciting and context-based approach to studying Chemistry at Second-Level. This course is now taken by over 17,000 Second-Level pupils across the U.K.

This course is structured to unfold as a series of ‘Chemical stories’ as illustrated in storylines. The SAC course uses contextual examples to teach chemical concepts. SAC has the following outcomes:

- To show the ways Chemistry is used in the world and in the work that chemists do;
- To broaden the appeal of Chemistry by showing how it relates to people’s lives;
- To broaden the range of teaching and learning activities used; and
- To provide a rigorous treatment of Chemistry to stimulate and challenge a wider range of learners, laying the foundations for future studies yet providing a satisfying course for those who will take the study of Chemistry no further.

(Bennett and Lubben 2006)

This context-based approach has proven to result in more effective learning and chemical understanding (Bennett and Lubben 2006). Where appropriate in a story, there are ‘excursions’ to consolidate the chemical concepts needed to understand the story. As learners progress through the course, new concepts are met and older concepts are revised in different contexts. This approach is often referred to as a ‘drip-feed’ or ‘teach in time’ approach where the chemical content is broken up into manageable chunks for the learner and only presented to them on a ‘need-to-know’ basis. Such an approach reduces the cognitive overload of the learner. (The ‘drip-feed’ approach will be discussed in greater detail below). Pupils involved in the SAC course reported greater enjoyment and interest in what they were learning (Reid 2000, Bennett and Lubben 2006). A greater proportion of SAC pupils go on to study Chemistry or Chemistry-related courses at University (Bennett and Lubben 2006). As mentioned above, this same context based approach has been used for development of Physics, Biology and Science curricula in the UK.

An example of a context-based initiative in the US is ‘ChemCom: Chemistry in the Community’. This was developed for Second-Level schools by the American Chemical Society (ACS). From this initiative, a similar curriculum was developed at Third-Level in the
U.S.; Chemistry in Context (Schwartz 2006), where “students are exposed to the inquiring, experimental, and often tentative nature of Science” (Schwartz, 2006, p. 983). The goals of this context-based programme are outlined below:

- To motivate learners to learn Chemistry and understand its societal significance.
- To teach them fundamental concepts of Chemistry.
- To lead them to discover the theoretical and practical significance of Chemistry.
- To equip them to locate information and address technical issues.
- To develop analytical skills, critical judgement, and the ability to assess risks and benefits and evaluate information.
- To provide hands-on experience with chemical phenomena. (Schwartz 2006)

Another U.S. initiative relating Chemistry to the learners’ lives is ‘CHEMISTRY is in the NEWS’. This programme enables students to see the connections, to understand Chemistry and its role in society, and to use this knowledge in the evaluation and in making judgements about choices presented in everyday life (Glaser 2004). This programme has a particular focus on Organic Chemistry.

‘Chemie im Kontext’ (ChiK) is a context-based Chemistry curriculum which has been developed in Germany. It was developed by Chemistry teachers, school authorities and Science educators for all grades and types of schools. ChiK links three conceptual principles with a four phase lesson structure. The three contextual principles are: Context orientation, Cross-linking knowledge to basic concepts and Methodological diversity. Context orientation refers to the introduction of topics using personally or socially relevant topics e.g. Hydrogen-fuel call cars. One of the units named ‘Plastic in cars’ is an example of how Organic Chemistry concepts can be presented in a contextual manner for the learner. The cross-linking of knowledge to basic concepts offers a structure to the learners for the systematic and cumulative development of knowledge and understanding. Finally methodological diversity refers to the more active role of the learners.

The four phases in the lessons are:

1. Contact Phase- learners become familiar with the new context.
2. Curiosity and Planning Phase- learners participate in planning and structuring future work.
3. Elaboration Phase – Independent learner activity supported by the teacher as little as possible.
4. Final Phase – freshly acquired chemical subject knowledge is extracted from the original context and applied to new contexts. (Parchmann et al. 2006)

The PIN-Concept programme (previously introduced) for teaching Organic Chemistry outlines ‘criterion of scientific enculturation’ as one of its principles (Barke et al. 2012). The learners in that programme learn to see Chemistry as a Science which is relevant to the world and to their own lives. The learners become more aware of the chemists’ language and the value of scientific knowledge.

The courses introduced and outlined here provide an example of the structure and goals of context-based Chemistry education. Context-based chemical curricula are gaining popularity throughout the world (Gilbert 2006). Although, there is much research and anecdotal evidence of the effectiveness of the context-based approach, the significant differences between the content and pedagogy evident in these specific courses and those characteristic of other more traditional Chemistry courses, makes reliable comparative testing extremely difficult to design (Schwartz 2006). Schwartz (2006) did indeed highlight one criticism of context-based education: the concepts may be so closely linked to the issues used to introduce them that learners do not acquire the ability to generalise and transfer those ideas. While there is some evidence that context-based approaches are effective in motivating learners and enhancing their attitudes to Science, there is also some evidence that such approaches can adversely affect learners’ understanding of scientific ideas (DeJong 2007, Ramsden 1997).

There is much to be done before we can be sure of the scope and limitations of the educational value of this approach to teaching Chemistry (Gilbert 2006).

3. Meaningful Practical work

Many of the problems associated with and limitations of practical work in Organic Chemistry have already been discussed in Section 3.4.4 of this chapter. It is necessary, in light of this research, that practical work and activities are precisely designed to allow for maximum learning to occur. It is important that the teacher is aware of the difficulties and complications with practical work and plans practical work carefully in an effort to reduce or eliminate such problems. Micro-scale activities provide a possible solution. Because these practical activities are carried out on a smaller scale, the reactions happen much more quickly. This facilitates a smoother integration of practical work even within a theory class. It must be acknowledged
that this smooth integration is more feasible at Second-Level where all Chemistry classes usually take place in a laboratory setting. This approach is also particularly suitable for Second-Level as the apparatus are often less complicated and easier to set up. It may not be applicable to Third-Level where lectures are in lecture theatres and the practical activities are rigidly scheduled to a separate 2 or 3 hour session at another time. There are many advantages to integrating micro-scale activities into lessons. “Micro-scale Chemistry is a laboratory-based, environmentally safe, pollution-prevention approach accomplished by using miniature glassware and significantly reduced amounts of chemicals” (Singh, et al., 1999, p. 1684). Micro-scale is particularly useful for Organic Chemistry, and this is the domain of Chemistry where it was originally introduced. It was first introduced in Bowdoin College, Maine in the US (Singh et al. 1999). One of the main reasons for introducing micro-scale laboratory techniques into Organic Chemistry was to reduce the use of the potentially hazardous organic solvents (Zipp 1989). There are a number of other advantages for using micro-scale apparatus:

- Reduction in the amount of chemicals needed (financial saving).
- Reduction in the chemical waste generated (financial saving and safer).
- Decrease in glassware breakage (less fragile and better connections).
- Possible to carry out techniques that may be too dangerous at a larger scale (safer).
- Shorter reaction time requires less laboratory and class time.
- Possible for learners to carry out more trials under a greater range of conditions.

(Zipp 1989)

There is also a financial advantage to using micro-scale apparatus. Savings can be made on the amount of chemicals needed and dealing appropriately with the reduced amount of waste. These savings balance the long-term cost of equipping a laboratory with micro-scale equipment.

Reid (2008) and others have recommended the value of pre-laboratory sessions to prepare the learners for the laboratory session. Even if this is only to review and understand the reaction that they will be using or to practice the practical set-up of glassware, a preparatory session has immense value in facilitating cognitive development during the laboratory session, allowing the learner to see the ‘signal form the noise’ and reduce the possibility of memory overload. Supasorn et al. (2008) explained how learners with a greater spatial ability can
extract relevant information in the laboratory, better than those with lesser spatial ability. Difficulties in the laboratory can lead to the development of alternative frameworks (Supasorn et al. 2008), which can in turn lead to further misconceptions in the learner’s understanding of a concept. The manner of presentation of the problem or experiment to the learner affects their ability to learn from the practical activity. It is therefore important for teachers and educators to consider the presentation of the problem to the learners in the laboratory. Supasorn et al. (2008) recommended pre-laboratory simulation, visualisation of the molecular process and familiarity with the macroscopic procedure as ways to support the laboratory learning environment, allowing the learner to be more active.

Computer-based molecular modelling is also effective in helping the learners to understand the abstract concepts in Organic Chemistry (Jones 2001). Jones (2001) has recorded and reported the positive effect of incorporating computer-based molecular modelling as part of the pre-laboratory exercises. This facilitates the learners’ understanding at a microscopic scale of what is happening during the laboratory practical (macroscopic).

“Writing is a necessary and valuable epistemological tool for learning” (Prain, 2006, p. 195). Writing activities can be incorporated into laboratory classes to facilitate the learners’ understanding of the macroscopic observations. Some research has claimed that learners “need opportunities to write in ways that enable engagement, clarification, and consolidation of emerging understandings” (Prain, 2006, p. 179). Writing can be used as a tool for shaping and clarifying the learners’ knowledge (Prain 2006). Traditional laboratory reports are often meaningless to the learner and serve only as ‘an extra piece of work they have to submit’. Schroeder and Greenbowe (2008) proposed the use of a SWH for laboratory reports. Table 3.10 shows the laboratory report format a traditional report and an SWH report. The beginning questions are generated by the learner and can only be answered by completing the experiment. This SWH incorporates Process-Orientated Guided Inquiry Learning (POGIL) activities. These have been shown to increase student performance and reduce drop-out from the course. The titles of some experiments were changed in these classes to ensure that the answers of the investigation were not given in the title. Using the POGIL approach in lectures, combined with the SWH in the laboratory reports, learners in this study were encouraged to think more critically and construct their own knowledge about the topics (Schroeder and Greenbowe 2008).
Table 3.10 Laboratory report format comparison reproduced from (Schroeder and Greenbowe 2008).

<table>
<thead>
<tr>
<th>Traditional laboratory report</th>
<th>The Science Writing Heuristic report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title and purpose</td>
<td>Beginning questions</td>
</tr>
<tr>
<td>Procedure</td>
<td>Safety considerations</td>
</tr>
<tr>
<td>Data and observations</td>
<td>Tests and procedures</td>
</tr>
<tr>
<td>Balanced equations, calculations, graphs</td>
<td>Data and observations</td>
</tr>
<tr>
<td>Discussion</td>
<td>Claims</td>
</tr>
<tr>
<td>Conclusion</td>
<td>Evidence</td>
</tr>
<tr>
<td></td>
<td>Reading and reflection</td>
</tr>
</tbody>
</table>

Zoller and Pushkin (2007) designed a problem-based laboratory course incorporating Higher Order Cognitive Skills (HOCS) for Organic Chemistry. This course was effective in increasing learners’ achievement. The facilitation of cognitive skills and cognitive development is another approach that can be taken to improve learner understanding and attitudes to Organic Chemistry.

4. **Facilitating Cognitive Development**

   “In designing teaching programmes, we need to take into account the change in cognitive levels at secondary level, the small percentage reaching formal thinking before leaving school and entering university, and the wider cognitive range of students at tertiary level”

   (Childs, 2009, p. 199).

Learners can have knowledge without understanding (Bodner, 1992). Without appropriate strategies to facilitate learners’ levels of cognitive ability, learners will resort to rote learning and are not given the opportunity to develop a true or deep understanding of Organic Chemistry. The high cognitive demand of Chemistry has been discussed earlier in the chapter (Section 3.4.2). Chemistry learners must be able to work and understand processes and reactions in two worlds: the macroscopic world and the molecular world, and represent them in a third world- the symbolic.

Libby (1995) used learning cycles to teach Organic Chemistry. The learning cycles are designed to “assist students in their progression from Piaget’s concrete operational stage of reasoning into the abstract level of formal reasoning” (Libby, 1995, p. 626). Many current Organic Chemistry curricula are overloaded, and so more is expected of the learners in less
time. This situation does not facilitate, and can hinder, cognitive development. “Everyone reverts to concrete operational or pre-operational thought whenever they encounter a new area” (Herron, 1978, cited in Bodner, 1986, p. 873). Libby (1996) views learning as an active framework and new material must be familiar or concrete so that it can manipulated and understood. “The learning cycle approach to teaching attempts to dissect course material into manageable chunks and to allow the students to work with each chunk to try make sense of it” (Libby, 1995, p. 626). There are three phases involved in the learning cycle: the exploration phase, concept invention phase and application phase. Through these phases, the learners discover patterns in data and learn how to devise theories in the same way as practicing chemists. The course material is specifically designed to ensure continuity from the general knowledge and abilities that the learners have at the beginning, and to build on them. New material is presented in a manner allowing the learners to ‘discover’ patterns and concepts (exploration phase). Learners are encouraged to explore various approaches to dealing with the problems, to reach a concept that best deals with the problem presented (concept invention phase). The learners then test their derived concepts or processes (application phase) and these concepts can then be used as a basis for the next exploration activity.

The ‘criterion of supporting cognitive skills’ is supported in the PIN-Concept programme which has been outlined earlier (Barke et al. 2012). While the natural cognitive limits are acknowledged in this programme, the development of cognitive skills is supported. These learners become aware of their own thought patterns and develop the ability to abandon the concrete external supports to develop and improve their self-concept.

Most of the other approaches discussed here (visualising the sub-microscopic, improving practical work, using a contextual approach and re-arranging the sequence of topics in the curriculum) all contribute in the facilitation of the cognitive development of the learner. Improved teaching strategies can help to reduce overload and encourage true understanding for the concrete operational learner in allowing them to develop abstract thought. Some programmes designed to facilitate cognitive development have been discussed in Section 3.3.1.2 above, so these will not be discussed again here, but they provide one model for developing thinking skills through Science activities. The “ITS Chemistry” programme (Sheehan 2010) which has been mentioned earlier was a successful intervention carried out in Irish Second-Level schools. This success illustrated how the incorporation of such teaching
approaches and strategies can be effective in facilitating the cognitive development of the learner.

5. **Structure and Sequence of the curriculum**

Many researchers have recognised the need to change how Chemistry and Science are taught. Bodner (1992) expressed the view that “something is wrong with the way Science is taught, and we need to restructure Science education” (Bodner, 1992, p. 186). The material needs to be presented in a manner that accounts for the psychology of the learner rather than the logic of the subject (Reid 2000, Hassan et al. 2004, Johnstone 2000b). The presentation of Organic Chemistry in Scottish syllabi has been modified to account for the learners’ misconceptions that were identified (Hassan et al. 2004).

Hassan et al. (2004) explained how much of the Organic Chemistry curricula in Second-Level focus on hydrocarbons with a particular focus on the carbon skeleton. However, at Third-Level, the focus often shifts to functionality of the compounds. In this situation, ‘the pupils are taught to originally focus on the skeleton, and then they have to switch to the functional groups’ (Hassan et. al, 2004, p. 41).

Bodner (1992) explained how one can determine the psychological order for the presentation of material:

1. Start with a topic that is closest to the learners’ experience.
2. Build from the learners’ experience to more abstract notions when the learner senses a need for some way to explain what he or she has already observed.
3. No-one learns going from the generic to the specific.
4. Start with systems that have relatively few parameters and work toward more complex systems.

These guidelines support the use of contextual examples and an applications-led curriculum as discussed earlier. The constructivist model supports the idea that the best sequencing of content in a curriculum or syllabus is to suit the novice learner and not what the experts perceive as logical (Bodner 1986). Rowe (1983) also advised teachers and educators to begin by working from what the learners already know and to do so slowly, as “information delivery rates should be slower in the beginning of the course” (Rowe, 1983, p. 955).
Organic Chemistry is a useful section of the Chemistry curriculum to use as an introduction to other topics (Johnstone 2000b). Gas, oil, food, fuels, clothing and plastics etc. are all part of the learners’ everyday lives. Since the Long Term Memory already knows and recognises these applications of Organic Chemistry, this provides an anchor for the introduction of Organic Chemistry (Johnstone 2010). If the Perception Filter is appropriately prepared, this will ensure that the Working Memory Space will not be overloaded, and thus, will operate at its full capacity. Such a psychological organisation of the curriculum may facilitate the learners’ understanding better than the traditional, logical approach. A lot of Organic Chemistry can be taught with only the knowledge of a few elements (carbon, hydrogen, oxygen and nitrogen). The organic compounds will become familiar to the learners much quicker since they are generally limited to only a few elements. Molecular models can be used to introduce the sub-microscopic level of knowledge using a three-dimensional concrete approach. The homologous series in Organic Chemistry can also be used to provide an insight to learners about molar relationship. The mole is a significant area of General Chemistry and can be introduced firstly through Organic Chemistry as illustrated in Figure 3.26 below.

![The Tangible Mole](image)

*Figure 3.26 Comparison of molar volumes using alcohols as an homologous series reproduced from (Johnstone 2010).*

The sequence in which Organic Chemistry is taught is often also determined by textbooks. Some textbooks, for example, use functional groups as their organising principle, while others organise content around bonding (single, double, triple bonds). Taagepera and Noori (2000) used electronegativity as the organising principle for Organic Chemistry. Green and
Rollnick (2006) decided that Organic Chemistry is characteristically a linear subject and also used electronegativity as a central point. Another example of teaching Organic Chemistry topics using a theme is the use of electrophiles and nucleophiles to facilitate the learners’ understanding of organic reactions (Fleming et al. 2000). This provides the learner with a logical approach to understanding mechanisms. The traditional ‘arrow-pushing’ approach does not provide a realistic picture of electron flow between molecular orbitals. Ideally a combination of both approaches is necessary to develop a holistic understanding of reaction mechanisms. A ‘Reverse Socratic’ method was used in the lecture sessions, where the front row learners each week, rather than the lecturer, initiated the dialogue. The learners’ seating plan rotated each week. Quizzes, tests and assigned readings ensured they prepared well before coming to class. Frequent, anonymous and formative assessments were used to provide the learners and teachers with feedback.

Green and Rollnick (2006) introduced fundamental ideas such as arrows and electron mapping for reaction mechanisms early in the course and they were subsequently used in all later sections. This approach could be referred to a ‘spiral’ approach as topics are introduced at the beginning and revisited throughout to allow a continuation and extension of understanding. However, in using this approach, as with other approaches, “students who have not managed to identify the organising principle, resort to memorisation of specifics for tests, which are forgotten soon after as lack of an organising principle prevents the carry-over of concepts into long-term memory” (Green and Rollnick, 2006, p. 1379).

A two-cycle approach to teaching Organic Chemistry has been trialled by Grove et al. (2008) in Miami University, Gravert (2006) in St, Mary’s University of Minnesota and Sartoris (1992) in Wittenberg University, Ohio. The two-cycle approach, also referred to as the ‘spiral’ curriculum, involves separating Organic Chemistry into cycles, rather than two consecutive courses. The first course provides the learners with an insight into the fundamentals of Organic Chemistry, which are traditionally covered in the two semester course, but at less depth. Emphasis in this first cycle may be placed on structure and bonding, resonance and aromaticity, stereochemical concepts, nomenclature and the functional group concepts. This first semester prepares the learners for the second semester of Organic Chemistry which may be more organised around a reaction mechanism approach. The second semester forces the learner to recall and relearn what they have covered in their first semester of Organic Chemistry. The first semester ‘survey’ course of Organic Chemistry may be
useful for degree courses which do not require in depth knowledge, and provides the learner with an insight into Organic Chemistry (e.g. those specialising in Biology or Physics). Alternatively, for learners who will be studying more Organic Chemistry, the two-cycle approach allows them to learn more, as they are less over-whelmed and less frustrated in their attempt to understand Organic Chemistry. Even though the rate of attrition was less than half of that for the previous year (with traditional two semester Organic Chemistry courses), it was found that towards the end of the second semester of the two-cycle course, many learners had to abandon their search for understanding and instead turn back to rote memorisation (Grove et al. 2008). Rushton et al. (2008) recommended a cyclical curriculum where topics e.g. polarity are introduced earlier, and then revisited with reference to Organic compounds to determine physical properties. Learners taught in this manner showed a positive understanding of the topic (Rushton et al. 2008).

Reingold (2004) in Juniata College, Pennsylvania proposed a curriculum modification by combining Organic Chemistry with Biochemistry. This approach aimed to make Organic Chemistry more approachable and beneficial for learners majoring in Biology. In traditional courses, many of the aspects of Organic Chemistry that are of interest to these students such as bio-molecules and metabolic pathways, are not discussed due to lack of time, or merely inserted as footnotes. In comparison, this course is more approachable and applicable for learners whose primary degree will be in Biology. Such an integrated Organic Chemistry with Biology module would be most beneficial for Biology students in their second year of study at Third-Level, as they would have at that stage developed a greater Chemistry knowledge (Reingold 2004).

This psychological approach and sequencing of topics facilitates the learner’s understanding and prevents overload. The PIN-Concept developed in Germany outlined the principle of ‘criterion of limitation’. This principle adapts the same concept that ‘new terms, methods and thought patterns should be taught only with a few suitable examples until they are consolidated within this limited cognitive domain [of the learner] (Barke et al., 2012, p. 246). This approach prevents distraction by the ‘noise’ (Johnstone 1991) in the learning environment and encourages the problem-solving process.
6. **Variety of teaching styles**

“The extent of learning that occurs in a Chemistry course taught by the lecture method is independent of the lecturer” (Dinan and Frydrychowski, 1995, p. 429).

Attendance at lectures has only a marginal effect on student performance at Third-Level (Dinan and Frydrychowski 1995). Team learning approaches, which are often implemented in the US, give more responsibility to the learners. While students may be individually and group assessed, a team learning approach demands a clearly written textbook. This is necessary to enable the learners to learn by themselves, and enable the lecturer to take the role of a facilitator e.g. to clarify particular student difficulties and queries (Dinan and Frydrychowski 1995). Co-operative learning has also proven successful in the form of take-home quizzes with definition-type questions progressing to mechanistic problems. By working in groups on the ‘take-home’ quizzes, learners have the opportunity to discover, discuss and challenge concepts before they are fully exposed to them in the class (Hagen 2000).

“Learning is best facilitated when the focus is on the students who are doing the learning, and not on the teacher” (Bodner, 1992, p. 190).

As well as changing the curriculum content, the sequence of topics etc., learner difficulties will still persist unless the teaching methods and styles are altered. Bodner (1992) described much teaching as didactic: ‘a linear descendant of a system introduced in medieval universities’ (Bodner, 1992, p. 186). This instructive style of teaching is often described as the ‘Jug and Mug’ model, where the teacher is the source of all knowledge, and it is simply transmitted to the learners. This sends a signal to the learners that they do not have to be responsible for their own learning or even read the textbook for themselves. Casey (2011) has integrated the use of a variety of teaching approaches in the teaching of Third-Level Organic Chemistry in University College Dublin, Ireland. Further details of the approaches used and effectiveness of these are included in Table 3.12.

Katz (1996) and Paulson (1999) combined team learning, student-directed learning, learning cycles and grade-study performance contracts to increase retention rates in Organic Chemistry. Paulson (1999) found that such techniques were more beneficial when the rationale for their use was explained to the learners. As a result, the learners were able to apply the principles of mechanistic Organic Chemistry to a wider variety of problems, and
also gained a better understanding of the laboratory sessions (Paulson 1999). By developing the learners’ independence and level of responsibility in the classroom, their approach to learning may be improved. Katz (1996) used ‘Student Directed Learning’ to encourage a more productive learning cycle and positive emotions and attitudes amongst the learners. This required increased input by the learners; increased learner ownership, level of learners’ active learning, learner accountability and learner control. While the content of the Organic Chemistry course was not altered, the topics were approached as ‘Big Ideas’ rather than individual unrelated material (Table 3.11).

Table 3.11 Big ideas, related skills and contextual applications of Organic Chemistry reproduced from (Katz 1996)

<table>
<thead>
<tr>
<th>Big Idea</th>
<th>Related Skills</th>
<th>Relevance to Pharmacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbolic Language—I</td>
<td>Using the octet rule</td>
<td>Understanding drug structures</td>
</tr>
<tr>
<td></td>
<td>Constructing correct; Lewis dot, Kekulé, Line, and Condensed structures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drawing structural isomers</td>
<td></td>
</tr>
<tr>
<td>Polarity</td>
<td>Calculating formal charges</td>
<td>Understanding drug solubility and absorption</td>
</tr>
<tr>
<td></td>
<td>Recognizing polar bonds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recognizing polar molecules</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predicting water solubility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predicting phase change temps</td>
<td></td>
</tr>
<tr>
<td>Symbolic Language—II</td>
<td>Using electron-pushing arrows to show; resonance, Acid–Base reactions, and Nucleophilic Substitution reactions</td>
<td>Understanding drug metabolism</td>
</tr>
<tr>
<td>Energy and Reactivity</td>
<td>Using electron-pushing arrows to show formation of reactive intermediates</td>
<td>Fundamental knowledge for understanding of organic mechanisms</td>
</tr>
<tr>
<td></td>
<td>Construction and interpretation of energy profiles</td>
<td></td>
</tr>
<tr>
<td>Symbolic Language—III</td>
<td>Functional group recognition</td>
<td>Understanding the significance of chirality in drugs</td>
</tr>
<tr>
<td></td>
<td>Reaction classification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reagent classification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stereochemistry</td>
<td></td>
</tr>
<tr>
<td>Reactions and Mechanisms</td>
<td>Multistep synthesis</td>
<td>Understanding drug synthesis and metabolism</td>
</tr>
<tr>
<td></td>
<td>Alkene addition mechanisms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Free radical substitution mechanism</td>
<td></td>
</tr>
</tbody>
</table>

Bodner (1992) outlined several advantages of having a two-way dialogue between the teacher and learner rather than a one-way transmission from the teacher:

- It starts with a concept that makes sense to the learners.
- It builds from their understanding towards ours.
It shows why chemists use molarity, instead of other approaches that might seem preferable to the learners.

It shows that chemical knowledge is a product of rational thought, not arbitrary rules to be accepted on the basis of authority.

It approaches a concept that is meaningful to the learners. (Bodner 1992)

The role of the instructor should not be someone who teaches, but instead someone who facilitates learning (Bodner 1992). Learners need to work together for effective problem-solving (Strickland et al. 2010). Active learners learn more than passive learners (Bodner 1986). Bowen and Bodner (1991) presented learning as a linear sequence: preparation, production and evaluation. However, they acknowledged that for more difficult problems, the linear process of solution is not appropriate. It has been found that graduate students use inter-related concepts and processes to solve problems and communicate the solution to others. After proposing each step in the solution, learners evaluate the situation (e.g. reaction synthesis) to see if it is worthwhile continuing on the particular pathway. Rather than the linear process of preparation, production and evaluation, more difficult problems are solved in cycles of these stages. Bowen and Bodner (1991) referred to Bowen’s (1988) recommendations that teachers should consider helping learners to learn in the following ways:

- Choose useful representational systems for a problem.
- Select useful tactics within the representational system for solving the problem.
- Abandon a representational system if it does not provide a solution, yet consolidate gains to decide what to do next.
- Evaluate the solution.

A representational system here refers to ‘a collection of interrelated concepts and processes that a problem solver uses to solve a problem and communicate the result to others’ (Bowen and Bodner, 1990, p. 155). As well as team learning amongst learners in the class, a Partnership Programme is also useful (Platt et al. 2008). This programme involves training peer-leaders to facilitate workshops. In the workshops, learners explained, discussed and negotiated their understanding of concepts and ideas.

An approach using guided-learning, co-operative learning and pre-laboratory activities have fostered critical, creative and complex thinking skills for learners (Browne and Blackburn
This allows learners to be more confident in their laboratory practice and able to work from hints rather than the traditional ‘recipe-style’ lab instructions.

Shibley et al. (2001) have described the value of incorporating a writing assignment in the teaching of Organic Chemistry. This learner-centred approach enhances course content as learners discover applications of the subject matter not covered in class. This activity also provides the learners with experience of writing a professional scientific article as a scientist would. While the same course topics are covered, this out-of-class activity increases the learners’ interest and ability to think scientifically about the subject matter. Many researchers advocate a problem-solving approach to learning, deviating from the traditional algorithmic exercises given to learners in class as well as in examinations (Overton 2001, Bodner 1987, Taagepera and Noori 2000). The provision of in-class examples of problems that cannot be solved by resorting to a memorization of rules facilitates the learners’ understanding of the value of mechanistic learning (Anderson and Bodner 2008).

The ‘cone of learning’ shown in Figure 3.27 highlights and summarises the effectiveness of active learning methodologies in maximising the amount of content that the learner can remember.
The combination of teaching styles that have been referred to in this section are effective in creating a more supportive learning environment (Dougherty 1997). Research by Dougherty (1997) has shown that a co-operative learning experience results in increased learning and retention. Performance contracts were used to outline what is expected of the learner at the beginning of the course. It is important that the learning outcomes and expectations are made explicit to the learner from the beginning.

7. **Awareness of and Addressing Misconceptions**

Creating a cognitive structure for a complex body of knowledge, such as Organic Chemistry, is not easy (Nakhleh 1992). Misconceptions were defined in Section 3.4.4. Some explanation was also given about how learners form misconceptions. “Since students do build their own concepts, their construction of a chemical concept sometimes differs from the one that the instructor holds and has tried to present” (Nakhleh, 1992, p. 191). It is important that teachers and educators understand how misconceptions are formed as this can inform better teaching strategies. Ideally, if the teacher is aware of possible misconceptions, these may be avoided completely, or else addressed and alleviated before they are stored as incorrect frameworks in the learners’ Long Term Memory.

Nakhleh (1992) gave some suggestions for educators to limit learner misconceptions:

- Introduce scientific terms by emphasising the difference between the everyday meaning and the more precise scientific meaning.
- Be precise when explaining topics that have multiple definitions.

Taber (2002) explains ‘scaffolding’ as a balance between spoon-feeding learners and expecting them to cope without support. If given the appropriate support at the beginning, the learner may develop a better and more accurate understanding of the concept. This support structure can then be removed slowly as the learner develops confidence in their own knowledge and understanding of the topic. Taber (2002) used the analogy of constructing and building a ‘Knowledge of Chemistry’, just as a physical building needs firm foundations, so does learning. Scaffolding is derived from the work of Vygotsky (Vygotsky 1978). Vygotsky spoke about the learner’s Zone of Proximal Development (ZPD). The learner is able to achieve and learn more when supported appropriately by an expert (Taber 2002). However, this does not mean that the expert does the work for the learner. This does present a dilemma
for the teacher: how difficult to make the task, to prevent overload and still facilitate cognitive development?

“In practice, teachers have to be able to set tasks that students are not able to succeed in when totally unsupported. The teacher then provides the support, which is gradually reduced as the learner is able to master the ideas, until no support is needed”

(Taber, 2002, p. 71)

In his book, Chemical misconceptions-prevention, diagnosis and cure, Taber (2002) suggested three strategies to reduce learners’ misconceptions: DARTs, PLANKs and POLES. These acronyms will be explained below. DARTs are Directed Activities Related to Text. The simplest types of these are cloze tests, and other examples include labelling already drawn diagrams, or completing a text by interpretation of information given in a diagram. Through completion of DART exercises, the learner should build their own collective and comprehensive set of notes on a particular topic. These are more effective than if the same content was handed to the learner or simply ‘copied’ from a book or screen. DARTs are designed to ensure learners’ mind are active when they are working (Taber 2002).

There are two situations when the learner needs support to develop understanding and construct new knowledge: when learners have the necessary prior knowledge but are not aware of it, and when new ideas exceed the processing capabilities (Working Memory Space) of the learner. There are two ways in which the teacher can offer support to the learner in this situation to ensure the new concepts are accurately perceived and understood:

- **PLANKs (PLAtforms for New Knowledge)** - presentation of ideas that are already available to the learner in a new form to aid the learner in reorganising their knowledge to build up new ideas.
- **POLES (Provided Outlines Lending Support)** – give the learner a framework for exploring and succeeding in a concept area, which allows the learner to come to know about the topic.

PLANKs and POLES lend support to the learner in developing concepts. It is important that this scaffolding is only relied upon while the learner is developing understanding and confidence in a topic (Taber 2002).
Some of the approaches discussed above for teaching Organic Chemistry were stand-alone initiatives, while others were integrated into set syllabi and curricula. Table 3.12 includes a summary of the stand-alone initiatives which have been trialled and evaluated at Second-Level and Third-Level. Some of the initiatives e.g. molecular modelling and representations and facilitation of cognitive development are not included in this table as these were integrated into already set curricula. This table includes the combination of teaching approaches used in each initiative and a brief evaluation of the effectiveness of each approach. It is important to note that while some of the initiatives listed in Table 3.12 were focused specifically on Organic Chemistry, some also included other elements of General and Inorganic Chemistry. Although the level that each initiative was effective at is specified in Table 3.12, each of these initiatives and approaches can be applicable to teaching Organic Chemistry both at Second-Level and Third-Level.
<table>
<thead>
<tr>
<th>Name of initiative</th>
<th>Teaching approaches used</th>
<th>Evaluation of effectiveness</th>
<th>Level of Chemistry Education</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salters Chemistry Course <em>(SAC)</em></td>
<td>• Context-based. • Applications-led. • Avoid curriculum overload. • Development of schema. • Enabling transfer of content. • Personal relevance to students.</td>
<td>Increased pupil interest, enjoyment and uptake of Chemistry at third level</td>
<td>Second-Level U.K. (and has been introduced into other countries)</td>
<td>(Bennett and Lubben 2006, Pilot and Bulte 2006)</td>
</tr>
<tr>
<td>Industrial Chemistry</td>
<td>• Context-based (focus on Industry). • Variable teaching approaches. • Avoid curriculum overload. • Development of schema. • Enabling transfer of content. • Personal relevance to students.</td>
<td>• Developed better understanding of Chemistry applications. • Improved teachers’ teaching-improved student learning. • Context of industry was equally appealing to both genders.</td>
<td>Second-Level Weizmann Institute of Science, Israel</td>
<td>(Hofstein and Kesner 2006) (Pilot and Bulte 2006)</td>
</tr>
<tr>
<td>Chemistry in Context <em>(CiC)</em></td>
<td>• Context-based. • Avoid curriculum overload. • Development of schema. • Enabling transfer of content. • Personal relevance to students.</td>
<td>• Long term understanding. • Positive attitudes and engagement in Science. • Helpful for students not continuing to study Science. • Higher expectancy from students. • Teacher satisfied with students’ performance.</td>
<td>Third-Level U.S.A.</td>
<td>(Schwartz 2006) (Pilot and Bulte 2006)</td>
</tr>
</tbody>
</table>
### Chemie in Kontext (ChiK)
- Context-based.
- Avoid curriculum overload.
- Development of schema.
- Enabling transfer of content.
- Personal relevance to students.

- Increased learners’ motivation to learn Chemistry.
- Increased learners’ interest in Chemistry.
- Learners enjoyed being able to follow their own interests within the themes of the curriculum.

**Second-Level Germany**  
(Pilot and Bulte 2006, Parchmann et al. 2006)

### Spiral Curriculum
- Prevention of overload.
- Spiralling.
- Drip-feed approach.
- Need-to-know introduction of topics.
- Psychological order of content.

- Learners retain greater understanding. Organic Chemistry no longer perceived as a difficult subject.
- Greater understanding even for non-Chemistry students.
- Instructor is revitalised by new approach.
- Reduced attrition rates.

**Third-Level**  
Miami University, University of Minesota, Wittenberg University, U.S.A.  
(Grove et al. 2008, Gravert 2006, Sartoris 1992)

### Phenomena-orientated and Inquiry-based Network-Concept (PIN-Concept)
- Introduction of new concepts using concrete examples.
- Constructivist Development.
- Drip-feed approach.
- Development of schema.
- Facilitation of Cognitive development.
- Context-based activities.

- Noticed improvement in learners’ understanding and performance even for weaker class groups.
- Learners enjoyed Chemistry.
- Learners gain a deeper methodical understanding.

**Third-Level and Second Level Germany**  
Harsch and Heinmann  
English version reported by Barke et al., 2012.
|----------------------------|----------------|----------------|-----------------------------|------------------|-------------------|--------------------------------------|----------------------------------------|----------------------------------------|-------------|
3.5.2. The need for an Organic Chemistry Intervention in Ireland

As discussed throughout this chapter, difficulties and challenges persist amongst learners at Second-Level and Third-Level in Chemistry, and Organic Chemistry in particular. If these difficulties are continually ignored and discounted, it is evident that the quality of Science graduate students will decrease, therefore lowering the quality of the workforce available in this most prominent industrial sector in Ireland in the 21st century (Section 2.1.1 in Chapter Two). By improving teaching and learning strategies for Organic Chemistry in the Leaving Certificate and at an introductory level in Third-Level education, graduates of a higher calibre will be produced, who are better prepared for employment in a diverse range of scientific careers. If the particular topics of difficulty within Organic Chemistry can be identified, as well as the reasons for the difficulties diagnosed, improved teaching and learning strategies can be made available to facilitate the understanding of Organic Chemistry in Ireland.

Many researchers have made recommendations to ensure the sustainability and long term success of intervention programmes similar to those described above (Section 3.5.1). Some of these recommendations are listed here:

- The practitioners should be involved in the design of the programme, as well as in the implementation and evaluation of the materials and methods.
- Teaching programmes need to take into account the change in cognitive levels of present day learners as well as the diversity of mixed ability classes.
- Teaching and learning at Third-Level needs to be research-led.
- The innovation must be pedagogically sound and lead to improved performance and learning.
- The intervention programme must be sustainable within its own academic context.

(Platt et al. 2008, Childs 2009)

Learners studying Organic Chemistry at Third-Level without any prior experience of Leaving Certificate Chemistry will experience the same difficulties as encountered by Leaving Certificate pupils when they are first introduced to the topic. This presents the prospect of designing an intervention programme for the teaching of Introductory Organic Chemistry applicable at both Second-Level and Third-Level. However, CER has not been applied in the
way that the researchers have hoped (DeJong 2000). There is discontinuity between the work of the educational researchers uncovering ‘misconceptions’, and those charged with developing the curriculum and actually teaching the learners (Taber 2001).

“Teachers expect research to be presented to them in a form they can readily apply, and are too busy doing their job (teaching) to read the research literature; researchers expect teachers to interpret reported findings before applying them in the classroom, and are too busy doing their job (researching, and publishing in research journals) to communicate directly to teachers”

(Taber, 2001, p. 45).

This is why the combined design of teaching materials and methods informed by literature, practitioners and learners and inspired by previous initiatives would provide a valuable resource to Second-Level teachers and Third-Level lecturers.

The European Chemistry Thematic Network (ECTN) was established to identify potential areas for innovation in the teaching and learning of Higher Level Chemistry Education. It is clear that many of the traditional approaches to teaching used in the past are no longer adequate to support the present education system. Many educators have come to realise that even though they have the content knowledge, their pedagogical content knowledge is lacking. Many discover when correcting examinations that what they thought they had taught, and what the learners had actually learnt was quite different. Knowledge cannot be transferred intact from the mind of one person to the mind of another (Bodner 1986).

Eilks and Byers (2010) highlighted the dangers also that when a teacher increases input to address leaning difficulties, this can all too often encourage learners to reduce their own efforts. Working out examples with learners may have traditionally been seen as a beneficial method of learning. However, Eilks and Byers (2010) used the analogy of passengers in a car who see no difficulty getting to a location because the driver knows the way. However, these passengers may be incapable of making the journey on their own at a later date. In the same way, learners may have a false feeling of understanding when following a teachers’ solution to a problem.
Chickering and Gamson, (1987) provided these guidelines for good practice in Chemistry Education:

1. Encourage learner-faculty contact,
2. Encourage co-operation among learners,
3. Encourage active learning,
4. Give prompt feedback,
5. Emphasise time on task,
6. Communicate high expectations,
7. Respect diverse talents and ways of learning. (Chickering and Gamson 1987)

The following potential areas for innovation in teaching and learning of Chemistry were outlined by Eilks and Byers (2010). The unique nature of Chemistry needs to be addressed. Chemistry has been described as a three-dimensional subject by Johnstone (1991). Specific teaching strategies involving visualisation techniques are clearly needed to facilitate the learner’s understanding of complex shapes and models. Problem-based learning and inquiry-orientated approaches are both context-based. This ‘situated cognition’ gives the learner a greater appreciation of the significance of the required learning to the context in which it is used. More emphasis needs to be placed on constructive group-work and co-operative learning in Chemistry Education. Research-based teaching and learning, innovative practical work, co-operative learning and online teaching methods offer an alternative to traditional teaching methods. A classroom learning experience can always be enhanced through the inclusion of site visits to chemical industries or work placement. Such activities clarify the practical applications of what is learned in the classroom. The use of a wider variety of innovative and formative assessment techniques can also promote meaningful learning (Eilks and Byers 2010).
3.5.3. Theoretical Background for an Organic Chemistry Intervention Programme in Ireland

It is evident from the discussion so far, that learners at Second-Level and Third-Level have difficulty understanding Organic Chemistry. Perkins (2007) outlined three optional responses for the teacher on identifying the learners’ difficulty with a particular topic:

1. Teach the same - Blame the learner and carry on teaching in the same manner.
2. Teach Harder - Focus on the difficult areas and spend more time on them.
3. Teach Smarter – Look at why learners find these topics difficult and develop a better way of teaching to facilitate understanding. (Perkins 2007)

Teaching smarter involves diagnosing the areas of difficulty that learners have, and trying to teach that topic in a different manner to alleviate the misconceptions or difficulties. This approach has been used as a background for the ‘Organic Chemistry in Action!’ intervention programme, using the guiding principle: “Smarter Teaching-Better Learning”.

Chemistry needs to be taught in a way that allows learners to construct their own knowledge rather than simply memorising unrelated facts. However, as discussed already if the hierarchy and order of teaching Organic Chemistry is developed and planned by the teacher or other experts, it is necessary to acknowledge the difference in thinking patterns between novice learners and experts (Taagepera and Noori 2000). What is logical to a teacher may not seem at all logical to the learner (Johnstone 2000a). The sequencing of topics in this intervention programme is aimed to facilitate the psychological development of the Second-Level pupils.
A number of research paradigms were explored in defining the theoretical perspective of this research project. Brookfield (2005) outlined the distinctive characteristics of Critical Theory as a framework for research. Critical theory is concerned with generating knowledge that can be provided to individuals to help them understand their situation and can then result in action that leads to change. The goal of critical theory is to create a more ideal alternative to the present situation (Brookfield 2005). Positivism as another alternative perspective underpins quantitative and objective research. In this scientific method, the researcher begins with a theory, collects data and makes numeric measures of the observations (Creswell 2009).

However, the constructivist model was chosen as the most appropriate paradigm for this research study. The constructivist model has become popular in Science Education as a teaching approach (Palmer 2008). In this model “students use their existing preconceptions to interpret new experiences, and in doing so, these preconceptions may become modified or revised.....learning proceeds as children actively reconstruct their ideas as they become presented with new information” (Palmer, 2008, p. 201). Constructivist development was a key principle in the PIN-Concept in Germany. ‘Terms and reasoning patterns should always be built methodically, step-by-step, and in a guided inquiry-based learning process” (Barke et al., 2012, p. 246).

The Organic Chemistry in Action! intervention programme is based on the theoretical background of constructivism as well as the other ideas outlined in this chapter:

- Learning is a result of the learners’ activities and exposure to the world around them (Byrnes 2009)
- Learning is constructed by building new knowledge upon a foundation of prior knowledge – learners use their partial understanding to build complete understanding.
- Learners can interpret new information using prior knowledge to perceive new information (Pirie and Kieren 1992)
- The constructivist theory considers individual learning as well as developmental differences (Byrnes 2009).
- Teachers must be familiar with what learners already know to assist them in developing conceptions and making material relevant and meaningful to them.

Fensham et al. (1994) outlined the two main historical sources for the development of the constructivist theory. One is the philosophical source as a general theory of knowledge, and
the second is the experience of reflective practitioners attempting to improve and facilitate learning. A third source may also be included here: professional educational researchers (Fensham et al. 1994). Incorporating many of the theories that have been discussed throughout this chapter, constructivism, as a theoretical background offers a holistic approach for the teaching and learning of Organic Chemistry to facilitate understanding and development of positive attitudes towards the subject. Figure 3.29 provides a summary of the theoretical background of constructivism, which was used to inform the development of the Organic Chemistry in Action! programme and selection of the design criteria for this intervention programme.

![Figure 3.29 Summary of the theoretical background of Constructivism (Bruner 1960, Ausubel 1968, Taber 2002, Collins et al. 1987)](image)

“To learn Science from a constructivist philosophy implies direct experience with Science as a process of knowledge generation in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and teacher”

(Fensham et al., 1994, p. 51)

Action Research has become a popular framework for investigating the effect of intervention programmes (Bodner et al. 1999). Action Research as a framework for the development, implementation and evaluation of the Organic Chemistry in Action! programme will be discussed in detail in Chapter Four. There is much evidence of the success and suitability of this framework from previous research studies investigating the use of alternative approaches to teaching Organic Chemistry (Bauer 1998, Lowrey 1996). The Action Research approach helped to answer the research questions in these investigations. Action Research will be
discussed in more detail as the theoretical framework of this research project on Section 4.2 of Chapter Four that follows.

Bodner et al. (1999) summarised the benefits of using the Action Research methodology:

- Changes are made in what we teach or the way we teach it,
- Evaluation occurs while the changes are being made,
- As many sources of information are collected as possible,
- We never presume that all learners will benefit from the change, and are constantly searching for ways to maximize positive effects and minimize negative effects of these changes,
- The learners are knowing, active participants in the decision-making process about changes that should be made in the next iteration in the innovation cycle.

The design criteria for the ‘Organic Chemistry in Action!’ intervention are:

1. Spiral approach and Drip feed introduction of topics
2. Linked Learning outcomes and assessment.
3. Formative and Summative assessment.
5. Guided inquiry learning.
7. Integration of applications-led and context-based Chemistry.
8. Integration of Practical Work.
9. Identify and Address Misconceptions.
10. Variety of teaching approaches.

These design criteria of the ‘Organic Chemistry in Action!’ programme will be outlined in detail in Chapter Five with examples and illustrations of the teaching materials.
Chapter 4

Methodology
4.1 - Introduction

This research project was carried out in two cycles. This chapter outlines the methodology of both cycles of the project. The aim of the methodology is to “describe the approaches to, kinds and paradigms of research”, while the research methods refers to the “techniques and procedures used in the process of data-gathering” (Cohen et al., 2009, p. 47).

As explained and illustrated in Figure 1.1 in Chapter One, this project had three phases (Cycle One, and Cycle Two- parts A and B). Section 4.2 which follows outlines the theoretical framework of the project. This research methodology used in this project can be described as ‘Action Research’. Action Research is a cyclical process: this project had two cycles. Different research methods were used in both cycles. The research methods that were chosen and used in both cycles of the project are discussed in Section 4.3 along with a rationale for their appropriateness to this project. Section 4.4 outlines the validity and reliability of the chosen research methods. The ethical implications of all phases of the project are outlined in Section 4.5. The steps involved in carrying out the Second-Level Study and the Third-Level Study in Cycle One of the project are outlined in Section 4.6. The steps involved in the evaluation of Cycle Two of the project (Development, Implementation and Evaluation of the Intervention Programme) will be outlined in Section 4.7. Section 4.8 will outline the limitations of the both cycles of the study. Details of the design, development and implementation of the intervention project are outlined in Chapter Five.

Table 4.1 which follows provides an overview of the cycles involved in the overall research project. The research methods used in each phase are also detailed with reference to the specific techniques used to gather the data.
Table 4.1 Overview of the two-cycle Action Research Project.

<table>
<thead>
<tr>
<th>Two-cycle Action Research</th>
<th>Details</th>
<th>Research Methods</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cycle One</strong></td>
<td>Introductory Literature Review</td>
<td></td>
<td>Oct 2009-March 2010</td>
</tr>
<tr>
<td></td>
<td><strong>Quantitative:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Second Level Pupil Questionnaire (I).</td>
<td></td>
<td>April 2010-Nov 2010</td>
</tr>
<tr>
<td></td>
<td>• Chemistry Teacher Questionnaire.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Quantitative:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Third Level Student Questionnaire.</td>
<td></td>
<td>Nov 2010-Feb 2011</td>
</tr>
<tr>
<td></td>
<td>• Organic Chemistry Lecturer Questionnaire.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cycle Two</strong></td>
<td>Part A</td>
<td>Design and Development of Intervention Programme.</td>
<td>Feb 2011-Aug 2011</td>
</tr>
<tr>
<td></td>
<td><strong>Quantitative:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Chemistry Teacher Review Questionnaire.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Qualitative:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Classroom Observations.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• Teacher Interviews.</td>
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<td></td>
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<tr>
<td></td>
<td>• Teacher Diaries.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• Focus Group</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2 - Theoretical Framework

4.2.1. Selecting a Theoretical Framework

Kuhn (1970) emphasised the importance of selecting a research paradigm to guide and direct the researcher. The use of a paradigm makes research more effective by helping researchers select problems that can be solved and also helps in selecting the most suitable methods for collecting the data to solve the problems (Kuhn 1970). There are many theoretical frameworks for different types of research and evaluation. These theoretical perspectives, their advantages and limitations, have been described and outlined in the literature (Patton 2002, Bodner and Orgill 2007). Bodner and Orgill (2007) categorised the theoretical frameworks into three theoretical perspectives: Constructivism, Critical Theory and Hermeneutics. Hermeneutics includes theoretical frameworks such as Phenomenology, Phenomenography, Narratology, Ethnology and Ethnomethodology, Situated Cognition and Communities of Practice as well as Action Research (Bodner and Orgill 2007). The Greek word *hermeneuein* translates to ‘to interpret’. An important feature of hermeneutics is spiraling. Bodner and Orgill (2007) described the spiraling understanding of reading and interpreting a text; “The first interpretation of the text is based on the prior knowledge the researcher brings to the text, but this prior knowledge is changed by reading the text. As a result, the researcher brings a different perspective to the second reading, which changes the knowledge the researcher brings to the third reading, and so on” (Bodner and Orgill, 2007, p. 16).

The chosen theoretical framework used for the structure and methodology of this research project was Action Research. The background, principles, process and limitations of this framework will now be discussed.

4.2.2. Action Research as a Theoretical Framework

Action Research is described using many different names in the literature. Alternative names include Emancipatory Research, Action Learning, and Collaborative Inquiry as well as Contextual Action Research. O’ Brien (1998) describes Action Research as ‘learning by doing’, and outlined the cornerstone of Action Research that knowledge is derived from practice, and practice informed by knowledge, in an ongoing process (O’ Brien 1998).
The philosopher John Dewey (1859-1952) believed that educators should be involved in community problem solving. Research and practice should not be seen as two separate identities but instead combined and unified to complement each other. This is the essential framework for this project: using CER to inform classroom practice and in turn to use the observations and analysis of classroom practice for improved research.

“Action research...aims to contribute both to the practical concerns of people in an immediate problematic situation and to further the goals of social science simultaneously. Thus, there is a dual commitment in action research to study a system and concurrently to collaborate with members of the system in changing it in what is together regarded as a desirable direction. Accomplishing this twin goal requires the active collaboration of researcher and client, and thus it stresses the importance of co-learning as a primary aspect of the research process”

(Gilmore et al. 1986)

Table 4.2 below summarises many of the elements involved in Action Research.

<table>
<thead>
<tr>
<th>Purposes</th>
<th>Foci</th>
<th>Key Terms</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>To plan, implement, review and evaluate an intervention designed to improve practice or solve local problem.</td>
<td>Everyday practices.</td>
<td>Action</td>
<td>Context-specific.</td>
</tr>
<tr>
<td>To empower participants through research involvement and ideology critique.</td>
<td>Outcomes of interventions.</td>
<td>Improvement</td>
<td>Participants as researchers.</td>
</tr>
<tr>
<td>To develop reflective practice.</td>
<td>Participant empowerment.</td>
<td>Reflection</td>
<td>Reflection on practice.</td>
</tr>
<tr>
<td>To promote equality democracy.</td>
<td>Reflective practice.</td>
<td>Monitoring</td>
<td>Interventionist-leading to solution of ‘real’ problems and meeting ‘real’ needs.</td>
</tr>
<tr>
<td>To link practice and research.</td>
<td>Social democracy and equality.</td>
<td>Evaluation</td>
<td>Empowering for participants.</td>
</tr>
<tr>
<td>To promote collaborative research.</td>
<td>Decision-making.</td>
<td>Intervention</td>
<td>Collaborative.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Problem-solving</td>
<td>Promoting praxis and equality.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Empowering</td>
<td>Stakeholder research.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planning</td>
<td></td>
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<td></td>
<td></td>
<td>Reviewing</td>
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</tbody>
</table>

Action Research can also be described as an informal, qualitative, subjective, interpretive, reflective and experiential mode of inquiry in which all those involved are contributors (Hopkins 1985). Action Research is designed to bridge the gap between research and practice in order to improve practice and contribute to a theory of education and teaching, which can then be accessible to other teachers (Cohen et al. 2007). This project involved
collaboration with practicing and experienced Second-Level Chemistry teachers in an effort to clearly identify the main areas of difficulty in the Organic Chemistry section of the Leaving Certificate Chemistry syllabus and the consequential development, implementation and evaluation of teaching materials to facilitate the teaching and learning of Organic Chemistry.

4.2.3. Principles and Processes of Action Research

Winter (1943) outlined six key principles of Action Research. These principles are outlined below as adapted from Yasmeen (2008):

1. **Reflexive critique**: Use of notes, transcripts, and official documents to make implicit claims authoritative. Ensures that reflections and processes make explicit the interpretations, biases and assumptions on which judgements are made.

2. **Dialectical critique**: To understand the relationships between both the phenomena and the context.

3. **Collaboration of resources**: Each person’s ideas are equally significant as potential resources. Everyone’s view is taken into consideration as a contribution to understanding the situation.

4. **Risk**: The process of change threatens original ways of doing things, thus creating fear for some practitioners.

5. **Plural Structure**: The nature of the research results in multiple possible actions and interpretations. A report should act as a support for on-going discussion among collaborators, rather than a final conclusion of fact.

6. **Theory, practice and transformation**: Theory informs practice and practice refines theory in a continuous transformation. People’s actions are based on assumptions, theories and hypotheses, and with observed results, theoretical knowledge is enhanced.  

(Winter 1943, Yasmeen 2008)
As can be seen from these guiding principles, Action Research is a cyclical process linking theory, practice and reflection. There are four stages in the cycles of Action Research. These stages are illustrated in Figure 4.1.

![Figure 4.1: Action Research Protocol reproduced from (MacIsaac 1996)](image)

Each cycle of the Action Research protocol has four repeating steps. The main characteristics of these steps are outlined here:

1. The General Plan: This stage involves an initial exploratory stance to understand the problem and then develop plans for an intervention strategy.
2. Action: This refers to the implementation of the plan that was derived in the previous step.
3. Observation: This refers to the monitoring during and after the implementation phase. Observations and data are collected in various forms.
4. Reflection and Revision: The next step in the Action Research cycle is generated through reflection on the findings and observations of the previous cycle. New or modified strategies are suggested and this leads to the beginning of a new cycle and a revised plan.
The cyclical process is intended to foster deeper understanding of a given situation, starting with conceptualising and particularising the problem and moving through several evaluations (MacIsaac 1996). The Action Research Model outlined by Susman (1983) is more detailed than the model shown in Figure 4.1. This alternative model is shown in Figure 4.2 below.

![Figure 4.2 Susman (1983) Alternative Model for Action Research (adapted from Yasmeen, 2008)](image)

Although this model is more detailed than Figure 4.1, it is essentially illustrating the same cyclical process of Action Research. The cycle begins with the identification of a problem. After several possible solutions are considered, a definite plan is made and it is then implemented. Data on the implemented intervention is collected and analysed. The findings from this cycle are then used to reassess the problem and the process repeats the same cycle again. As can be seen from both models (Figures 4.1 and 4.2), Action Research is formative rather than summative in nature. This facilitates the development and implementation processes as negative aspects can be removed and positive aspects enhanced within the cycle.

Figure 4.3 illustrates the steps involved in both cycles of this project as an Action Research project.
Identification of difficulties in Organic Chemistry at Second-Level and Third-Level, recognition of a need to improve teaching strategies for Organic Chemistry.

**Development of Questionnaires:**

**Distribution of Questionnaires:**
Pupil and Teacher Questionnaires at Second-Level. Student and Lecturer Questionnaires at Third-Level.

**Part A**
**Design of the intervention programme**
Selection of content, design criteria, Informed by practitioners, Cycle One Findings and CER.

**Part B**
**Evaluation of the intervention programme**
Evaluation of the effectiveness of the intervention programme through analysis of the observation lenses used.

**Part B**
**Analysis of the intervention programme**
Classroom observations, school visits, focus group, Teacher Diaries, Teacher Interviews and questionnaires, Pupil Questionnaires, comparison with a Control Group.

**Future Work:**
Revision of the intervention programme in light of feedback from practitioners.

Figure 4.3 Structure of this project within the Action Research framework.
It is important to explain that the framework used in this research project (Figure 4.3) is an adaptation of the traditional Action Research framework. In the traditional framework, each cycle is a repetition of the previous cycle, where consecutive cycles are modified versions of the previous cycles in reflection on the observations made. However, although Cycle One informed and directed Cycle Two, both cycles are not repeating cycles of each other, even though they each have the same steps as the traditional Action Research protocol. The researcher recognised the need to first establish Organic Chemistry as an area of difficulty at Second-Level and Third-Level in Ireland, and to identify the particular areas of Organic Chemistry that pupils and students have difficulty with (Cycle One). It would not have been practical to begin Cycle One of this project with an intervention programme without firstly clarifying the areas that need to be addressed in designing an intervention programme for Leaving Certificate Organic Chemistry. For this reason, Cycle One does not involve the implementation of an intervention, but instead the distribution of questionnaires at Second-Level and Third-Level. The framework of this project adheres to the paradigm of Action Research: the findings of Cycle One informed and directed the plan of the intervention programme used in Cycle Two. Cycle Two was divided into two parts: A and B. Part A of Cycle Two involved the planning, designing and development of the intervention programme, which was then implemented and evaluated in part B of Cycle Two. It was intended to revise the teaching materials at the end of the Cycle Two and to disseminate these for wider use in the teaching of Organic Chemistry at Second-Level and Third-Level.

The theoretical background, constructivism, was outlined in Chapter Three (Section 3.5.3). The theory of constructivism and other CER theory were used to inform and determine the planning stages in both cycles of the Action Research project.

4.2.4. Assumptions and Criticisms of Action Research

Hunter (2007) outlined the underlying assumptions or beliefs of Action Research. There are three main assumptions:

1. Teachers introduce changes in the curriculum or in the way they teach because they perceive weakness in the current situation.

2. Any significant intervention into a practicing classroom will have an effect. Instead of asking ‘Was there an effect?’ the action researcher asks ‘What is the effect on all participants involved?’
3. Changes in instruction seldom benefit all learners equally. Educational research can have both positive and negative effects; while some learners may benefit from the change, some may be harmed.

The main criticism of Action Research is that the model focuses most of the attention on the action itself and changing the setting, rather than the development of research techniques and procedures (Hunter 2007). Many critics view Action Research as a method of solving practical problems rather than a method of gaining valid research knowledge. Here are some of the weaknesses of Action Research:

- Lack of environmental control: any one variable may never be isolated in an Action Research study. This makes it difficult to identify how one dependent variable is influenced by other variables.
- Local utility of the research conclusions: the development of models with high external validity can be very difficult from an Action Research project, due to the lack of generalisation. Action Research projects tend to specific, focused and localised.
- Personal Bias: Action Research requires the researcher to be aware of their own biases and personal interests, as these can hinder the processes and the conclusions.

(Orlikowski and Baroudi 1991)

As well as these weaknesses of Action Research, Zuber-Skerritt (1996) in Cohen et al. (2007) formulated some other problems that an Action Researcher may face: establishing an economical method of work regarding the amount of data gathering and processing; validating the small-scale and often very specific new insights gained from the investigation; making the intervention materials available to anyone who wishes to use them; and contributing to a genuine improvement of understanding and skill in return for the time and energy expended.

Despite these assumptions, limitations and criticisms, it is important to realise that Action Research is an effective paradigm for the linking of theory and practice through collaboration between researchers and teachers. Action Researchers maintain that “their work contributes to theory in a much deeper and thorough fashion….adding texture to theoretical ideas and as being a way of dealing with complex reality that cannot be adequately described by an oversimplified theory” (Hunter, 2007, p. 159).
As a research methodology, Action Research combines six ideas:

- A straight-forward cycle of identifying a problem, planning an intervention, implementing the intervention, evaluating the outcome.
- Reflective practice.
- Political emancipation.
- Critical theory.
- Professional development.
- Participatory practitioner research. (Cohen et al., 2007, p. 312)

4.3- Research Methods

Action Research is more of a holistic approach to problem-solving, rather than a single method for collecting and analysing data (O’ Brien 1998). Action Research, therefore, allows for several different research tools to be used within the one project. Data collection and analysis in Action Research should be driven by the research questions being asked (Hunter 2007). The research questions guiding each cycle of this Action Research project have been outlined in Chapter One (Section 1.3). This has been the case throughout the two cycles of this project. In the first cycle, only quantitative methods of research and analysis were used. This cycle of the project involved a large sample of Second-Level teachers and pupils as well as a sample of Third-Level lecturers and students. In the second cycle of the project, there were six schools involved in implementing the intervention programme. A combination of quantitative and qualitative research methods were used to assess and evaluate the effectiveness of the intervention from both the pupils’ and teachers’ perspectives, and also through comparison with a Control Group.

4.3.1. Quantitative Research Methods

“Quantitative data analysis is a powerful research form...often associated with large-scale research, but can also serve smaller scale investigations with case studies, action research, correlational research and experiments” (Cohen et al., 2007, p. 501)

Surveys, questionnaires and tests can all be analysed quantitatively. Quantitative analysis refers to numerical analysis. Key concepts in numerical analysis include scales of data, parametric and non-parametric data, descriptive and inferential statistics as well as dependent and independent variables. The numerical analysis in this project was carried out using SPSS
(Statistical Package for the Social Sciences) software versions 16 to 19. Although updated versions of SPSS were used for analysis of the quantitative data in Cycle Two of this research study, the quantitative data was analysed in the same way in each of these versions of the software.

In inputting the data for each of the questionnaires, each of the questions and the possible responses were coded using numbers. The numbers (dependent on the kind of data coded) were distinguished as they were inputted into the variable view in SPSS. The ‘nominal’ scale refers to distinct categories e.g. male or female. The ‘ordinal’ scale by its name introduces order into the data. This scale was used for analysis of Likert scales used e.g. 1= strongly agree and 5= strongly disagree. The numerical scale refers to simple numeric values e.g. a test score or an age. Nominal and ordinal data were generally considered non-parametric. Non-parametric data are generally derived from questionnaires and surveys, while parametric data tend to be derived from experiments and tests (Cohen et al. 2007). When all of the data was inputted, the Kolmogorov-Smirnov Test was used to investigate if the data was parametric or non-parametric. Non-parametric data are those which make no assumptions about the population, while parametric data assume knowledge of the characteristics of the population. In order for inferences to be made on parametric data, a normal curve of distribution is assumed.

The way in which the results were presented and described was dependent on the type of the data. Non-parametric data was described using frequencies, median and the inter-quartile range, while parametric data was described using the mean and standard deviation. In the first step of exploring quantitative data, frequencies, percentages and cross-tabulations of the data were presented. The SPSS package provided many ways of presenting this descriptive data including: frequency and percentage tables, bar charts, histograms, line graphs, pie charts and scatter plots.

Cohen et al. (2007) define a variable “as a construct, operationalised construct or particular property in which the researcher is interested” (Cohen et. al., 2007, p. 504). An independent variable is one which causes a particular outcome e.g. part of an experimental group or a control group. In comparison a dependent variable is an outcome variable that is caused as a consequence of an independent variable.
Further analysis of variables that may have affected other variables begins with a null hypothesis ($H_0$) e.g. there is no statistical significant difference between pupils who studied Junior Certificate Science and pupils who did not. Having set this null hypothesis, the appropriate test for significance was carried out. “A statistical significant result is one for which chance is an unlikely explanation” (Kirk, 1999, p. 337). If the hypothesis is statistically significant, this null hypothesis is rejected and the alternative hypothesis ($H_a$) is accepted e.g. there is a statistical significant difference between pupils who studied Junior Certificate Science and pupils who did not.

The p-value reveals whether the relationship or correlation between the variables is significantly sound. The smaller the p-value, the less likely it is that the sample results come from a situation where the null hypothesis is true. A p-value less than 0.05 was deemed significant for this research. In some cases p-values less than 0.01 or 0.001 were also included. These provide stronger evidence in favour of the alternative hypothesis:

- $P > 0.05$: No evidence against $H_0$ in favour of $H_a$.
- $P < 0.05$: Evidence against $H_0$ in favour of $H_a$.
- $P < 0.01$: Strong evidence against $H_0$ in favour of $H_a$.
- $P < 0.001$: Very strong evidence against $H_0$ in favour of $H_a$.

The types of statistical tests chosen to test the hypotheses in both cycles of this research project were dependent on the types of data emerging from the various questionnaires. The appropriate statistical tests were used with the data from the Pupil Questionnaires (n=276) and Student Questionnaires (n=121) in Cycle One, and also the Pupil Questionnaires in Cycle Two (n=117, n=87). The large sample sizes of each of these groups ensured the validity of the appropriate tests used. The statistical tests were not used for the smaller sample of teachers (n=73) and lecturers (n=20) in Cycle One and for the six teachers involved in Cycle Two. Figures 4.4 and 4.5 summarise how the appropriate tests were used for analysis of non-parametric data and parametric data respectively throughout both cycles of this Action Research project.

Four different questionnaires were designed, distributed and analysed in Cycle One of the project to gain information about the difficulties of Organic Chemistry at Second-Level and Third-Level in Ireland. The design, distribution and analysis of these specific questionnaires will be outlined in detail in Section 4.6 of this chapter. A Pupil Questionnaire was also used
to compare the attitudes and performance of the pupils in the Intervention Group and a Control Group of pupils in Cycle Two. A Teacher Questionnaire was also used in Cycle Two to gain information from the teachers after their implementation of the intervention and to guide the semi-structured Teacher Interviews that were also carried out. The design, distribution and analysis of these questionnaires will be outlined in detail in Section 4.7 of this chapter.

![Diagram showing statistical tests for non-parametric and parametric data]
4.3.2. Qualitative Research Methods

“Qualitative methods express the assumptions of a phenomenological paradigm that there are multiple realities that are socially defined. Rich description persuades by showing that the researcher was immersed in the setting and giving the reader enough detail to make sense of the situation.”

(Firestone, 1987, p. 16)

Qualitative data analysis involves organising, accounting for and explaining the data. It involves making sense of data in terms of the participants’ definitions of the situation, noting patterns, themes, categories and regularities (Cohen et al. 2007). There are many ways of analyzing qualitative data and multiple interpretations of the data can be made. This is why it is important that the researcher decides on a ‘fit for purpose’ method of data analysis, dependent on the research questions to be answered. All of the research carried out in Cycle One of the Action Research project was done through quantitative analysis. However, some qualitative methods were used in the analysis of Cycle Two.

“The quantitative model of educational research, in which the performance of experimental and control sections is compared, has the advantage that we always know whether or not the hypothesis being tested was supported by the data collected in the study. The answer is given by the ‘objective’ test of statistics.”

(Hunter, 2007, p. 161)

Hunter (2007) however, stresses that such statistical tests are unable to accurately measure the ideas and strategies that interest the participants in an intervention programme. “No research methodology operates in a philosophical vacuum” (Hunter, 2007, p. 162). For this reason, it would not be accurate to evaluate an intervention programme using quantitative methods alone. Qualitative data was used to focus on the Chemistry classes involved in Cycle Two and to gain an insight from the views of the six teachers, who were the practitioners. The collaborative nature of Action Research lends itself well to interviews (Hunter 2007). Teacher interviews were carried out with each of the participating teachers after the implementation of the programme. The questions for the Teacher Interviews were guided by the classroom observations carried out during the implementation phase and also the Teacher Diaries and Chemistry Teacher Review Questionnaires, which were completed during and after the implementation of the intervention respectively. Details of the design, distribution and evaluation of these research methods used in part B of Cycle Two will be discussed in detail (Section 4.7).
From the field notes gathered through the Classroom Observations, Teacher Diaries, Teacher Interviews and the Focus Group with the participating pupils, the researcher matched, compared, contrasted and ordered the emerging findings as themes. The intention was to move from description to explanation and theory generation (LeCompte and Preissle, 1993, in Cohen et al., 2007). Cohen et al. (2007) outlined five ways of organising and presenting qualitative data: by groups, by individuals, by issues, by research questions and by instrument. In this study, the qualitative data was analysed by a combination of two of these methods; firstly by instrument (Chapter Eight) and then by research questions (Chapter Nine). The data from the Classroom Observations, Teacher Diaries and Teacher Interviews were all presented individually and then the emerging themes were grouped in relation to the research questions asked. Cohen et al., (2007) cautioned the importance of self-awareness of the researcher in conducting qualitative data analysis. The coding and categories set by the researcher pre-determined the findings in some sense. It is inevitable that the researcher brings her own preconceptions, interests, biases, preferences and background to the data. Therefore, it is important that the analysis is as objective as possible. Due to small numbers of participating teachers involved in Cycle Two, it was decided that the qualitative data would be best analysed and coded manually by the researcher.

A systematic method of analyzing the qualitative data was designed and applied. These methods are described in Table 4.3 and Figure 4.6.

*Table 4.3 Methodological tools for analysing qualitative data (adapted from guidelines by LeCompte and Preissle, 1993, in Cohen et al 2007)*

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytic induction</td>
<td>Data are scanned to generate categories of phenomena, relationships between these categories are sought and working typologies and summaries are written on the basis of the data examined. The process of redefinition and reformulation is repeated.</td>
</tr>
<tr>
<td>Constant Comparison</td>
<td>Researcher compares newly formulated data with existing data and categories and theories which have been devised and which are emerging, in order to achieve a perfect fit between these and the data.</td>
</tr>
<tr>
<td>Typological Analysis</td>
<td>This is a classificatory process where data are put into groups, subsets or categories on the basis of some clear criterion.</td>
</tr>
<tr>
<td>Enumeration</td>
<td>Categories, frequencies of codes, units of analysis, terms, words or ideas are counted. This enables incidence to be recorded and statistical analysis of the frequencies to be undertaken.</td>
</tr>
</tbody>
</table>
Figure 4.6 Data analysis of Qualitative research reproduced from (Creswell 2009)
4.3.3. Mixed Methods of Research

The theory and explanation of both research methods of gathering and evaluating data have been discussed individually above. Table 4.3 provides a summary of the differences between quantitative and qualitative research methods. While both approaches are different, the results of the two methodologies can be complementary (Firestone 1987).

<table>
<thead>
<tr>
<th></th>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assumptions about the world</strong></td>
<td>Based on a positivist philosophy – assumes there are social facts with an objective reality apart from the beliefs of individuals.</td>
<td>Based on a phenomenological philosophy – assumes that reality is socially constructed through individual or collective definitions of the situation.</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Seeks to explain the causes of changes in social facts through objective measurement and quantitative analysis.</td>
<td>More concerned with understanding the social phenomenon. Seeks to explore, interpret and build theory.</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td>Employs experimental or correlational designs to reduce error and bias.</td>
<td>Helps the reader to understand the definitions of the situation of those studied.</td>
</tr>
<tr>
<td><strong>Research Process</strong></td>
<td>Focused, known variables, established guidelines, predetermined methods, detached view.</td>
<td>Holistic, unknown variables, flexible guidelines, emergent methods, context-bounds, personal view.</td>
</tr>
<tr>
<td><strong>Data analysis</strong></td>
<td>Statistical analysis, stress on objectivity, deductive reasoning.</td>
<td>Search for themes and categories, acknowledgement that analysis is subjective and potentially biased, inductive reasoning.</td>
</tr>
<tr>
<td><strong>Presentation of findings</strong></td>
<td>Use of numbers, statistics, aggregated data, formal voice, scientific style.</td>
<td>Use of words, narratives, individual quotes, personal voice and literary style.</td>
</tr>
<tr>
<td><strong>Role of the researcher</strong></td>
<td>Detached to avoid bias.</td>
<td>Immersed in the phenomenon of interest.</td>
</tr>
</tbody>
</table>

Table 4.4 Summary of differences between quantitative and qualitative research (Firestone 1987, Leedy and Ormond 2005).

While quantitative and qualitative studies present the researcher with different kinds of information, they can be used together to triangulate and to gain more confidence in the final conclusion. Triangulation is the use of two or more methods of data collection. Analysis in Cycle two (effectiveness of the Organic Chemistry in Action! intervention programme)
involved a mixed method of analysis combining quantitative and qualitative techniques to evaluate the effectiveness of the intervention. The qualitative methods used included interviews, focus group, classroom observations and teacher diaries, while the quantitative methods used included pupil and teacher questionnaires. The differences presented in section 4.3.1 and 4.3.2 of quantitative and qualitative methods respectively highlight the strengths and weaknesses of both methods. Both approaches provide different types of information to the researcher.

“By analogy, triangular techniques in the social sciences attempt to map out, or explain more fully, the richness and complexity of human behaviour by studying it from more than one standpoint and, in so doing, by making use of both quantitative and qualitative data”

(Cohen et. al., 2007, p. 141)

Figure 4.7 below illustrates how combining the ‘best of both’ research methods contributes to a holistic evaluation.

Figure 4.7 Advantages of using a ‘mixed-method’ approach to research (adapted from Firestone, 1987)

Figure 4.7 highlights the positive aspects of both research methods contributing to an effective mixed methods approach. However, it is important to acknowledge the weakness of both approaches also. In quantitative analysis, the confidence of generalisability is dependent on a representative and random sample. As well as providing description and detail, qualitative analysis can often conclude with ambiguous statements. For this reason, the combination with quantitative data helps to clarify the conclusions made. Both research
methods can complement each other. When focused on the same issue, qualitative and quantitative studies can triangulate different methods to assess the robustness or stability of findings (Jick 1979). Cohen et al. (2007) outlined two main advantages of using this mixed-methods (triangulated) approach to research. The researcher can be confident that the data collected is not simply an artefact of a single research method, and where data from different research methods correspond, the researcher can be confident that this data is valid. Triangulation can act as a method of ‘checking data’, and is not limited to the findings of a single research method.

4.4- Validity and Reliability

“It is suggested that reliability is a necessary but insufficient condition for validity in research; reliability is a necessary precondition for validity, and validity may be a sufficient but not necessary condition for reliability” (Cohen et. al, 2007, p. 133)

The above descriptions of validity and reliability are somewhat confusing. It is important to begin by clearly defining these words, which are often incorrectly used interchangeably, in a similar way to the incorrect references to accuracy and precision in laboratory studies.

Simply, if a piece of research or data is invalid or unreliable, then it is worthless. Hammersley (1987) defined an account as ‘valid’ “if it represents accurately those features of the phenomena that it is intended to describe, explain or theorise” (Hammersley, 1987, p. 69). Due to the different nature of quantitative and qualitative research (as discussed already), validity can be defined differently in both methods. Cohen et al. (2007) recommended the following: careful sampling, appropriate instrumentation and appropriate statistical treatments to ensure validity in quantitative data. Cohen et al. (2007) also highlighted the error and bias that arises in qualitative data, thus affecting its validity; the subjectivity the opinions, attitudes and perspectives of respondents, as well as the subjectivity of the researcher. While there are different types of validity to be considered in quantitative and qualitative research, internal and external validity are common to both. Internal validity is concerned with the accuracy of the data. It demonstrates that the explanation of an event or a set of data from a piece of research can be sustained (Cohen et al. 2007). External validity on the other hand, refers to the degree in which the results can be generalised to the wider population or situations. This issue of generalisation is often problematic. The final type of validity that will be discussed here is content validity. This is dependent on the fairness and
comprehensiveness of the instrument used to gather the data. Considerations to ensure validity and reliability in the design of questionnaires and tests, interviews and observations will be discussed below in Sections 4.4.1, 4.4.2 and 4.4.3.

Firstly, it is important to understand what is meant by reliability and the different types of reliability. The meaning of reliability differs in quantitative and qualitative research. In quantitative research, reliability refers to “dependability, consistency, and replicability over time, over instruments and over groups of respondents” (Cohen et al., 2007, p. 146). Quantitative research assumes that if the same methods were used with the same sample, the results should be the same; it assumes a possible replication of results. However, due to the different nature of qualitative research, the assumption of possible replication is not the focus. In qualitative research, it is possible that two researchers studying a single setting may come up with different results and data, based on their own bias. Reliability as replicability can be addressed in qualitative research in the following ways:

- **Stability of observations:** whether the researcher would have made the same observations and interpretation of these if they had been observed at a different time or in a different place.

- **Parallel Forms:** whether the researcher would have made the same observations and interpretations of what had been seen if he or she had paid attention to other phenomena during the observation.

- **Inter-rater reliability:** whether another observer with the same theoretical framework and observing the same phenomena would have interpreted them in the same way. (Denzin and Lincoln 1994)

### 4.4.1. Considerations in Questionnaires

Validity of postal questionnaires can be seen from two viewpoints (Belson 1986). The first consideration is whether the respondents complete the questionnaires honestly and accurately and the second consideration is whether the non-respondents would have given the same answers as the respondents gave. Belson (1986) termed this problem of non-response as ‘volunteer-bias’. Hudson and Miller (1997) suggest many ways to maximise the response rate in postal questionnaires.
These include:

- Including a stamped addressed envelope.
- Organising multiple rounds of follow-up.
- Stressing the importance and benefits of the questionnaire.
- Providing the interim data from the returns and non-returns to involve and engage them in the research.
- Checking addresses and changing them if necessary.
- Following up questionnaires with a phone-call.
- Tailoring follow-up requests to individuals rather than generalised letters.
- Detailing features of the questionnaire itself.
- Issuing invitations to a follow-up interview.
- Understanding the nature of the population in depth, so that effective targeting strategies can be used. (Hudson and Miller 1997)

The advantage of using a questionnaire over an interview is because it tends to be more reliable. This is because questionnaires are anonymous, and thus they encourage greater honesty and they are more economical than carrying out interviews. However, the disadvantage of questionnaires is that there is often a low response rate, and misunderstandings of the respondent cannot be clarified, there may be problems for respondents with limited literacy, and they can often be completed in a rush or inaccurately (Cohen et al. 2007).

4.4.2. Considerations in Tests

The ‘Hawthorne’ effect comes into play when participants are asked to complete a test. Cohen et al. (2007) explained this effect wherein, by simply informing the group that this is an assessment situation, it will be enough to disturb their performance. However, this disturbance in performance may be for the better or worse, dependent on the individuals. There are a range of factors which can affect the reliability of a test: time of the day, time of school year, perceived importance of the test, formality of the test situation, anonymity of the test, guessing answers, how the test is administered and how it is marked etc. Four main factors can affect the reliability of a test: range of the group that is being tested, the group’s level of proficiency, the length of the test and the way in which reliability is calculated (Wolf, 1994, referenced by Cohen et al., 2007).
Overall, factors that can affect the validity and reliability of the test can be dependent on the test itself, the group taking the test or the researcher’s marking. The types of possible error from each of these three sources are discussed in detail by Cohen et al. (2007). Some of the main points are summarised in Table 4.5.

Table 4.5 Summary of sources of error from the test item, participants and researcher using Tests (Cohen et al. 2007)

<table>
<thead>
<tr>
<th>Test Items</th>
<th>Participants</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Task may be multi-dimensional; the question of transferability of knowledge is raised.</td>
<td>• Motivation and interest effect performance.</td>
<td>• Errors in marking – attributing, adding and transfer of marks.</td>
</tr>
<tr>
<td>• Context of the task affects the pupil / student’s performance.</td>
<td>• The relationship between the assessor and the pupil / student exerts an influence on the assessment.</td>
<td>• Different markers giving different marks for the same pieces of work.</td>
</tr>
<tr>
<td>• The validity of the items may be in question.</td>
<td>• Physical, emotional and social conditions of the assessment exert an influence. Assessments should be given under normal classroom conditions.</td>
<td>• Inconsistency in the marker – being harsh in the early stages and more lenient in the later stages of correction.</td>
</tr>
<tr>
<td>• Language used in the assessment (may not even be the pupil / student’s first language).</td>
<td>• The Hawthorne Effect- by informing pupils / students of the assessment, performance will be disturbed.</td>
<td>• Variations in the award of grades – for work that is close to grade boundaries, some markers may place the score in a higher or lower category then other markers.</td>
</tr>
<tr>
<td>• Readability level of the task may distract from the content being assessed.</td>
<td>• Pupils and students often respond as they feel is ‘expected’ of them.</td>
<td>• The Halo effect: a pupil / student who is judged to do well or badly in one assessment is given undeserved favourable or unfavourable assessment respectively in other areas.</td>
</tr>
<tr>
<td>• The size and complexity of questions and numbers may distract from those who understand the concepts.</td>
<td>• Time of the day, week, school term etc. influences performance.</td>
<td></td>
</tr>
<tr>
<td>• Form and presentation of questions affect the results.</td>
<td>• Pupils and students may not always be clear about what the questions asks.</td>
<td></td>
</tr>
<tr>
<td>• Questions might favour boys over girls or vice versa.</td>
<td>• A pupil / student may be able to perform a specific skill in a test, but not in the wider context of learning.</td>
<td></td>
</tr>
<tr>
<td>• Boys perform better than girls on multiple choice questions.</td>
<td>• Cultural, ethnic and gender backgrounds effect how meaningful an assessment is.</td>
<td></td>
</tr>
<tr>
<td>• Girls perform better than boys on essay type questions.</td>
<td>• Pupils’ and students’ personalities affect their performances.</td>
<td></td>
</tr>
<tr>
<td>• Girls perform better than boys in written work.</td>
<td>• Learning strategies and styles used, make a difference to test performance.</td>
<td></td>
</tr>
<tr>
<td>• A test may be long to ensure coverage, but boredom and loss of concentration may impair reliability.</td>
<td>• The context in which the task is presented affects performance.</td>
<td></td>
</tr>
</tbody>
</table>
4.4.3. Considerations in Interviews

One way of validating interview measures is to compare the interview data with data from another research method (triangulation). This method of checking validity is called convergent validity. It is important when conducting interviews to try to minimise the bias as much as possible. The sources of bias (from the interviewer) include:

- Attitudes, opinions and expectations of the interviewer.
- Tendency for the interviewer to see the respondent in his or her own image.
- Tendency of the interviewer to seek answers that support preconceived notions.
- Misperceptions on the part of the interviewer of what the respondent is saying.
- Misunderstandings on the part of the respondent of what is being asked.

(Cohen et al. 2007)

Given the interpersonal nature of interviews, it is inevitable that the researcher will have some influence on the interviewee. Studies have shown that race, religion, gender, sexual orientation, status, social class and age can all be sources of bias during an interview (Scheurich 1995). It is important to ensure reliability of interviews, by preparing them as structured interviews. Changes in wording, context and emphasis between respondents undermine the reliability of interviews as a method of gathering valid data. Open-ended interviews enable the respondent to demonstrate their own opinions and attitudes more clearly. Given the advantages of structured and open-ended interviews, a semi-structured interview style was adapted for the analysis in Cycle Two of this research project. The use of the Teacher Questionnaire to inform the leading questions for the Teacher Interviews will be explained in detail in Section 4.7.

4.4.4. Considerations in Observations

The subjective nature of observations leads to many considerations in order to ensure validity and reliability. As well as ensuring external validity, observations must also be carried out carefully to ensure internal validity. There are several threats to validity and reliability:

- The researcher may not be aware of important previous events (while they observe the ‘present’).
- Informants may be unrepresentative of the sample in the study.
• The presence of the observer might bring about different behaviours.
• The researcher might become too attached to the group to see it dispassionately.

(Cohen et al. 2007)

In some cases the researcher may ask a colleague or another person who is independent of the research study to carry out interviews and observations with the participants. The use of an independent interviewer or observer can increase the objectivity of the data collected. The absence of an impartial, external evaluator might be seen as weakening the strength and validity of the research findings (Bennett and Millar 2005). It is difficult to ensure the collection of unbiased data when the researcher is directly involved with the participants. However, due to the time and financial constraints of this research project, it was not feasible to involve an external evaluator. Due to similar practical constraints, the evaluation of all other intervention programmes listed in Table 3.12 in Chapter Three was carried out by those that had developed the materials. An advantage of such internal evaluation is that the developers are most familiar with the content and criteria of the intervention programme and therefore best-informed to evaluate the programme effectively.

As mentioned already, the mixed-methods approach to research and use of triangulation is an effective way of providing validity and reliability to observations where they can be supported by quantitative data. Also, by structuring observational research, it itself can provide quantitative data e.g. preparing an observational rubric. An observational rubric was designed and used for the classroom observations carried out in Cycle Two. This helped to ensure that the same pupil and teacher behaviour and actions were observed in all classes that were observed.

4.5- Ethical Considerations

Ethical behaviour is of great importance in research, and in particular in research involving human beings as is the case in this research project. The participants involved in the Third-Level Study were students and lecturers and the participants involved in the Second-Level study were 5th and 6th year Leaving Certificate Chemistry pupils and their Chemistry teachers. A random sample of Second-Level schools teaching Leaving Certificate Chemistry and a random sample of Third-Level institutions were selected and invited to participate in this research study. The methods of selection used will be discussed later in Section 4.6.
Ethical approval was sought from the University of Limerick Research Ethics Committee (ULREC). See Appendices C, D, and E for all ethical documentation proof of ethical approval for this project.

Throughout this research study, efforts were made to ensure the anonymity of the participants and participating institutions and the confidentiality of the results attained. Anonymity ensures the participant that their name or institution will not be identifiable in any results published or presented from the research. The use of letters to code participating institutions and numbers to code the questionnaires in this study ensured that the privacy of all participants was guaranteed. Confidentiality in research means that although the researcher knows who has provided the information, they will not make this known publicly.

In the Second-Level study, the names of all of the schools and teachers involved were known to the researcher. The researcher coded each school with a letter. The Teacher Questionnaire for that school had the same school identification letter, and Pupil Questionnaires sent to the school were numbered (according to the number of pupils in the class) and labelled with the school identification letter also. The identity of the Second-Level pupils was never known to the researcher and they were only identified by their school identification letter and number. Information sheets and consent forms were sent to the parents / guardians of the participating pupils.

To ensure confidentiality and anonymity in the Third-Level study, a ‘Gate Keeper’ was employed. This was necessary because the students’ performance in the Diagnostic Test was compared with their performance in their end of semester Organic Chemistry examinations. To compare their test results with the examination results (attained from the participating lecturers), a confidential method needed to be developed to keep the identification of the students anonymous to the researcher. Like in the Second-Level study, each participating Third-Level Institution was coded with a letter and the questionnaires distributed were numbered. The role of the Gate-Keeper was to collate on a separate sheet, the students’ I.D. numbers, the corresponding questionnaire number that they completed, and the students’ examination grades. The student I.D. numbers remained unseen by the researcher. However, through the Gate-Keeper, the researcher was able to compare the examination grade with the questionnaire I.D. number and thus the performance in the Diagnostic Test. The identification of the Third-Level students was not revealed to the researcher.
When contacting the participating schools, colleges, teachers, lecturers, students and guardians of the participants under 18 years of age, necessary information had to be provided. The necessary information sheets and consent forms are included in the Appendices C, D and E. These will be explained and referred to when the methodology of Cycle One (Section 4.6) and Cycle Two (Section 4.7) are outlined in greater detail.

All information sheets and consent forms were headed with the official University of Limerick logo at the top of the page. These included the necessary details as outlined by the University of Limerick Research Ethics Committee.

The information sheets included:

1. Brief description of topic and method – interview/questionnaire etc., explaining what a participant will be expected to do.
2. Amount of time involved for participant.
3. Where the research will take place- will participant have any say in this?
4. Any risks or benefits to participant.
5. Explanation of participant’s right to anonymity.
6. Rights of participant not to answer questions and withdraw at any time. Also right to contact Chair of the Science and Engineering Research Ethics Committee if have any concerns about participating in the research.
7. Contact information: name of researcher/supervisor and Chair of Science and Engineering Research Ethics Committee. (ULREG 2012)

The consent forms included a declaration from the participant stating that they understood the nature of their participation in the research, the nature of their role as a participant, the freedom to withdraw at any time and also their entitlement to confidentiality.

In the Second-Level study in Cycle One and evaluation of in the intervention programme in Cycle Two some of the pupils involved were under the age of 18 years. In these cases, the University of Limerick Child Protection Guidelines were adhered to. The necessary information and consent forms were provided to the parents / guardians and returned before the questionnaires were distributed. The pupils and students in the Second-Level and Third-Level studies that were over the age of 18 signed their own consent forms. Informed consent forms were also signed and returned by all participating teachers. Consent protects and
respects the rights of self-determination and places some responsibility on the participant should anything go wrong in the research (Cohen et al. 2007).

4.6 – Methodology of Cycle One- Second-Level and Third-Level studies

As explained in Chapter One, this research project had two cycles. The methodology of Cycle One will be outlined in detail in the following sections (4.6.1, 4.6.2 and 4.6.3). As outlined in Table 4.6, there were two distinct studies as part of Cycle One of the Action Research project. The main focus of Cycle One was the Second-Level study. It was decided to also carry out a brief examination of the teaching and learning of introductory Organic Chemistry at Third-Level. The purpose of this study was to investigate if common difficulties exist in Second-Level and Third-Level Organic Chemistry.

Table 4.6 Outline of the Action Research in Cycle One

<table>
<thead>
<tr>
<th>Action Research</th>
<th>Research Tools</th>
<th>Participants</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second-Level Study</td>
<td>Second-Level Pupil Questionnaire (I)</td>
<td>5th and 6th year Leaving Certificate pupils who had covered the Organic section of the Chemistry syllabus.</td>
<td>May 2010</td>
</tr>
<tr>
<td></td>
<td>Chemistry Teacher Questionnaire</td>
<td>Second-Level Chemistry teachers.</td>
<td>Nov 2010</td>
</tr>
<tr>
<td>Third-Level Study</td>
<td>Third-Level Student Questionnaire</td>
<td>Students from different Third-Level courses after studying at least one introductory level Organic course.</td>
<td>Nov 2010-Mar 2011</td>
</tr>
<tr>
<td></td>
<td>Organic Chemistry Lecturer Questionnaire</td>
<td>Lecturers of introductory level Organic Chemistry at Third-Level.</td>
<td>Feb 2011</td>
</tr>
</tbody>
</table>

Questionnaires were used for quantitative analysis in Cycle One. The pupil and student questionnaires used also included a Diagnostic Test to assess understanding of Organic Chemistry. The Second-Level Pupil Questionnaire (I) and the Chemistry Teacher Questionnaire are included in Appendix F. The Third-Level Student Questionnaire and the Organic Chemistry Lecturer Questionnaire are included in Appendix G. The Second-Level study and the Third-Level study both followed the same methodology. The steps of the
Action Research cycle were adapted: the questionnaires were designed (in the planning step),
distributed (in the action step) and evaluated (in the observation step). These stages of Cycle
One were illustrated in the top half of Figure 4.3 in Section 4.2.3 of this chapter.

4.6.1. Design and Piloting of the Questionnaires

Different types and styles of questions were used in each of the four questionnaires that were
developed in this cycle of the project. These included open-ended questions, closed
questions, dichotomous questions, multiple choice questions and rating scales. Table 4.7
which follows summarises the question styles used in each part of each of the questionnaires.
The Second-Level Pupil Questionnaire and the Third-Level Student Questionnaire were both
two-part questionnaires. Part A in both questionnaires sought background information from
the participants while part B in both was a Diagnostic Test to assess their understanding of
Organic Chemistry. For this reason, some reference is made in Table 4.7 to parts A and B of
both of these questionnaires. In comparison the Chemistry Teacher Questionnaire and the
Organic Chemistry Lecturer Questionnaire were both one-part questionnaires, and both were
much shorter in length than the pupil and student questionnaires.

The common attributes of each of the question styles used in each of the questionnaires will
be discussed here. In the Sections that follow (4.6.1.1 to 4.6.1.4), specific elements of each of
the four questionnaires will then be outlined individually.

As can be seen in Table 4.7, all of the questionnaires designed combined the use of open-
ended questions with closed questions and Likert rating scales. Questionnaires can be
structured, semi-structured or unstructured in their nature. Cohen et al. (2007) outlined a
simple rule of thumb to follow when structuring a questionnaire: the larger the sample size,
the more structured, closed and numerical the questionnaire may have to be, and the smaller
the size of the sample, the less structured more open and word-based the questionnaire may
be. This rule was applied in the design of these four questionnaires. The pupil and student
questionnaires had a larger sample size than the teacher and lecturer questionnaires, and for
this reason, they were more structured while the latter two questionnaires allowed for more
open-ended questions. There are advantages for using both types of questions.
Table 4.7 Question styles in each of the four questionnaires designed in Cycle One (See Appendices F and G).

<table>
<thead>
<tr>
<th>Question Style</th>
<th>Second-Level Study</th>
<th>Third-Level Study</th>
<th>Organic Chemistry Lecturer Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Second-Level Pupil Questionnaire (I)</td>
<td>Third-Level Student Questionnaire</td>
<td></td>
</tr>
<tr>
<td>Open-ended</td>
<td>Section A: Listing the most difficult topics. Used to justify reasons for some dichotomous responses.</td>
<td>Section B: Used in questions 4, 7 and 9 of the Diagnostic Test to illustrate the answer and to justify the answers given.</td>
<td>Used in questions relating to teaching background, textbooks used, laboratory work and to provide a rationale for decisions made on the Likert scales. Allowance for any further comments at the end of the questionnaire.</td>
</tr>
<tr>
<td>Closed</td>
<td>Section A: Dichotomous style for General Information: year of study, gender, level of Chemistry, yes/no answers.</td>
<td>Dichotomous style used for time of year Organic Chemistry is taught, implementation of mandatory experiments and sequence of teaching.</td>
<td>Dichotomous style used for questions relating to class size, resources and teaching methods used and study of Leaving Certificate Chemistry.</td>
</tr>
<tr>
<td>Fill in the blanks</td>
<td>Section B: Used in questions 1, 2, 3, 5, 6 and 8 in the Diagnostic Test</td>
<td>Not Used</td>
<td>Not Used</td>
</tr>
</tbody>
</table>
Closed questions prescribe the range of responses that the respondent can choose from. The questions on personal information and previous Science and Mathematics experiences were mostly in a dichotomous style, and were answered by ticking the necessary boxes. The benefits of using closed questions include the generation of frequencies of response which is useful for statistical treatment and analysis, and the ability to make comparisons. They are also easier to code than open-ended questions (Bailey 1994). However, open-ended questions are more useful where the possible answers are unknown to the researcher and where many responses are possible. Open-ended questions can lead to irrelevant information and are more time-consuming to code and analyse (Bailey 1994).

A Likert scale was used to measure the participants’ attitudes towards Organic Chemistry, practical work in Organic Chemistry and also particular topics. Likert scales are so-named after their deviser, Rensis Likert (1932). The use of these scales helps to provide a range of responses to a given statement or question. It is important that the categories used are discrete and cover the range of possible responses that the respondent may want to give (Cohen et al. 2007). Likert scales “...are widely used in research... for they combine the opportunity for a flexible response with the ability to determine frequencies, correlations and other forms of quantitative analysis” (Cohen et al., 2007, p. 327). By following Likert scales with an open-ended question, this provides the researcher with a qualitative and quantitative measurement of the respondents’ opinions. This combined approach was adapted in each questionnaire. Providing an open-ended question following a Likert scale provides the respondent with the opportunity to add any further comments that would not have been possible within the restrictions of the scale.

Treagust (1988) proposed a two-tier question style. The first tier, part (a) of the question, asks the pupils to answer a given question, while the second tier, part (b) of the question, asks them to best explain as to why they chose their answer in part (a). A similar two-tiered approach was used in some of the questions in the questionnaires, and also in the Diagnostic Tests. In the Diagnostic Tests the ‘why’ questions probed a deeper understanding of the topic. This two-tier approach validates whether the participants’ answers to part (a) are coherent with their view and understanding of the topic or if they are simply random guesses. Another advantage and benefit of using the two-tier questions is that analysis of the participants’ responses to part (b) of the questions may also provide feedback about pupils’ and students’ alternative conceptions. Once these alternative conceptions and misunderstandings have been
identified, teaching methods can be modified to remedy the problem. Alternative teaching methods and materials can be used to specifically address the non-scientifically acceptable conceptions that exist (Treagust 2006).

As mentioned above and in Table 4.7, the pupil and student questionnaires both contained a Diagnostic Test in part B of the questionnaires. These Diagnostic Tests were ‘domain-referenced tests’, and designed specifically to test the participants’ understanding of Organic Chemistry. In Chapter Three, reference was made to many previous studies that have been carried out investigating particular difficulties in Organic Chemistry. While the tests used in these studies would provide a piloted, refined and reliable test instrument, the researcher decided that the specific questions used in these tests were not suitable for the Irish pupils and students in this research study. While developing a ‘home-grown’ test for both of the Diagnostic Tests was time-consuming to devise, pilot and refine, it was beneficial as it ensured that the purpose and content of the test was deliberately fitted for the specific requirements of this Cycle of the study. Two Diagnostic Tests were developed, one for use at Second-Level and one for use at Third-Level.

“Diagnostic Testing is an in-depth test to discover particular strengths, weaknesses and difficulties that a student is experiencing, and is designed to expose causes and specific areas of weakness or strength. This often requires the test to include several items about the same feature, so that for example several types of difficulty in a student’s understanding will be exposed” (Cohen et al., 2007, p. 419)

Because both Diagnostic Tests were developed by the author, it was important that they were reviewed by experts in the respective fields (Second-Level and Third-Level Chemistry educators) and also piloted. Issues relating to the Working Memory as discussed in Section 3.3.2.2 had to be considered also. The aim of both Diagnostic Tests was not to assess the participants’ mental capacities, but instead provide an accurate appraisal of their Organic Chemistry knowledge and understanding. One such consideration involved keeping the demand of the question (Z) less than the students’ mental capacity (X) for a fair examination of the students’ knowledge of Organic Chemistry (Johnstone and El-Banna 1986) (Figure 3.19). By asking pupils the same concept in different questions, this explored the consistency of the participants’ answers and comprehension of the topic. This also helped to distinguish whether factors such as the style and type of question, terminology used etc. influenced the participants’ ability to understand and answer the question. A distinct effort was made
throughout in designing the questions for both Diagnostic Tests to ensure that while the content was familiar to the participants, the actual compounds and reactants used were not too familiar, to limit the possibility of choosing correct answers through memorisation.

The specific content selection, timing, sequencing of questions, the marking scheme and scoring of each test was scored will be detailed in Sections 4.6.1.1 (Second-Level Pupil Questionnaire) and 4.6.1.3 (Third-Level Student Questionnaire) below.

4.6.1.1. Second-Level Pupil Questionnaire (I)

The Second-Level Pupil Questionnaire (I) was a two-part questionnaire. Part A of the questionnaire was three pages and Part B was the Diagnostic Test which was six pages long. This questionnaire required 35-40 minutes for completion.

Part A

Part A in the Second-Level Pupil Questionnaire (I) sought personal information from the participants: year of study, age, gender and level of Leaving Certificate Chemistry that they were studying. The pupils were also asked about their experience of Science and Mathematics at Second-Level with a particular focus on their attitudes towards the Organic section of the Leaving Certificate Chemistry course.

A five-point Likert scale similar to that used by Ratcliffe (2002) and Sheehan (2010) was adapted for the Second Level Pupil Questionnaire (I). On this scale, 1= Very Easy, 2= Easy, 3= Neutral, 4= Difficult, 5= Very Difficult (Ratcliffe 2002). For the questions asking about attitudes to learning Organic Chemistry and opinions on the practical work, three positively phrased statements were given to be rated on the scale; 1= Strongly Agree, 2= Agree, 3= Neutral, 4= Disagree and 5= Strongly Disagree. Only one three-point Likert scale was also used in the Second-Level Pupil Questionnaire (I) to indicate the pupils’ preference for each of the three topics in Junior Certificate Science. These written attributes were complemented by a pictorial aid to facilitate the pupils’ completion of the questions. Figure 4.8 shows part of the question assessing attitudes towards different topics within Organic Chemistry.
CHAPTER FOUR   METHODOLOGY

Table 4.8 Content and source of each question in the Second-Level Diagnostic Test.

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing Organic compounds</td>
<td>Designed by author</td>
</tr>
<tr>
<td>2</td>
<td>Naming Organic compounds</td>
<td>Designed by author</td>
</tr>
<tr>
<td>3</td>
<td>Isomerism.</td>
<td>(Reid 2003) Modified by author</td>
</tr>
<tr>
<td>4</td>
<td>Electron Density and electrophilic attack.</td>
<td>(Taagepera and Noori 2000) Modified by author</td>
</tr>
<tr>
<td>5</td>
<td>Reaction Types.</td>
<td>Designed by author</td>
</tr>
<tr>
<td>6</td>
<td>Organic Synthesis.</td>
<td>Designed by author</td>
</tr>
<tr>
<td>7</td>
<td>Reaction Mechanism.</td>
<td>Designed by author</td>
</tr>
<tr>
<td>8</td>
<td>Classification of Organic compounds.</td>
<td>Designed by author</td>
</tr>
<tr>
<td>9</td>
<td>Physical Properties of Organic compounds.</td>
<td>(Taagepera and Noori 2000) Modified by author</td>
</tr>
</tbody>
</table>

Figure 4.8 Example of the five-point Likert rating scale as used in Section A of the Second Level Pupil Questionnaire.

In other questions in part A, open-ended questions were used giving the pupils an opportunity to explain their responses in the closed style questions. These open response questions were useful in justifying the pupils’ opinions, and to gain a greater insight into their attitudes towards Organic Chemistry.

Part B

Part B in the Second-Level Pupil Questionnaire (I) was the Diagnostic Test. The Diagnostic Test was composed of nine questions. Each question assessed the pupils’ understanding of a different topic in Organic Chemistry. The topics in the Second-Level Diagnostic Test were topics from the Organic section of the Leaving Certificate Chemistry syllabus, Section 5 and Section 7 (DES 1999a).

Drawing Organic Compounds

Naming Organic Compounds

Classification of Organic Compounds
As explained earlier, many of the questions in the Diagnostic Test were designed by the researcher. Some questions were adapted and modified from relevant research studies. These are referred to in Table 4.8. Due to the specific nature of the test (based on Leaving Certificate Organic Chemistry content), other questions available in the literature would not have ‘fit the purpose’ of this Diagnostic Test. The Leaving Certificate examination papers (SEC 2011) presented a useful bank of questions to specifically assess the pupils’ understanding of the syllabus content. However, no questions were taken or adapted from the Leaving Certificate examination papers, as the researcher felt that these questions may have been previously seen and practised by the pupils. For the test to be valid, it was important that the questions used had not been seen or practised by the pupils prior to testing. Leaving Certificate examination questions are sometimes repetitive and predictive in their style. This Diagnostic Test was specifically designed to test the pupils’ understanding of concepts in Organic Chemistry and not simply as a recall of content that they had remembered. E.g. assessing an understanding and application of the IUPAC Nomenclature rules rather than simply recalling the name of a familiar compound. The questions assessing Organic reactions, mechanisms and synthesis were designed by the author because they specifically contained reactions that the pupils would have studied on the Leaving Certificate syllabus. Space was provided in each question in the Diagnostic Test to answer each of the questions directly into the questionnaire paper.

The test was piloted by 36 pupils in four different Second-Level schools and the necessary refinements and changes were made before distribution to the sample group. Piloting the test was also important to time how long it would take for pupils to complete. The Second-Level Diagnostic Test took 30-35 minutes to complete.

In part A of the draft questionnaire, the pupils had been asked to indicate which of the mandatory Organic experiments they had carried out themselves, which were seen as teacher demonstrations and which had they never seen at all. Due to the disparity among pupils within in the same class in answering this question, it was decided that this question would instead appear in the Chemistry Teacher Questionnaire instead. As an alternative, the pupils were simply asked to indicate their favourite and least favourite Organic experiment and to explain why. A more detailed and longer list of Organic topics was included in the pilot questionnaire for which the pupils were expected to rate on the five-point Likert scale. From the pupils’ response, it was evident that many may not have understood the individual topics,
so instead a shortened list using the headings from the Leaving Certificate syllabus was used in the Second-Level Pupil and Chemistry Teacher Questionnaires.

Analysis of performance on individual questions in the pilot Diagnostic Test was also useful. The length of the individual questions as well as the overall test needed to be reduced, as it was too time-consuming and reduced the possibility of participants attempting and completing all sections. Consideration about the ordering of the questions was raised, as the questions toward the end of the test were the most poorly answered. The pilot Diagnostic Test was designed with the questions in ascending difficulty, culminating with mechanisms and synthesis. Even though the climax of more difficult topics allowed the participant to build confidence when answering the preliminary easier questions, it was decided to alter the order of some of the questions. By not having the most difficult questions at the end of a 10-page questionnaire, it was hoped that this would increase the percentage of attempts in these types of questions. In the pilot questionnaire, the topics which are commonly perceived as ‘easier’ such as naming, classification, drawing and physical properties were included at the beginning of the test with ascending difficulty leaving the questions assessing understanding of reaction, synthesis and mechanism to the end of the test. These topics are perceived as ‘more difficult’ and they were poorly attempted and answered in the pilot Diagnostic Test. It was unknown to the researcher if this was due to their difficult nature or tiredness and boredom of the pupils towards the end of the test. For this reason, in the revised test, the sequencing of the topics was changed. The sequence of topics can be seen in Table 4.8. Some of the questions assessing topics which the pupils had answered well in the pilot Diagnostic Test were moved towards the end of the revised Diagnostic Test. Some of the ‘easier’ topics were left at the beginning of the test, as the researcher felt that these questions mat help to increase confidence and motivation, if answered well by the pupils.
Piloting the questionnaire also allowed the marking scheme to be piloted also. All questions in the test were evenly weighted. There were nine questions in the test; each question was worth 40 marks, giving a total of 360 marks. Figures 4.9 and 4.10 that follow provide examples of two of the questions from the Second-Level Diagnostic Test. The full test is included in Appendix F. Figure 4.9 that follows shows Question Two from the Second-Level Diagnostic Test. This question assessed the pupils’ ability to name organic compounds. This was an eight part question and the pupils were given credit for each compound named correctly (8 x 5 marks). The combination of condensed and extended structures also allowed the researcher to assess whether the presentation of a compound affected the pupils’ ability to recognise the functional group and name the compound systematically. A similar combination of structural representations was used in the question assessing the participants’ ability to classify compounds according to their functionality.

![Figure 4.9 Question Two in the Second-Level Diagnostic Test.](image)

Question Four assessed electron density and electrophilic attack (Figure 4.10). This question assessed the pupils’ knowledge of the transfer of electrons, which is an integral aspect of reaction mechanisms.
4.6.1.2. Chemistry Teacher Questionnaire

The Chemistry Teacher Questionnaire had just one part and aimed to find out the teachers’ perspective and approach to teaching Organic Chemistry at Second-Level. The styles of questions used in the Chemistry Teacher Questionnaire are outlined in Table 4.7. The full questionnaire is included in Appendix F. The same five-point Likert rating scales as were used in the Second-Level Pupil Questionnaire were used again in this questionnaire. The pictures were not included with the Likert ratings. The teachers were given an opportunity after each Likert rating to provide reasons for their decisions. The same statements and listing of Organic Chemistry topics as were used in the Second-Level Pupil Questionnaire were used in this questionnaire. This decision was made by the researcher to facilitate the comparisons.
that could be made in the evaluation stages between the teachers’ and pupils’ attitudes and perspectives. There were more open ended questions at the end of the Teacher Questionnaire. These allowed the teachers to answer about the teaching resources and methods they use in their teaching of Organic Chemistry. A closed question was not appropriate here, as the researcher did not want to predict the answers that the teachers may have given.

This questionnaire was piloted by 10 Chemistry teachers, each teaching Chemistry in different Second-Level schools. The necessary refinements were then made before distribution to the testing sample. The questionnaire was timed, and took 10-12 minutes to complete.

A note was included at the end of this questionnaire for interested teachers to contact the researcher if they were willing to participate in Cycle Two of this Action Research project. It was through this correspondence that the sample group of teachers were self-selected for participation in Cycle Two of the project (implementation of the intervention programme).

4.6.1.3. Third-Level Student Questionnaire

The Third-Level Student Questionnaire had two parts; part A and part B. Part A was just one page, while part B, which was the Diagnostic Test was six pages. The questionnaire required 40 minutes for completion.

**Part A**

Part A in the Third-Level Student Questionnaire sought to find some personal information about the students as well as their experiences of Science and Mathematics at Second-Level. All of these questions were asked as closed questions. The students were asked to indicate on a five-point Likert scale their attitudes towards their study of Organic Chemistry at Third-Level. The same rating scale that was used in the Second-Level Pupil Questionnaire was also in this questionnaire. The pictures to elaborate the ratings were also included (Figure 4.8). While the style of the Likert scale used was similar to that used in the Second-Level Pupil Questionnaire, the criteria listed were specific to Third-Level Organic Chemistry. (The criteria on the Second-Level Likert scale were related to the Leaving Certificate Chemistry syllabus).
Part B

Part B in this questionnaire was a Diagnostic Test. This Diagnostic Test contained eight questions. Each question was designed to assess the students’ understanding of a different topic in Organic Chemistry. The level of Organic Chemistry that was assessed in the Third-Level Diagnostic Test was based at an introductory standard at Third-Level. The syllabi for Introductory Organic Chemistry courses in three Third-Level institutions were consulted in the design of this questionnaire to ensure that all of the content assessed had been covered by the students. The lecturers of each of the five Third-Level cohorts that participated in the study approved the Diagnostic Test as a suitable and accurate test of the content taught in their respective courses. The topics assessed in each question of the Diagnostic Test are listed in Table 4.9.

Table 4.9 Content and source of each question in the Third-Level Diagnostic Test.

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing organic compounds</td>
<td>Designed by author</td>
</tr>
<tr>
<td>2</td>
<td>Identification of organic species</td>
<td>Designed by author</td>
</tr>
<tr>
<td>3</td>
<td>Electron Density</td>
<td>(Taagepera and Noori 2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modified by author</td>
</tr>
<tr>
<td>4</td>
<td>Naming organic compounds</td>
<td>(Reid 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modified by author</td>
</tr>
<tr>
<td>5</td>
<td>Classification of organic compounds</td>
<td>(Reid 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modified by author</td>
</tr>
<tr>
<td>6</td>
<td>Isomerism</td>
<td>(Reid 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modified by author</td>
</tr>
<tr>
<td>7</td>
<td>Shape and structure of hydrocarbons.</td>
<td>Designed by author</td>
</tr>
<tr>
<td>8</td>
<td>Mechanism of reactions.</td>
<td>Designed by author</td>
</tr>
</tbody>
</table>

The rationale for the author designing many of the questions in the Diagnostic Test has already been explained. To make the test a fair diagnostic tool, no questions were sourced from the examination papers at any of Third-Level institutions involved. Some questions from the literature were adapted and used appropriately. The styles of questions used in the Diagnostic Test were outlined in Table 4.7. A full copy of the Diagnostic Test can be seen in Appendix G.

Figure 4.11, that follows shows the grid of compounds that were used to answer Questions Four, Five and Six of the Diagnostic Test. This ‘Structural Communication Grid’ is a powerful diagnostic tool, and was adapted from Reid (2003). Because the participants do not know how many answers are expected for each part, guessing is eliminated. While the correct
answers indicate the comprehension of nomenclature, classification and isomerism, wrong answers offered by the students can also reveal misunderstandings and misconceptions, in particular, if one particular incorrect answer is popular. The inclusion of a number of compounds eliminated the students’ use of elimination techniques in their answering. (A similar grid was used only in Question Three of the Second-Level Diagnostic Test).

This questionnaire was piloted in the University of Limerick with different cohorts of students to those that were involved in the sample group. This pilot study involved 82 students in total. The piloting confirmed the amount of time necessary to complete the questionnaire and also highlighted the need to make the structural representations of the organic compounds more uniform. These changes were made, as can be seen by the representations in Figure 4.11. Much of the background detail (attitudes to Leaving Certificate Chemistry etc.) that was included in the pilot questionnaire was omitted from the final questionnaire. In the final questionnaire, part A was only one page, though this was much longer in the pilot questionnaire. It was the researcher’s opinion that if less time was spent on Section A, the students would be better able to attempt and answer all of the questions in the Diagnostic Test in part B. The eight questions were evenly weighted. Each question was given a total of five marks, resulting in an overall test score of 40 marks (8 x 5 marks).
Figure 4.11 Structural Communication Grid used in the Third Level Diagnostic Test (adapted from Reid 2003)
4.6.1.4. Organic Chemistry Lecturer Questionnaire

The aim of this questionnaire was to seek information from those teaching Organic Chemistry at Third-Level. The questionnaire was specifically addressed to those lecturing fundamental or introductory Organic Chemistry courses. As outlined in Table 4.7, the majority of questions were open-ended questions. A copy of this questionnaire is included in Appendix G. The questionnaire was divided into five sections, which were indicated in colour and by a letter. These included: Teaching Organic Chemistry, Areas of difficulty in First Year Organic Chemistry, Use of teaching resources, Practical work and the lecturers’ perspective of their students’ experience of Organic Chemistry.

Space was also provided at the end of the questionnaire for the lecturers to provide any further comments or feedback from their experience of teaching Organic Chemistry at Introductory Third-Level. The questionnaire was designed specifically for those teaching introductory level Organic Chemistry, because it was the researcher’s belief that many of the difficulties that exist at Second-Level Organic Chemistry are present also at Third-Level. This may be particularly true for those students in Third-Level who have no prior experience of Leaving Certificate Chemistry.

As will be discussed in Section 4.6.2.2 that follows, this questionnaire was distributed by email and completed electronically. This allowed the responding lecturers to provide as much detail as they felt necessary to answer the open-ended questions. The boxes provided for the answers were expandable, and so some of the returned questionnaires extended past three or four pages. Similarly to the previous questionnaires, the closed questions and Likert scales were followed by open-ended questions to allow expansion of the lecturer’s response.

The pilot questionnaire was evaluated by three practising Third-Level lecturers (two of whom were lecturing Organic Chemistry). The pilot questionnaire was then refined in light of the feedback and recommended changes.

Table 4.10 that follows provides a summary of the content and layout of the Third-Level Student Questionnaire, Organic Chemistry Lecturer Questionnaire, the Second-Level Pupil Questionnaire (I) and the Chemistry Teacher Questionnaire. The specific topics and questions of the Second-Level and Third-Level Diagnostic Tests have previously been detailed in Tables 4.8 and 4.9 respectively. For this reason, they are not repeated in Table 4.10.
Table 4.10 Summary of the content in the four questionnaires used in Cycle One.

<table>
<thead>
<tr>
<th>Second Level Pupil Questionnaire (I)</th>
<th>Chemistry Teacher Questionnaire</th>
<th>Third Level Student Questionnaire</th>
<th>Organic Chemistry Lecturer Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Personal Information:</strong></td>
<td></td>
<td><strong>Personal Information:</strong></td>
<td><strong>Teaching Organic Chemistry:</strong></td>
</tr>
<tr>
<td>• Age.</td>
<td>• Stage of school year to teach</td>
<td>• Age.</td>
<td>• Number of years teaching.</td>
</tr>
<tr>
<td>• Gender.</td>
<td>Organic Chemistry.</td>
<td>• Gender.</td>
<td>• Level of Organic Chemistry taught.</td>
</tr>
<tr>
<td>• Year of Study.</td>
<td>• Attitudes towards Organic</td>
<td>• Course of Study.</td>
<td>• First Year Organic Chemistry.</td>
</tr>
<tr>
<td></td>
<td>Chemistry.</td>
<td></td>
<td>• Assessment of Organic Chemistry.</td>
</tr>
<tr>
<td><strong>Previous Science and Mathematics:</strong></td>
<td>**Attitudes towards Organic</td>
<td></td>
<td><strong>Areas of difficulty in First Year Organic Chemistry:</strong></td>
</tr>
<tr>
<td>• J.C. Science (Level, Grade and</td>
<td>Chemistry.</td>
<td></td>
<td>• Likert rating scale</td>
</tr>
<tr>
<td>preference of strands)</td>
<td>• Assumed pupils’ perspective</td>
<td></td>
<td><strong>Use of Resources:</strong></td>
</tr>
<tr>
<td>• Other Science subjects studied for</td>
<td>of Organic Chemistry.</td>
<td></td>
<td>• Textbooks</td>
</tr>
<tr>
<td>the L.C.</td>
<td>• Implementation of Mandatory</td>
<td></td>
<td>• Teaching resources.</td>
</tr>
<tr>
<td>• Participation in Transition Year</td>
<td>Organic experiments.</td>
<td></td>
<td>• Teaching methods.</td>
</tr>
<tr>
<td>Programme and Science competitions.</td>
<td>• Likert rating of teaching</td>
<td></td>
<td><strong>Practical Work:</strong></td>
</tr>
<tr>
<td>• J.C. Mathematics (Level and Grade).</td>
<td>Organic topics.</td>
<td></td>
<td>• Effectiveness</td>
</tr>
<tr>
<td>L.C. Mathematics (Level).</td>
<td></td>
<td></td>
<td>• Integration</td>
</tr>
<tr>
<td><strong>Organic Chemistry in the L.C.:</strong></td>
<td><strong>Most difficult Organic topics</strong></td>
<td></td>
<td><strong>Your students’ experiences:</strong></td>
</tr>
<tr>
<td>• Attitudes towards Organic</td>
<td>to teach.</td>
<td></td>
<td>• Likert Rating.</td>
</tr>
<tr>
<td>Chemistry, mandatory experiments and</td>
<td>• Textbook used.</td>
<td></td>
<td>• Topics perceived as difficult.</td>
</tr>
<tr>
<td>difficult topics.</td>
<td>• Sequence of teaching Organic</td>
<td></td>
<td>• L.C. Chemistry</td>
</tr>
<tr>
<td>• Tutorial assistance with Chemistry.</td>
<td>content.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Likert rating of Organic topics.</td>
<td>• Suggested resources / materials for teaching Organic Chemistry.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diagnostic Test</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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4.6.2. Distribution and Implementation of Questionnaires

Ethical approval was sought and granted for each of the four questionnaires that were developed for the Second Level and Third Level studies. Appendix C contains the Ethics application form, letter of approval and necessary documentation that was distributed with the Second-Level questionnaires. Appendix D contains the Ethics Application form, letter of approval and the necessary documentation that was distributed with the Third-Level questionnaires.

4.6.2.1. Distribution and Implementation at Second-Level

There were 546 schools teaching Leaving Certificate Chemistry in Ireland in 2009 (DES 2009). From these schools, an 18% sample of 100 schools was chosen at random using SPSS version 16.0. SPSS has a random sampling procedure. The selection of the random sample was not affected by the list order of the schools (according to roll number). Of these 100 schools chosen, 33% were all-girls schools, 14% were all-boys schools and 53% were co-educational schools.

April was chosen as a good time of the year to disseminate the Second-Level Pupil Questionnaire (I) as the sixth year pupils would have the whole Leaving Certificate Chemistry course (including Organic Chemistry) covered and there was a higher possibility of some fifth year classes being eligible to participate also. It was important also that the schools were contacted and questionnaires distributed and returned before the end of May, as the teachers and pupils would then be more focused on the Leaving Certificate examinations. These 100 schools were contacted in April 2010. Each school was firstly contacted by phone call to find the name of the Leaving Certificate Chemistry teacher in the school. The researcher felt that it was important to address the Chemistry teachers directly when posting the school information letters. After sourcing the names of all Chemistry teachers involved, the information letter was posted to each of the schools. After posting, a second phone call was made directly to each of the selected Chemistry teachers to confirm their participation in the research study. Of these 100 schools, 73 (73%) of the Chemistry teachers agreed to take part in the Second-Level Study. Fifth and sixth year pupils were welcome to participate in this study, but it was essential that all pupils taking part had already covered the Organic Chemistry section of the Leaving Certificate Chemistry course. The
necessary consent forms, information sheets and questionnaires were sent to the participating Chemistry teachers in these schools.

Stamped and addressed envelopes were included when the questionnaires were posted to the schools. It was the researcher’s hope that this would facilitate the efficient return of the completed questionnaires. However, only 35 of these schools participated fully by having both the Chemistry teacher and pupils involved in the study. In the remaining 38 schools only the Chemistry Teacher Questionnaires were returned. No pupils from these schools participated in the Second-Level Study. It was necessary to follow-up with some of the Chemistry teachers to remind them to return the completed questionnaires and signed consent forms.

4.6.2.2. Distribution and Implementation at Third-Level

Unlike the Second-Level Study where the Second-Level Pupil Questionnaires and Chemistry Teacher Questionnaires were distributed together to the participating schools at the same time (April-May 2010), both questionnaires in the Third-Level Study were distributed separately.

The Third-Level Student Questionnaire was distributed in November 2010. November was chosen as a suitable time of the year, as the students involved were near the end (or finished) their study of Organic Chemistry for the semester and it was before the beginning of the examinations. This questionnaire was distributed to students in four different Third-Level institutions. These institutions involved in this research study were selected by the researcher. Two Universities were selected for participation and two Institutes of Technology. The Organic Chemistry lecturers in these institutions were contacted by email and asked if they would allow the students in their classes to complete the Third-Level Student Questionnaire at the end of their first or second semester of Organic Chemistry. Due to the mixed classes and cohorts in Third-Level education, some of the participating students had just completed their first semester of Organic Chemistry, and others had completed their second semester of Organic Chemistry at Third-Level. For many of the participating students, this was the end of their study of undergraduate Organic Chemistry.

The Third-Level Student Questionnaire was shown to the lecturers of the students from each of the four participating institutions. This was necessary to ensure that the content within the Diagnostic Test (Part B of the questionnaire) was a fair assessment of the varying course
material in the different institutions. This was not necessary in the Second-Level study as all of the participants involved were working with the same Leaving Certificate Chemistry syllabus (DES 1999a). Through communication with the lecturers of the modules, the number of students eligible for participation in each of the institutions was finalised. The required number of Third-Level Student Questionnaires along with the necessary ethical material was then posted directly to the Organic Chemistry lecturers in three of the participating institutions. The researcher was involved in the distribution of the questionnaires with the help of a Gate-Keeper in the fourth institution. The Third-Level Student Questionnaire was distributed during lecture slots that were organised by the lecturers involved. The involvement of the Gate-Keeper ensured that the identification of the students was not known directly to the researcher. The role of the Gate-Keeper as a mediator between the participating students, lecturers and the researcher has been outlined in Section 4.5. Reminder emails were sent to the other three participating lecturers responsible for the distribution and return of the Third-Level Student Questionnaires in the other three institutions. By the end of March 2011, the completed questionnaires were returned from three of the four institutions that were selected to participate. One of the universities did not fulfil their commitment to participation in this part of the Third-Level Study. In total, 121 Third-Level Student Questionnaires were completed by students in one university and two Institutes of Technology.

Unlike the other three questionnaires that were distributed by post in Cycle One of this project, the Organic Chemistry lecturers were contacted via email. The names and email contact details for the Organic Chemistry lecturers in 15 Third-Level institutions in Ireland were sourced online by the researcher. Email communication was deemed a suitable method of communication for this particular cohort, as most academic staff communicate through and frequently use emails. In total, 64 Organic Chemistry lecturers were contacted. In the first email, informing the lecturers of the research study, it was outlined that participants must be teaching or have experience of teaching introductory level Organic Chemistry. This specification immediately reduced the number of those lecturers that were eligible to participate. However, many of the respondents did forward the information on to the relevant lecturers in their institutions. The Organic Chemistry Lecturer Questionnaire was attached and distributed by email to the participating lecturers. In total, 20 lecturers teaching introductory level Organic Chemistry completed and returned the questionnaire.
electronic. Twelve of these participants were teaching at universities and eight were teaching at Institutes of Technology.

4.6.3. Description of the Sample Groups

This section provides a specific breakdown of the participants in the Second-Level and Third-Level studies. This is useful to see the response rate and representation of the participating sample groups.

4.6.3.1. Participants in the Second-Level Study

As outlined in Section 4.6.2.1, 100 schools were randomly selected and asked to participate in the Second-Level Study. In total, 73 schools participated by returning completed Chemistry Teacher Questionnaires (n=79). More than one Chemistry Teacher completed the Chemistry Teacher Questionnaire in six of these schools. Pupils from 35 of these 73 participating schools participated in the Second-Level Study by completing the Second-Level Pupil Questionnaire (I). Table 4.11 below provides a breakdown of the gender and type of the participating schools.

Table 4.11 Gender and type of the participating schools in the Second-Level Study.

<table>
<thead>
<tr>
<th>School gender</th>
<th>School type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls</td>
<td>Boys</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Schools teaching Leaving Certificate Chemistry (546)</td>
<td>136 (24.9%)</td>
</tr>
<tr>
<td>Schools randomly chosen and asked to participate in the study. (N=100)</td>
<td>33 (33.0%)</td>
</tr>
<tr>
<td>Schools from which teachers only participated in the study. (n=38)</td>
<td>5 (13%)</td>
</tr>
<tr>
<td>Schools from which the pupils and teachers participated in the study (n=35)</td>
<td>13 (37%)</td>
</tr>
</tbody>
</table>

Note: In the school types listed in Table 4.11, Comm= Community and Comp = Comprehensive.
Of the 546 schools teaching Leaving Certificate Chemistry, 100 of these were randomly selected to participate in the Second-Level Study. This selection process has already been outlined in Section 4.6.2.1. The percentages values are included in brackets in Table 4.11. These percentage values are useful in comparing the selected sample (N=100) and participating groups as a valid representation of the total population. The response rate from the 100 schools was 73%. In total 73 schools participated in the study. For clarity the number of participating schools is divided in Table 4.11. It can clearly be seen that in 38 of the schools, only the teachers participated, while the teachers and pupils in 35 of the schools participated. The total number of schools involved in the Second-Level study (n=73) represents 13.4% of the total number of schools offering Leaving Certificate Chemistry in Ireland.

In total, 276 pupils participated from 35 schools. Table 4.12 provides a brief profile of the pupils involved in the Second-Level study. Two pupils did not indicate their gender on the questionnaire and three did not indicate the level of Chemistry that they were studying for the Leaving Certificate.

| Table 4.12 Profile of the Chemistry pupils involved in the Second Level Study (n=276). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Participants    | n=276 (% of total) |
| **Gender**      |                 |                 |
| Male participants| 92              | (33.3%)         |
| Female participants | 182         | (65.9%)         |
| **Year of Study** |                 |                 |
| Sixth Year pupils | 258         | (93.5%)         |
| Fifth Year pupils | 18           | (6.5%)          |
| **Level of Leaving Certificate Chemistry** |                 |                 |
| Higher Level     | 246             | (89.1%)         |
| Ordinary Level   | 27              | (9.8%)          |

In total, 79 teachers participated in the Second-Level Study from 73 schools: 19 (24%) of these were male teachers and 59 (75%) were female. One teacher did not indicate their gender in the questionnaire.
4.6.3.2. Participants in the Third-Level Study

As explained in Section 4.6.2.2 above, the Third-Level Study was carried out in two parts. Four institutions were involved in the survey of the students (n=121), 12 institutions were involved in the survey of the Organic Chemistry lecturers (n=20).

Although two universities were invited to participate in the student survey of Third-Level Study, one of the universities did not return any of the questionnaires. Two Institutes of Technology were involved in the study. Table 4.13 shows the overall response rate (24.7%) and the breakdown of the number of possible participants and actual participants in each of the institutions.

Table 4.13 Participation in the Student survey of the Third-Level Study.

<table>
<thead>
<tr>
<th></th>
<th>Total number of possible participants (N)</th>
<th>Total number of participants n (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>University 1</td>
<td>240</td>
<td>86 (36%)</td>
</tr>
<tr>
<td>University 2</td>
<td>150</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Institute of Technology 1</td>
<td>60</td>
<td>17 (28%)</td>
</tr>
<tr>
<td>Institute of Technology 2</td>
<td>40</td>
<td>18 (48%)</td>
</tr>
<tr>
<td>Total</td>
<td>490</td>
<td>121 (24.7%)</td>
</tr>
</tbody>
</table>

As can be seen from the missing data in Table 4.14, five of the students did not indicate their gender in the questionnaires, and one did not indicate their study of Leaving Certificate Chemistry. There was a relatively equal gender breakdown in the total cohort (n=121) that completed the Third-Level Student Questionnaire.

Table 4.14 Profile of the Organic Chemistry students involved in the Third-Level Study (n=121)

<table>
<thead>
<tr>
<th></th>
<th>Participants</th>
<th>n = 121</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>55 (45.1%)</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>62 (50.8%)</td>
</tr>
<tr>
<td>Institution</td>
<td>University</td>
<td>86 (71.1%)</td>
</tr>
<tr>
<td></td>
<td>Institute of Technology</td>
<td>35 (28.9%)</td>
</tr>
<tr>
<td>Study of Leaving Certificate Chemistry</td>
<td>Higher Level</td>
<td>56 (45.9%)</td>
</tr>
<tr>
<td></td>
<td>Ordinary Level</td>
<td>7 (5.7%)</td>
</tr>
<tr>
<td></td>
<td>Not studied</td>
<td>58 (47.5%)</td>
</tr>
</tbody>
</table>
As mentioned in Section 4.6.2.2 above, the Organic Chemistry Lecturer Questionnaire was distributed to 64 lecturers in total (N=64), 22 of these were lecturing in Institutes of Technology and 42 were in universities. In total 20 lecturers completed and returned the Organic Chemistry Lecturer Questionnaire. This low response rate (31%) was partially due to the restriction of the questionnaire. The questionnaire was aimed specifically for lecturers teaching introductory or foundation level Organic Chemistry at Third-Level. Lecturers only teaching higher levels of Organic Chemistry did not therefore complete the questionnaire. Table 4.15 provides a brief profile of the participating lecturers. Of the 12 lecturers working in universities, 10 were male and two were female. Of the eight working in Institutes of Technology, 3 were male and 5 were female.

Table 4.15 Profile of the lecturers involved in the Third-Level study (n=20).

<table>
<thead>
<tr>
<th></th>
<th>Participants</th>
<th>N= 64 (% of total)</th>
<th>n = 20 (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>47 (73%)</td>
<td>13 (65%)</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>17 (27%)</td>
<td>7 (35%)</td>
</tr>
<tr>
<td>Institution Type</td>
<td>University</td>
<td>42 (66%)</td>
<td>12 (60%)</td>
</tr>
<tr>
<td></td>
<td>Institute of Technology</td>
<td>22 (33%)</td>
<td>8 (40%)</td>
</tr>
</tbody>
</table>

Note: The 20 participating lecturers were not from 20 different institutions. In total, 12 different institutions were involved in the study, 6 universities and 6 institutes of technology. There was more than one lecturer teaching introductory level Organic Chemistry in three of the Universities and two of the Institutes of Technology.

4.6.4. Analysis and Evaluation

The questionnaires from the Second-Level and Third-Level studies were analysed individually. However, all four questionnaires used in Cycle One of this research study were analysed in the same format. The question styles used in each of the questionnaires has been outlined in Section 4.6.1. The closed and open style questions were analysed differently using quantitative and qualitative methods respectively. These quantitative and qualitative methods of analysis have been discussed (Section 4.3). The closed-response questions and the Likert scale ratings were coded accordingly and then inputted into SPSS. Answers for some of the open-ended questions were coded. This was possible when there was a trend in the responses, or a number or common responses.
The questionnaires from both the Second-Level and the Third-Level study generated a large amount of data and allowed for detailed analysis and discussion. The results from the Second-Level study are presented in Chapter Six and the results from the Third-Level study are presented in Chapter Seven. The data was first examined to view frequencies of responses before further analysis was completed. The data was described using charts and frequency tables. In the presentation of the non-parametric results, as well as indicating the median, the 25th and 75th percentiles were also included. The 25th percentile (also known as the first quartile) refers to the value below which 25% of the observations were found. Similarly, the 75th percentile (also known as the third quartile) is the value below which 75% of the observations were found. The median is the 50th percentile. Including the 25th and 75th percentiles in the result tables in Chapters Six and Seven provide a more accurate presentation of the findings in the research studies carried out in Cycle One.

After the preliminary results were produced, cross tabulations were used to investigate the influence of contributing factors. This analysis involved determining which variables had an effect on the respondents’ attitudes and answers given, e.g. gender, level of Leaving Certificate Chemistry, Third-level course of study etc. The appropriate tests (outlined in Figures 4.4 and 4.5) were then used to investigate the statistical significance of the effect of these variables. In many cases, a significant correlation was observed between variables e.g. those studying Higher Level Mathematics performed better in the Diagnostic Test. However, it must be noted that such correlations do not explain why such a pattern exists and never indicates, on its own, any cause and effect in the relationship. In such instances, the researcher attempted to deduce and explain the observed correlations.

Although each questionnaire was firstly analysed as a separate item, the Second-Level Pupil Questionnaire and Chemistry Teacher Questionnaire were then evaluated together to identify the main areas of difficulty in Organic Chemistry in the Leaving Certificate. In the same manner, the Third-Level Student Questionnaire and the Organic Chemistry Lecturer Questionnaire were analysed separately and then evaluated together to gain an overview of the difficulties experiences in Organic Chemistry at Third-Level. At the end of Cycle One, the findings from both studies were evaluated as a whole to establish the main areas of difficulty to be addressed in the development of the intervention programme in Cycle Two of this Action Research project. The findings from Cycle One are discussed in Chapter Nine with respect to the research questions outlined in Chapter One.
4.7 – Methodology of Cycle Two- Evaluation of the Intervention Programme.

This Section outlines the methods of evaluation used to assess the effectiveness of the intervention programme, *Organic Chemistry in Action!* that was designed and implemented in Cycle Two of the project. The details of the design and implementation of the programme are explained in Chapter Five.

While much of the literature related to education evaluation refers to programmes being evaluated by external professional evaluators, there is also much evidence of intervention programmes that are evaluated by the researchers themselves. Bennet and Millar (2005) explained that this lack of an external and impartial evaluator may be seen to weaken any claims made about the success of an intervention. However, all of the other intervention programmes (Table 3.12 in Chapter Three) discussed have all been internally evaluated. There are certain advantages in having the developer involved as the evaluator as they have a clearer sense of the key features that need to be evaluated and of the outcomes that the programme is aiming for. (Millar 2005). The researcher in this project was both the developer and the evaluator.

“*Education evaluation is the process of delineating, obtaining and providing useful information for judging decision alternatives*”

(Millar, 2005, p. 16)

4.7.1. Mixed-Methods Approach

It is important to distinguish the difference between evaluation and assessment.

“*Evaluation is the process by which information is collected to make decisions on how instruction can or should be improved. Assessment is therefore a necessary but not sufficient component of evaluation*”

(Bodner *et al.*, 1999, p. 31)

It is important when measuring the effectiveness of an intervention programme such as *Organic Chemistry in Action!* to understand that assessment and evaluation are not synonyms. While the results and performance in an Organic Chemistry Test was compared with a Control Group of pupils, other methods of evaluating the intervention programme were also used. It is possible that an intervention can make a change in the classroom
environment without having any significant effect on examination performance (Bodner et al. 1999).

Bodner et al. (1999) outlined the unorthodox methodology for the evaluation of Action Research, known as ‘formative research’. This approach involves the use of a choice of quantitative and qualitative techniques. Many of the qualitative techniques are in the form of self-reports such as diaries, interviews and questionnaires. This method of evaluation helps the researcher to look beyond the simple question of ‘Did the pupils like the idea?’ to instead looking at if the intervention had an effect on classroom practice. Figure 4.12 illustrates the three different lenses that were used to evaluate the intervention programme; the participating teachers, the participating pupils and comparison with a Control Group.

Figure 4.12 Evaluation of the Organic Chemistry in Action! programme.
Figure 4.12 shows that within the evaluation from the teachers, four research methods were used. Three methods of research were used for the pupils’ evaluation of the intervention programme. The classroom observations provided the researcher with feedback from the pupils and the teachers. The triangulation of research methods is useful to validate the findings from each source. Refer to Appendix E for the details of ethical application and approval for the Teacher Interviews. Appendix H contains complete copies of the Teacher Diary template, Chemistry Teacher Review Questionnaire, Teacher Interview questions and the Second-Level Pupil Questionnaires (II) used in the evaluation of the intervention programme.

In appendix H, it can be seen that two different Second-Level Pupil Questionnaires were used in the evaluation of the intervention programme in Cycle Two. The *Organic Chemistry in Action: Second-Level Pupil Questionnaire (II)* was distributed to the pupils who participated in the intervention programme.

This questionnaire had three parts:

- **Part A**: Background Information and participation in Science and Mathematics, perceptions and attitudes to Organic Chemistry.
- **Part B**: Organic Chemistry Test for Understanding.
- **Part C**: Evaluation of the *Organic Chemistry in Action!* programme.

The *Control Group: Second-Level Pupil Questionnaire (II)* was distributed to pupils in the Control Group. These were pupils from schools not participating in the intervention programme that were learning Organic Chemistry through traditional teaching methods. This questionnaire had two parts; A and B. These parts A and B were identical to parts A and B (described above) in the Organic Chemistry in Action: Second-Level Pupil Questionnaire (II). For this reason, Part C of the Organic Chemistry in Action: Second Level Pupil Questionnaire (II) was used to evaluate the effectiveness of the programme through the lens of the participating pupils. Parts A and B of both pupil questionnaires were analysed together and used to compare the participating pupils’ attitudes and content knowledge of Organic Chemistry with that of the Control Group.
4.7.2. Feedback from participating teachers

The feedback from the participating teachers was obtained using four different methods combining qualitative and quantitative approaches. The Classroom Observations and Teacher Diaries were carried out and completed during the implementation phase. The Teacher Questionnaires and Teacher Interviews were completed and carried out when the teachers had completed their implementation of the *Organic Chemistry in Action!* programme.

4.7.2.1. Classroom Observations

The classroom observations were carried out during the implementation phase of the intervention programme. These will be outlined in Section 5.3.3 of Chapter Five. These visits also served as a useful method of informed evaluation. During these visits, the researcher had the opportunity to observe the teachers’ behaviour, activity and implementation of the intervention programme. This gave the researcher an opportunity to become more aware of the advantages and difficulties that the intervention programme and materials present the teacher with. It also gave the researcher an opportunity to witness for herself many of the aspects and issues that were raised by the teachers in the diaries, interviews and questionnaires e.g. poor timing of the lessons.

The teacher diaries, questionnaires and interviews as well as the classroom observations were all used to evaluate the intervention programme from the teachers’ perspective. This triangulation of evaluation techniques are useful to “explain more fully the richness and complexity of human behaviour by studying it from more than one standpoint and, in so doing, by making use of both quantitative and qualitative data” (Cohen et al., 2007, p. 141).

The qualitative data was transcribed and then compared by instrument and research question to identify the themes and trends emerging. Miles and Huberman (1994) in Cohen *et al.* (2007) outlined these 12 tactics for generating a meaning from transcribed data:

1. Counting frequencies of occurrence.
2. Noting patterns and themes.
3. Using informed intuition to reach a conclusion.
4. Setting items into categories, types, behaviours and classifications.
5. Using connotative language to reduce data, making patterns and connecting data with theory.
6. Splitting variables to elaborate, differentiating ideas.
7. Subsuming particulars into the general – moving towards clarifying key concepts.
8. Factoring: bringing a large number of variables under a smaller number of unobserved hypothetical variables.
9. Identifying and noting relations between variables.
10. Finding intervening variables.
12. Moving from metaphors to constructs, to theories to explain the phenomena.

(Miles and Huberman, 1994, cited by Cohen et al., 2007)

The methods used to analyse qualitative data were discussed in Section 4.3.2 above (Table 4.3). The findings from each of the research tools were analysed individually at first and then common categories and emerging themes were used to summarise the overall feedback from the teachers involved in the study.

4.7.2.2. Teacher Diaries

Teacher Diaries were given to the participating teachers with their Teacher Resource Kits before they began teaching the intervention programme. A copy of the template of the Teacher Diary is included in Appendix H. The teachers were provided with guiding questions at the beginning for use when reflecting and evaluating each lesson and unit. The researcher hoped that these diaries would act as a record of events for each of participating teachers. The teachers were asked to record particular activities and lessons that were successful and enjoyed by their class and also to outline why some of the materials and planned activities did not work as planned in their classrooms. The diary allowed the teachers to express their own immediate thoughts and opinions after teaching the lesson. This was seen as necessary by the researcher as the other evaluation tools used were post-intervention. It was important to capture the teachers’ initial feedback and thoughts, while teaching the programme. These diaries also provided the teachers with the opportunity to record and highlight any technical and content oversights or errors in the materials, to facilitate the later revision of the materials.
4.7.2.3. Chemistry Teacher Review Questionnaires

The Chemistry Teacher Review Questionnaires were distributed to all of the participating teachers on their completion of the intervention programme. The question styles used in this questionnaire included Likert rating scales and open-ended questions. The advantage of using these question types has already been discussed in Section 4.6.1. The Likert scales provided a quantitative analysis of the teachers’ attitudes and use of the specific materials (resources, Pupil Workbooks, Teacher Guidebook), as well as the practical activities and design elements of the intervention programme. The teachers were asked to indicate their intention or not to use the materials in the future. In comparison, the open-ended questions provided the teachers with more freedom to express their own opinions and attitudes about specific aspects of the programme, the materials, its effectiveness and how it could be improved. The teachers were also given the opportunity to outline if and how implementing the intervention programme had increased their awareness of pupil misconceptions and how to deal with these.

4.7.2.4. Teacher Interviews

After each participating teacher returned their Teacher Review Questionnaire and Teacher Diary, these were used to guide and structure questions for the individual Teacher Interviews. These interviews were carried out when the researcher visited the schools at the end of the implementation phase. While some of the same questions were asked of each of the teachers, some of the questions differed as directed by the findings of the individual questionnaires and diaries. While consistency is important in the evaluation methods used with all teachers, the researcher felt it was important that the individual feedback and comments from teachers were addressed and understood clearly so that an accurate evaluation of the programme would be made.

4.7.3. Feedback from Participating Pupils

Feedback for the evaluation of the Organic Chemistry in Action! programme from the pupils was sourced using three methods (Figure 4.12). The Classroom Observations which were carried out during the implementation phase provided an insight into the pupils’ experiences. The Organic Chemistry in Action: Second-Level Pupil Questionnaire (II) was also distributed at the end of the programme. Part C of this questionnaire gave the pupils an opportunity to individually report their experience of the programme.
4.7.3.1. Classroom Observations

The Classroom Observations will be explained in greater detail in Chapter Five, as they were part of the implementation phase of the intervention programme. Using the prepared rubric (See Appendix H), the pupils were observed. This observation provided qualitative data of the pupils’ participation, motivation and interest in the programme. This qualitative data was useful to complement and help to explain the findings from Part C of the questionnaire completed by the pupils who experienced the *Organic Chemistry in Action!* programme. The observational classroom visits and Part C of the *Organic Chemistry in Action: Second Level Pupil Questionnaire (II)* were used together to evaluate the pupils’ views on the *Organic Chemistry in Action!* programme.

4.7.3.2. Focus Group

A Focus Group was held with the pupils in the Chemistry class in School B. The details of this Focus Group will be outlined in Chapter Five (Section 5.3).

4.7.3.3. Organic Chemistry in Action: Second-Level Pupil Questionnaire (II)

This questionnaire was designed and distributed to the participating pupils at the end of the implementation phase of the intervention programme. This three-part questionnaire has already been explained above. The structure and design of the questionnaire was similar, but not the same as the Second-Level Pupil Questionnaire (I) that was used in Cycle One. The rationale for the question types used and styles of questions included were already discussed in Section 4.6.1.

Part C was only included in the Organic Chemistry in Action: Second Level Pupil Questionnaire (II), distributed to the pupils who experienced the intervention programme. In Part C of the questionnaire, a Likert rating was used using a pictorial scale to allow the pupils to rate the effectiveness and helpfulness of the resources, Pupil Workbooks, practical activities and contextual links within the intervention programme. Open ended questions were also included to allow the pupils to outline and justify their favourite and least favourite elements of the intervention materials. Part C was analysed separately from Parts A and B, as it specifically addressed the *Organic Chemistry in Action!* programme.

Parts A and B of the questionnaire were used for comparison with the Control Group. These will be discussed in Section 4.7.4.
4.7.4. Comparison with a Control Group

As well as seeking feedback from the teachers and pupils involved in the implementation of the *Organic Chemistry in Action!* programme, it was also important to compare the performance and attitudes of these pupils with pupils that were taught Organic Chemistry in the traditional manner (Control Group).

“Without a comparison (control) group... it is possible that the effects in terms of, say children’s enjoyment of the lessons, or their results in tests, would have happened anyway, and cannot be reliably attributed to the approach”  (Elbourne and Gough, 2005, p. 37)

Parts A and B of the both questionnaires distributed to the pupils in the Intervention Group and the Control Group were identical.

**Part A**

Part A investigated the pupils’ background participation in Science and Mathematics and also their perceptions and attitudes to Organic Chemistry in the Leaving Certificate. Much of the same question types that were used in Part A of the Second-Level Pupil Questionnaire (I) from Cycle One were used again in this questionnaire. However, some of the questions were not included. Questions from the Second-Level Pupil Questionnaire (I) that were not included in the Pupil Questionnaires (II) in Cycle Two were questions relating to preference for the sections in Junior Certificate Science, participation in Transition Year and questions relating to the mandatory experiments. The topics and details of topics included in the Likert rating scale were extended in the questionnaires used in Cycle Two. For example rather than listing ‘Organic reactions’ as a topic to be rated as easy or difficult by the pupils, each type of reaction on the Leaving Certificate syllabus i.e. addition, substitution, elimination etc. were listed individually. This allowed the pupils to indicate which reaction types in particular they find easy or difficult. The researcher believed that modifications such as this in the Organic Chemistry in Action: Second Level Pupil Questionnaire (II) and the Control Group: Second Level Pupil Questionnaire (II) would provide more detailed and useful feedback about the individual topics in Organic Chemistry. Another question included in both of these questionnaires and that was not in the Second Level Pupil Questionnaire (I) used in Cycle One was a question asking the pupils about their confidence and intention to attempt an Organic Chemistry question in the Leaving Certificate examination.
Analysis of Part A from the pupils in the Intervention Group and those from the Control Group provided the researcher with information on what effect the programme had in changing the pupils’ attitudes to Organic Chemistry and how it affected or influenced their intention to attempt the Organic Chemistry questions in the Leaving Certificate examination. Through comparison of the pupils’ responses on the Likert rating scale and in the open response questions in Part A, the researcher was able to evaluate the effectiveness of the intervention programme in alleviating the difficulties perceived by those learning Organic Chemistry for the first time.

Part B

Part B of the questionnaire was an assessment of the pupils’ understanding of Organic Chemistry. The same Test for Understanding of Organic Chemistry was given to the Intervention Group and the Control Group. This assessment of pupil knowledge and comparison with a Control Group was only a part of the overall evaluation of the effectiveness of the programme. The importance of using other methods of evaluation as well as assessment of content knowledge has already been outlined and discussed at the beginning of this Section. This Test for Understanding is included in full in the questionnaires included in Appendix H. In designing the Test for Understanding in both of the Second-Level Pupil Questionnaires (II) for analysis of the effectiveness of the intervention programme, the limitations of Second-Level Pupil Questionnaire (I) and Third-Level Student Questionnaire used in Cycle One were addressed and used to improve the design and structure of this questionnaire.

It was decided by the researcher that the Second-Level Pupil Questionnaires (II) would include many of the same questions used in Diagnostic Test in the Second-Level Pupil Questionnaire (I) from Cycle One of the project. There were two reasons for using the same questions. It was expected that the findings from the Control Group in Cycle Two would mirror the findings from the Second-Level Pupil Questionnaire (I) in Cycle One, validating the specific topics in Organic Chemistry that have been identified as difficult. By giving the same test to assess content knowledge to the Intervention Group pupils, as all other Second-Level pupils involved in the research, this ensured that they were evaluated in the same manner as the other pupils and not precisely on the Organic Chemistry in Action! programme. The pupils in the Intervention Group pupils and the Control Group had all
covered and learned the same Organic Chemistry content from the Leaving Certificate syllabus.

While most of the content that was assessed in the Diagnostic Test remained the same, the presentation and style of the questions was altered from the Second Pupil Questionnaire (I). One question was altered appropriately from the Third-Level Diagnostic Test used in Cycle one. Analysis of the poor attempts and avoidance of some questions in Second-Level Pupil - Questionnaire (I) and Third-Level Student Questionnaire guided the researcher in clarifying the presentation and wording of some questions.

Details of the questions that were modified from the previous Diagnostic Tests and new questions included are explained in Table 4.16. Question 10 was adapted from the Leaving Certificate Higher Level examination paper. The question was taken from the 2003 paper, Question Six (parts a, b, c and d). This question was included to assess whether the experimental group could answer traditional questions.

Parts A and B of the Organic Chemistry in Action: Second-Level Pupil Questionnaire (II) and the Control Group: Second-Level Pupil Questionnaire (II) were analysed together and the results in part A and performance in the Test for Understanding (Part B) were compared. These comparisons were useful in providing the researcher with information about the effectiveness of the intervention programme with respect to pupils’ attitudes, perceptions and content knowledge of Organic Chemistry.
Table 4.16 Modifications made to the Second Level Diagnostic Test and Third Level Diagnostic Test questions (Cycle One) for use in the Pupil Questionnaires, Part B in Cycle Two.

<table>
<thead>
<tr>
<th>Question</th>
<th>Modifications made to the question style and content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapted from Q1 in the Second Level Diagnostic Test Pupil Questionnaire (I): Pentane was included in the table. Even though this is a simple straight chained alkane. A correct response in drawing the condensed and extended structure of this alkane (very similar the butane example given) will ensure that the pupils understood what was asked in the question. It may also increase their confidence in answering the rest of the question.</td>
</tr>
<tr>
<td>2</td>
<td>Adapted from Q2 in the Second Level Diagnostic Test Pupil Questionnaire (I): The layout of the question was altered. For convenience, a space was provided beside each compound for naming instead of using the letters in each box. Only four compounds in the condensed structure were given to name.</td>
</tr>
<tr>
<td>3</td>
<td>Adapted from Q2 and Q3 in the Second Level Diagnostic Test Pupil Questionnaire (I): More distinct and clearer extended structures of compounds D, E and F were used. Compound G was changed to pentane. Compound I (butanone) was added. This allowed for assessment of isomers that are not within the same functional group e.g. D and I. The pupils were asked to name four of these compounds (as shown in their extended structures).</td>
</tr>
<tr>
<td>4</td>
<td>Adapted from Q4 in the Second Level Diagnostic Test Pupil Questionnaire (I): Part a) of this question was not included in Pupil Questionnaire (I). This part of the question assesses the pupils’ ability to recognise and name the chlorine radical and methane molecule and also to indicate that the radical will attack the molecule. Part b) of the question is similar to the question in Pupil Questionnaire (I). However, the wording of the reaction parts of this question is changed to no longer suggest which species attacks and which is attacked.</td>
</tr>
<tr>
<td>5</td>
<td>Adapted from Q6 in the Second Level Diagnostic Test Pupil Questionnaire (I): A short introduction is given to the question explaining what is formed in each of the two steps. The directions for part a) and part b) are made more distinctive. In addition giving the name of the reactant, pupils are also asked to give the molecular formula of the reactant.</td>
</tr>
</tbody>
</table>
## CHAPTER FOUR

### METHODOLOGY

<table>
<thead>
<tr>
<th>6</th>
<th>Adapted from Q7 in the Second Level Diagnostic Test Pupil Questionnaire (I): The word ‘curved’ was included to describe the types of arrows to be used to show the mechanism of the reaction. The picture of a single and double headed arrow was also shown to facilitate and encourage the students’ use of these arrows in their response.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Adapted from Q8 in the Second Level Diagnostic Test Pupil Questionnaire (I): Part a) of this question was introduced due to the pupils’ confusion between functional groups involving the carbonyl and hydroxyl groups as was identified in Pupil Questionnaire (I). Having to circle the functional group will provide information on the pupils’ recognition of the functional groups within the compounds. The structure of compound F is made clearer for the pupils to understand. Alkanes were listed in the table. Compound G was added so that the pupils cannot use a process of elimination in answering and see that there may be more than one compound of a particular functional group (alcohol) and other compounds that do not fit into any of the functional groups listed (G).</td>
</tr>
<tr>
<td>8</td>
<td>Adapted from Q9 in the Second Level Diagnostic Test Pupil Questionnaire (I): The compounds used in this question were changed. Methane was compared with methanol as it has a more similar structure, and both compounds have one central carbon atom. The presentation of the question was also changed to show the structural formulae of the compounds. The structural formulae may help the pupils to recognise the polarity of the compounds.</td>
</tr>
<tr>
<td>9</td>
<td>Adapted from Q9 in Third Level Diagnostic Test Student Questionnaire: Both of the compounds used were changed. The pupils were asked to name the family of the compounds and also to identify the bond angle and molecular shape about two different carbon atoms in both hydrocarbons (propanol and propene). Both structures were represented as 2-D extended structures. 3-D diagrams were not used as these would have facilitated any pupil guessing of the bond angles.</td>
</tr>
<tr>
<td>10</td>
<td>Adapted from Leaving Certificate 2003 Higher Level paper: Question Six. Part (e) in this question was not included as it assessed the ionic addition mechanism which was already assessed in Question Four of this Test. This question was included to assess if the pupils were competent in answering a question taken from the Leaving Certificate examination paper.</td>
</tr>
</tbody>
</table>
4.8 – Limitations of the Action Research Project

4.8.1. Limitations of Cycle One

A common limitation of both of the studies (Second-Level and Third-Level) in Cycle One is that the researcher was only present for the completion of one set of the questionnaires (in the Third-Level study). The researcher was dependent on the co-operation of lecturers in the other Third-Level institutions and the Chemistry teachers in the Second-Level schools involved to ensure that the questionnaires were distributed and completed as intended (confidentially and without conferring with peers or Chemistry textbooks and notes).

In each of the questionnaires, the respondents were asked to rate their attitudes towards the teaching and learning of Organic Chemistry. The information sheet provided to participants outlined the confidentiality of the results of the studies. Anonymity was guaranteed in the presentation of any results produced and the names of the teachers, schools, lecturers and institutions involved in the study remained confidential to the researcher. However, there is still a possibility that respondents (in particular the teachers and lecturers) may give what they feel is the ‘correct’ response to questions about their teaching and teaching methods, rather than explaining their actual practices. In the same way, students and pupils may be biased in their response to rating topics as easy or difficult. For correspondence with the researcher in this cycle of the research study, the names of the teachers, lecturers and institutions involved had to be known, but remained anonymous in the analysis. This protocol however, may have limited the honesty of the feedback given in the questionnaires, as respondents often provide the researcher with an answer that they feel is the perceived ‘correct’ or ‘expected’ response.

4.8.1.1 Limitations of the Second-Level Study

Response Rate

As explained above the 100 Second-Level schools chosen to participate in the study were chosen at random. 73 of the participating schools participated by completing and returning the Chemistry Teacher Questionnaire. However, the pupils (n=276) involved in the study were only from 35 of these schools. This is just a sample size of over 6% of the total number of schools (546) teaching Leaving Certificate Chemistry in Ireland in 2009. The percentage of Higher Level pupils (224, 88.1%) in the study was slightly above the national percentage
of pupils (83.3%) participating in Higher Level Leaving Certificate Chemistry (SEC 2011). Even though the number of females involved in the study (184, 66.6%) was above the national average (55.3%) (SEC 2011), the selection of schools was representative of all schools teaching Leaving Certificate Chemistry. A larger sample size for the Second-Level Pupil Questionnaire (I) would increase the validity of the findings.

The Chemistry Teacher Questionnaire was much shorter and quicker to complete. Completion of the Second-Level Pupil Questionnaire (I) required the teachers to allot one full class period (35-40 minutes) for the completion of this questionnaire. It also required some organisation from the Chemistry teachers for distribution and collection of the consent forms. The participation in the Second-Level Pupil Questionnaire (I) was dependent on the Chemistry teacher’s interest and participation. The pupils’ participation was restricted to the Chemistry teacher’s permission and facilitation of the research and also by the permission sought from their parent / guardian in the consent forms.

As well as these limiting factors, the time of year chosen to distribute the questionnaires to Second-Level schools may also have limited the response rate and reliability. April was chosen as it was towards the end of the school year to ensure that the Organic Chemistry content of the course was covered. However, many teachers felt that distribution and completion of the questionnaires too near the end of the school year was distracting for the pupils who were preparing for their Leaving Certificate examinations, and this reduced the response rate.

**Chemistry Teacher Questionnaire**

While the same Second-Level Pupil Questionnaire (I) was distributed to all schools (n=35) and pupils (n=276) involved in the Second-Level Study, the Chemistry Teacher Questionnaire that was distributed (n=79) was not completely uniform. The Chemistry Teacher Questionnaire is included in Appendix F. The Chemistry Teacher Questionnaire was distributed in two phases (May 2010 and November 2010). 36 teachers responded in May and a further 43 responded in November. Only limited information was sought from the first 36 Chemistry teachers about the strategies they use at present when teaching Organic Chemistry. Given the researcher’s analysis of the feedback from the cohort (n=36) that responded in May 2010, it was apparent, that adding Question 10 to the Chemistry Teacher Questionnaire would allow the teachers to specify the resources that they do use when teaching Organic Chemistry.
Chemistry as well as listing the resources that would be useful (Question 9). As a result of this addition of Question 10 to the second phase of Chemistry Teacher Questionnaires that were distributed, data for this question was only therefore available from 54% (n=43) of the total participating teachers (n=79).

It would have been beneficial to learn if all of the teachers were incorporating the use of models and computational representations etc. into their teaching of Organic Chemistry. However, the feedback given about the current use of such resources was still useful in informing the researcher when designing the teaching and learning materials for the intervention programme.

**Second-Level Pupil Questionnaire (I)**

Even though guidelines were provided for teachers disseminating the Second-Level Pupil Questionnaire (I) in their classes, the researcher cannot be certain how the Second-Level Pupil Questionnaire (I) was distributed. It is hoped that the questionnaires were distributed and completed within a Chemistry class period under the teachers’ supervision. It is hoped that there was no conferring among pupils or guidance from the Chemistry teachers. Because the researcher was not present during this testing, it is only the researcher’s belief that the Pupil Questionnaires were completed individually and confidentially as indicated in the information letter to the teachers. However, it is unknown if these testing conditions were implemented as instructed. The researcher is also not sure of the time allowed by the different Chemistry teachers for the pupils to complete the questionnaires. Some teachers may have allowed more time for completion than others. This is a factor that may have contributed to the low level of pupil attempts in some questions in the Diagnostic Test.

Some of the pupil responses in Question Two (naming the organic compounds) appeared to be squashed into the space provided. It is clear that the amount of space provided for the IUPAC names of the compounds given was too short. This may have influenced the pupils’ attempt of the question and also their response. The limited space provided for each answer was inconvenient and may have led to difficulties particularly for pupils with larger handwriting.

In Questions Two and Three of the Diagnostic Test, the extended structures of some of the organic compounds differed in size. This was because some of the compounds were smaller compounds e.g. propanoic acid, butanol etc. These smaller shorter chain compounds fitted
and filled the boxes provided well. However, the larger compounds e.g. 2,3-dimethylpentane and 2,2-dimethylpropane were included at a smaller font size to fit into the boxes provided. Differing font size of some compounds may have had an effect on the pupils’ perception of the compounds. The larger and clearer compounds may have been easier to name and identify while the compounds shown in smaller font may have been less noticeable for the pupils.

The inconsistency in the font size of structural representation used may have influenced the students’ ability to recognise the compound, and so attempt questions two and three. For all other questions, the compounds shown in the questions were of the same font and font size.

The table of electronegativity values was required by the pupils to answer Question Four (electron density). However, this table of values was included on the last page of the questionnaire (page ten) while Question Four was on page six of the questionnaire. This meant that the pupils had to flick over and back the pages to check the electronegativity values of the elements involved in the compounds given. This practice in itself, may have contributed to pupil error when answering the question. It would have been more user-friendly to simply list the electronegativity values of the elements involved with the question. This would eliminate the extra task for the pupils to find the elements in the table and accurately transfer the value to the page where they were working on the question.

4.8.1.2 Limitations of the Third-Level Study

Response Rate

In total, 121 students participated in this study. These students were from 13 different courses of study in three different Third-Level institutions. However 86 (71.1%) of the participants were from the same institute – a university. The remaining 35 (28.9%) of the participants were from two Institutes of Technology. Although efforts were made to involve another university in the study, these did not materialise. If a broader and more balanced sample of students were involved in the study from more Third-Level institutions, this may have provided more valid and reliable results.

Like in the Second-Level study, the participation of the students in the Third-Level Study was to some extent pre-determined by their lecturer’s agreement to participate in the research study. This was a particular limitation, where the questionnaires were not distributed or completed in one of the universities involved due to lack of co-operation or interest in the
research study on the part of the lecturer. This non-response reduced the overall response rate for this part of the study. If it were possible or ethical to contact the students directly, it is unknown if this may have increased the numbers of participating students in the Third-Level Study. The low response rate in the Third-Level Student Questionnaire is also as a result of the poor attendance in Third-Level lectures, which are not compulsory in many institutions.

Limiting the Organic Chemistry Lecturer Questionnaire to lecturers that were teaching introductory or foundational level Organic Chemistry greatly reduced the possible number of lecturers that were eligible to participate in this phase of the study (Table 4.15). In light of the feedback received from these questionnaires, it is the researcher’s belief that it might have been valuable to gain a further insight into the teaching methods and resources used by those teaching more complex Organic Chemistry in Third-Level courses.

**Organic Chemistry Lecturer Questionnaire**

The Organic Lecturer Questionnaire was distributed by email to the lecturers. This method of distribution was decided as the researcher felt it would be most convenient for the participants and allow for immediate and convenient return of completed questionnaires. The response rate was 31%. In total 64 lecturers were contacted, and 20 completed the questionnaire. Some lecturers did not complete the questionnaire as they were not teaching Introductory Organic Chemistry, so it was not relevant to them. Of the 20 lecturers involved in the study, 12 were teaching at universities and eight were teaching at Institutes of Technology. This imbalance in the lecturers’ background may have had an effect on the results given that the total sample size of lecturers (n=20) is small.

It is unknown if a hard copy of the questionnaire may have been more convenient and suitable for the lecturers to complete. While there were some advantages to circulating the questionnaire by email, there was also a risk, that the email may have been deleted or not read when received, and may have been ignored. Even though the email was re-sent to non-respondents, it is still unknown if any non-participants even read the email or questionnaire attached. An email read receipt would have been useful in the distribution of these questionnaires to track the questionnaires and re-send those that had not been read.

Some of the participants may have preferred to write their response. Hand-written responses may have allowed the lecturers more discretion and freedom in their responses. Perhaps, a pen and paper questionnaire may have been more insightful and useful for this reason, as it
may be perceived as less formal than a questionnaire completed and saved as a Word Document.

While the students were not asked about their attendance at the Organic Chemistry lectures and tutorials, it would have been useful to ask the lecturers about their students’ attendance. It is expected that the students’ attendance at lectures would have an effect on their attitudes towards and understanding of Organic Chemistry.

**Third-Level Student Questionnaire**

In part A of the Third-Level Student Questionnaire, it would have been beneficial to ask the students to comment on their own attendance in class as well as the extent of their own reading, research and study after class. This would have provided a deeper insight into the students’ level of input and their motivation to learn and understand Organic Chemistry.

The researcher was present when the questionnaire was completed in the three university classes, and so could supervise that the questionnaires were completed confidentially and without conferring between students. These questionnaires (n=86) were distributed and completed during a lecture or tutorial in the students’ timetable. However, the researcher was not present in either Institute of Technology when questionnaires were distributed and completed. Although, guidelines were provided and given to the lecturers involved, it is only the researcher’s belief that the questionnaires were completed in a similar confidential manner; without input or help from the lecturers of the classes.

While there were some inconsistencies in the organic structures shown in the Second-Level Pupil Questionnaire (I), the molecular structures presented in this questionnaire were consistent and all of the same font and size.

However, the use of the multiple choice grid on page four of the questionnaire with questions Four, Five and Six may have added extra complication to these questions. As well as being assessed on their knowledge of naming, classification and identification of isomers, the students also have to navigate the grid of 16 compounds to find their answers. This factor needs to be considered when reviewing the students’ performance in these questions. Perhaps, it may have been easier to have clearly shown the compounds to be named and compounds to be classified separately. Such presentation of a full page of structures may have caused a mental overload for some of the students and put them off answering the questions.
4.8.2. Limitations of Cycle Two

Response Rate:

The Teacher Resource Kits, Teacher Guides and Pupil Workbooks were prepared and printed for nine teachers in nine different schools with a total of 151 pupils. Of the nine teachers that attended the Training Workshop before the intervention of the teaching materials, only six of these teachers completed the entire intervention programme resulting in feedback from 87 participating pupils (57.6%). Due to time constraints in school and other pressures, the other three teachers did not complete the intervention programme within the time-frame that was specified. However, two of these teachers decided to trial the materials with their fifth year Chemistry classes in Spring 2012. The analysis of the feedback from these teachers has not been included in this thesis. However, it will be used to inform the revision and modification of the teaching materials. A larger sample would have increased the validity of the findings in the Intervention Group.

In comparison, the response rate and participation of the control schools was much higher than the schools participating in the intervention programme. In total ten schools with a total of 160 pupils were involved in the Control Group. Completed Pupil Questionnaires were returned from 117 (73.1%) of these pupils from nine of the schools.

Teacher Feedback

As outlined in Section 4.7 above, feedback was sought from the participating teachers using several research methods. Many researchers have highlighted the possible difficulties of implementing trial intervention programmes. The *Organic Chemistry in Action!* programme was trialled with six class groups as opposed to individual pupils. In such a case the execution of the programme is very much dependent on the teachers’ implementation of the programme. For this reason the outcomes are strongly dependent on the teachers’ level of commitment to the programme and therefore the measure of the outcomes may be imprecise (Millar 2005)

Evaluating the effectiveness of the intervention programme through feedback gained from individual teachers provided the researcher with only a subjective evaluation of the materials in many cases. While several of the teachers found certain aspects of the course very beneficial, there were other cases where the individual teachers were not in agreement about the effectiveness of particular teaching resources in the programme. While the researcher
appreciates that each teacher is an individual with their own teaching styles and approaches, the sometimes diverse feedback from the six teachers highlights the limitations of the small group of teachers that trialled the intervention materials. If it were feasible and affordable to have a larger cohort of teachers trialling the materials, the findings may be more consistent.

The researcher was not involved in the implementation of the programme in the Second-Level schools. This helped to ensure that the feedback from the practitioners was un-biased; however, if the researcher had the opportunity to teach the materials, the implementation may have been more accurate and conducted as intended by the researcher. As one of the participating teachers commented, it was difficult for the participating teachers to implement and deliver the Organic Chemistry programme as intended by the author.

**Teacher Training Workshop**

A Teacher Training Workshop was held in August 2011 to prepare the participating teachers to implement the *Organic Chemistry in Action!* programme in their classrooms. The details of this workshop will be outlined in Chapter Five (Section 5.3.2). This training only involved a half-day of induction for the teachers. It was not feasible to involve the teachers in more training and preparation before the implementation phase due to the geographical location of the participating teachers, and the fact that this training was voluntary and held during the teachers’ Summer holidays. While attendance at the Teacher Training Workshop was a compulsory element of the participation in the implementation phase, the teachers were not given expenses for this. Feedback about the teaching materials from these participating teachers at the end of the implementation phase suggests that the brief Teacher Training Workshop may not have been as efficient in conveying the philosophy of the teaching materials as was hoped by the researcher. The focus on improving pupils’ interests, attitudes and understanding in Organic Chemistry may have been over-looked by the focus of the participating teachers and pupils on preparation for the Leaving Certificate examination.

Although CER findings and the design criteria for the *Organic Chemistry in Action!* programme were outlined to the teachers in the Teacher Training Workshop, some of the teachers did not see the value and importance of the alternative teaching strategies incorporated into the *Organic Chemistry in Action!* materials. If it had been possible to involve these participating teachers in a more detailed and longer preparatory training before the implementation phase, the teaching materials might have been implemented more accurately. This limitation was imposed by the timescale of the project.
Pupil Feedback

Six of the nine schools completed their participation in the implementation phase of the intervention programme. The implementation of Cycle Two is outlined in Chapter Five that follows. However, only 87 of the 151 pupils who participated in the implementation completed the Pupil Questionnaires (Table 5.6 in Chapter Five). This reduced sample size affected the significance of the results and findings presented in Chapter Eight. While interviews were carried out with the participating teachers, only one Focus Group was held with the participating pupils. No individual pupil interviews were carried out. Carrying out pupil interviews may have been useful in providing the researcher with a greater insight into the pupils’ attitudes and experience of the Organic Chemistry in Action! programme.

Limitations of curriculum development

Much of the criticism of the intervention programme from the participating teachers and pupils was related to Leaving Certificate Chemistry examination. Some pupils were frustrated by the length of the Pupil Workbooks, the time and work they involved and the investigatory activities. They expressed the need for concise notes of ‘what they need to know for the exam’. It is apparent that although this programme aimed to make Organic Chemistry more understandable and interesting for the pupils, many of the pupils inevitably were only motivated to learn what they needed to know for the Leaving Certificate examination. This focus on the examination was also evident in much of the feedback gained from the participating teachers. Many teachers expressed concern about the length of time required for the inquiry-based activities and the non-syllabus material which was described as ‘not-necessary’ in some cases. While these teachers acknowledged the importance and value of these alternative teaching methods, they also expressed concern about wanting to have the entire Chemistry course completed before the mock examinations (usually in February).

Trying to implement an activity-based, inquiry-led teaching programme in an examination-driven classroom environment may not have provided the most accurate feedback about the value of the teaching resources. However, if such teaching resources are designed with intention for use at Senior Cycle in Second-Level, they will need to be modified to accommodate the teachers’ and pupils’ focus on the examination. The implications and difficulties of curriculum initiatives and curriculum developments will be discussed in greater detail in Chapter Nine.
Chapter 5

Organic Chemistry in Action!
5.1 - Introduction

In the previous chapter, Chapter Four, the theoretical framework of the research project along with the research methods used were outlined. The methodology of Cycle One and Cycle Two of the Action Research project were explained in Sections 4.6 and 4.7 respectively. The methodology of Cycle Two outlined in Chapter Four focused on the research methods used to evaluate the intervention programme. Cycle Two also involved the design, development and implementation of an intervention programme for teaching Leaving Certificate Organic Chemistry. This intervention was called *Organic Chemistry in Action!* These stages of Cycle Two will be outlined here in Chapter Five.

Using the findings from Cycle One (which will be presented in Chapters Six and Seven), and those from CER, the intervention programme was developed. The intervention materials were designed with specific reference to the current Irish Leaving Certificate Chemistry syllabus (DES 1999a). The materials can also be used with introductory Third-Level Organic Chemistry and the proposed new Leaving Certificate Chemistry syllabus (NCCA 2011b). The teaching materials were developed using specific design criteria. A variety of teaching approaches were employed throughout the intervention programme. The materials were trialled in six Second-Level schools. Feedback from the participants, as well as comparison with a Control Group (121 pupils from nine schools) using the traditional approach, were used to evaluate the intervention.

The bottom of Figure 4.3 in Section 4.2.3 of Chapter Four illustrates Cycle Two of the project. As can be seen, this cycle had two distinct parts. Part A involved the design and development of the intervention materials while part B involved the implementation and evaluation of these materials. The planning and action stages of Cycle Two will be detailed in this chapter, along with sample material from the intervention programme.
5.2 – Design and Development of *Organic Chemistry in Action!*

### 5.2.1. Selection of content

The *Organic Chemistry in Action!* programme was designed to cover specifically the requirements and guidelines of the Organic Chemistry content in the current Leaving Certificate Chemistry syllabus (DES 1999a). The programme covers the content of sections 5.1, 5.2, 5.3, 5.5 and 5.6 of the syllabus as well as section 7: 7.1 through to 7.5. It was the researcher’s decision to omit section 5.4 (Exothermic and Endothermic Reactions) in the development of this intervention programme. The rationale for omission of this content was that the content in section 5.4 was not purely Organic Chemistry. This research study aimed to address the specific difficulties in teaching and learning Organic Chemistry. The inclusion of heat of reactions, bond energies, heat of combustion, heat of formation, law of conservation of energy and Hess’ law etc. were considered to be beyond the scope of this research project. However, the researcher does acknowledge that these topics are closely linked to the study of Organic Chemistry and facilitate the pupils’ understanding of the applications of organic compounds e.g. combustion of hydrocarbons.

From the findings in Cycle One of this Action Research project, five main areas of difficulty were identified by those teaching and learning Organic Chemistry in Ireland. There areas are:

- IUPAC Nomenclature.
- Functional groups.
- Characteristics of organic compounds.
- Reactions: types and mechanisms.
- Practical work.

The difficulties involved in teaching and learning each of these topics will be discussed in detail in Chapter Nine (Section 9.3). Each of these topics are addressed in the *Organic Chemistry in Action!* programme, with reference to their depth of treatment in the Leaving Certificate Chemistry syllabus.

The mandatory experiments in sections 5 and 7 of the Leaving Certificate Chemistry syllabus were outlined in Chapter Two (Section 2.3.2). All seven mandatory experiments from section 7 of the syllabus were included in the *Organic Chemistry in Action!* programme along with mandatory experiment 5.2 (Preparation and properties of ethyne) from section 5 of the syllabus.
Action Research by its nature is collaborative (Bodner et al. 1999). For this reason, during the early stages of the development of the materials, a discussion group was held to share the ideas for the development of the programme. The annual conference of Irish Science Teachers Association (ISTA) was chosen as a suitable opportunity to meet with experienced and practising Leaving Certificate Chemistry teachers. This workshop was held on the second day of the conference (Saturday 9 April 2011) in Limerick Institute of Technology campus in Thurles, Tipperary. See Appendix I for a copy of the hand-out given to participating teachers in the two-hour workshop and discussion. 14 teachers attended the workshop and contributed to the discussion. This began with an hour-long workshop with practising Leaving Certificate Chemistry teachers. The background and philosophy of the intervention was outlined. In this workshop ideas and examples of proposed activities for the intervention programme were shared with the teachers in an activity-based workshop. The teachers were asked to fill out a short questionnaire to allow the researcher to gain some feedback from them. This questionnaire is also included in Appendix I.

Most of the teachers who participated in this exploratory workshop were already using molecular modelling in their teaching. However, only five of the teachers used the models in every Organic Chemistry class. Three teachers used the models only at the beginning of their teaching of Organic Chemistry. However, during the exploratory workshop, these teachers learned the value of integrating molecular models into practical classes and throughout the teaching of Organic Chemistry. Half (7) of the teachers did not have sufficient model kits in their schools for all the pupils to use. In such cases, the teachers explained that the molecular models were shared among groups of pupils or used by the teacher for demonstration purposes only. 11 of the 14 teachers already used I.T. resources in their teaching of Organic Chemistry. However, only 5 of these teachers used I.T. resources every day while the others used it less frequently. In most cases, the teachers explained that, where possible, they allow the pupils to carry out the mandatory experiments themselves.

However, the main issues raised by the teachers were the time limitations of the practical work and the lack of equipment which resulted in large groups of pupils working together or teachers demonstrating the experiments. Four of the teachers expressed their concern about the safety of the mandatory experiments and the use of banned oxidising agents (DES 2011a). The banning of dichromate for use in Second-Level schools in Ireland has already been discussed in Chapter Two (Section 2.3.3). While the alternative laboratory methods outlined
in the proposed *Organic Chemistry in Action!* programme were welcomed by most teachers at the workshop, some were not in support of the alternative set-ups, oxidations and micro-scale alternatives. However, the majority did agree with the alternative methods and were very positive in their feedback and responses to the demonstrations shown. The teachers explained that the biggest challenge when teaching Organic Chemistry is the length of the curriculum and the time constraints of the syllabus. The topics identified as difficult in Cycle One of this project were shared with the teachers. All of the teachers agreed with the particular topics identified as difficult in Organic Chemistry. This feedback confirms that the research carried out is representative of many Leaving Certificate Chemistry classrooms in Ireland. Overall, all of the teachers were very positive about the integrated use of model building, animations and using a context-based approach for teaching Leaving Certificate Organic Chemistry.

### 5.2.2. Design Criteria

Through this discussion of the design criteria, some references will be made to lessons and units in the intervention programme. The *Organic Chemistry in Action!* programme is made up of eight consecutive units. The sequence and structure of the programme will be outlined in detail in section 5.2.3 that follows.

After the selection of the content for the intervention programme, it was necessary to outline and define specific design criteria to facilitate the structuring of the lessons within the programme. A similar approach was taken by Harsch and Heinmann (1998) cited by Barke *et al.* (2012) by outlining their key principles in the PIN-Concept for teaching Organic Chemistry in Germany:

- Criterion of concreteness.
- Criterion of connection.
- Criterion of constructive development.
- Criterion of limitation.
- Criterion of intelligent consolidation.
- Criterion of supporting cognitive skills.
- Criterion of scientific enculturation. *(Barke *et al*. 2012).*

These criteria outlined by Barke *et al* (2012) are very similar to the criteria chosen independently in this study.
Bodner (1992) and Reid (2008) outlined four clear guidelines that should be considered when designing a curriculum:

1. Learners need to be able to apply the knowledge they have learned to their lives. The content needs to be relevant.

2. Learners need to see an overview of how the related topics come together.

3. Sequencing of topics needs to make sense to the learner. The connections between topics needs to be made clear.

4. Less content to allow for more understanding.

5. The focus should be on the learner and not the teacher.

The learners’ understanding can be enhanced and improved by pre-learning; lowering working memory demand can be achieved by changes in presentation and deliberately linking new material to older (Reid 2008). These recommendations by Bodner (1992) and Reid (2008) were incorporated and considered in the development of the specific design criteria for the Organic Chemistry in Action! programme. The ten key design criteria chosen were informed by the relevant findings in CER and developed with consideration of the specific requirements of the programme. Teaching and learning strategies that were detailed in section Chapter Three (Section 3.5) were integrated into the design criteria with a specific focus on their relevance to the areas of difficulty that were identified by teachers and pupils in Cycle One of the project.

The ten design criteria for the Organic Chemistry in Action! programme are illustrated in Figure 5.1. Each of these criteria will now be explained in detail through the use of relevant examples from the intervention materials.
1. **Spiral Curriculum and Drip-feed introduction of topics**

Johnstone (2006) recommended beginning at one corner of the triangle of Chemistry (Figure 3.2), and then moving along one side towards another corner before moving towards the centre of the triangle. This drip-feeding approach to teaching can facilitate the learners’ level of understanding of each aspect of Chemistry, rather than if all are introduced at once.

This spiral and drip-feed approach has also been recommended by Reid (2008), who suggested the following guidelines to reduce the load on the Working Memory Space: change the teaching order; modify the speed and sequencing of lessons; and break down complex areas to facilitate the human psychology of the Information Processing Model. This can be achieved by presenting information in a step-by-step manner to the learner. This ‘drip-feed’ approach will facilitate the pupils’ understanding of topics and reduce the problem of overload, as is often the case with Organic Chemistry.
Figure 5.2 illustrates how the spiral curriculum is structured. Figure 5.2(a) illustrates how different topics are introduced in each unit on a need to know basis. Figure 5.2(b) illustrates how each topic is then revisited and learned in more depth in a step by step spiral manner. The topic illustrated is Alkanes. Butane and methane are introduced in Unit 1 as hydrocarbons and as fuels. Unit 2 covers the three-dimensional structure of alkanes and alkanes as a homologous series, IUPAC nomenclature is also introduced with isomerism. Isomerism is revised in Unit 3 from the perspective of lowering the octane rating of fuels, while in Unit 4, the chemistry of the alkanes is revisited to understand the type of reactions they will undergo. This spiral continues throughout the eight units of the *Organic Chemistry in Action!* programme. In Unit 6, the formation of chloroalkanes is introduced and the mechanism of this reaction.

Figure 5.2 only provides an illustration of the spiralling introduction of one of the topics in the programme. Topics W, X, Y and Z etc. would be developed and spiralled in the same manner. Table 5.1 which also follows provides a summary of how the different topics in the Leaving Certificate Organic Chemistry syllabus are taught in a drip-fed manner and revisited throughout the eight units of the *Organic Chemistry in Action!* programme.

*Figure 5.2a* Drip feed introduction of different topics in each progressing unit (aerial view)

*Figure 5.2b* Spiralling development of Alkanes through units 1 to 3.

*Adapted from (Bulte et al. 2006)*

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Table 5.1 Summary of the Organic Chemistry in Action Spiral Curriculum

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<thead>
<tr>
<th></th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
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</tbody>
</table>

2. **Linked Learning Outcomes and Assessment**

Linking the learning outcomes with the assessment types used in the intervention programme is very important for both the pupils and the teachers. The learning outcomes for each unit are outlined at the beginning of the unit in the Teacher Guide. Learning outcomes are also included at the beginning of each lesson, along with the appropriate methods of assessment for each. By linking the assessment with the proposed learning outcomes for each lesson, it is easy for the teachers to evaluate what the pupils have learned in each lesson. Different types of formative assessment are used throughout the *Organic Chemistry in Action* programme: activities on model building, practical investigations, class discussions, worksheets, card-game activities, group classroom assessments and online assessment tools to appraise pupil learning. It is important that such formative assessment techniques are used and incorporated
into the teaching of Organic Chemistry. These help to provide the teacher with immediate feedback, informing them of whether the new concept has been clearly understood or not. The importance of formative assessment will be discussed below (criterion no. 3) and also with reference to the early identification of possible misconceptions (criterion no. 9).

The learning outcomes are also included at the beginning of each lesson in the Pupil Workbooks. It is important that the pupils are aware of what they will learn or are expected to know by the end of each lesson. This facilitates the pupils’ preparation for the lesson and development of concepts and connections with their previous knowledge. These learning outcomes are listed in the Pupil Workbook under the heading ‘In this lesson you will’ at the beginning of each lesson. Figure 5.3 provides an illustration of this.

![Figure 5.3 Illustration of how the learning outcomes are illustrated in the Pupil Workbook.](Source: Unit 3, Lesson 1)

**3. Formative and Summative assessment.**

Given anecdotal evidence from conversations with teachers, that there is a lack of formative assessment tools available for Organic Chemistry, such tools were designed and included in the teaching materials, and linked as explained above to the learning outcomes. The teachers were also provided with a table outlining the Leaving Certificate examination questions that the pupils should be able to complete after each unit of the programme. These were useful for summative assessment. It was necessary to include this link to the examination papers, as performance in the examination is the key motivation for many teachers and pupils at Second-Level.
However, to ensure the content of the programme was understood as well as learned in preparation for the examination, formative methods of assessment played a key role in every lesson of the programme. The formative assessment tools outlined below were valuable to the teachers in providing them with almost immediate feedback of whether the pupils had understood the content of the lesson or not.

Examples of novel formative assessment tools designed specifically for the Organic Chemistry in Action! programme include:

- Game cards.
- What have I learned?
- Classroom response cubes.
- Homework Assignments.
- Classification Charts.
- Check Lists.

Six different card games were designed for assessment and learning purposes. The game cards were particularly useful for assessment of reactions and reaction mechanisms, which were specifically identified as one of the key areas of difficulty in Cycle One of the project. Figure 5.4 provides an example of a ‘complete’ set from a card game for the assessment of Preparation of Esters.

![Figure 5.4 Complete set of cards: Preparation of esters.](Source: Unit 8, Lesson 4)

The rules of each of the card games were outlined in the Teacher Guide. ‘What have I learned?’ was a fill-in-the-blanks summary activity at the end of each lesson. This was useful to check if the pupils had achieved the learning outcomes. Homework assignments and exercises were provided for every lesson in the programme. These assignments assessed the pupils’ understanding and application of the concepts learned. Classification charts were also
included at the end of some of the units. Classification charts are useful in facilitating the pupils’ development of a ‘web’ of concepts and related concepts. The inclusion of these charts complemented the spiral structure of the programme; as the pupils completed each consecutive unit, they were able to extend their classification charts as the new concepts were introduced by developing and extending the pupils’ prior knowledge. Check lists were also used at the end of each unit to check for understanding and allow the pupils to self-assess their competency in each topic learned in the unit.

The classroom response cubes were cubes with four different coloured sides and two sides marked with T and F (True and False). The PowerPoint presentation for most of the lessons included multiple-choice-type assessment questions at the end of the lesson. The optional answers to the multiple choice questions were colour coded. The classroom response cubes enable the pupils to share their answer with the teacher immediately. The array of colours facing the teacher immediately provides the teacher with feedback from the pupils of whether the concept is understood or not. This classroom response tool enables the teacher to see each of the pupils’ responses, while the pupils are not looking at each other’s responses.

4. **Facilitating Cognitive Development.**

As explained in Chapter Three (Section 3.4.2) many of the fifth and sixth year pupils are still only at the concrete stage of cognitive development (Childs and Sheehan 2010). For this reason, it is difficult for them to comprehend abstract concepts requiring formal cognitive operations. The use of models is integrated into many of the lessons in the *Organic Chemistry in Action!* programme. The use of models provides a concrete and practical approach to understanding abstract concepts. Many different types of models were included in the *Organic Chemistry in Action!* teaching resources. Molecular models facilitate the pupils understanding of molecules: their three-dimensional shape and structure, their bond angles, isomerism and their properties. Molecular models provide the concrete learner with a more tangible understanding than could be explained through two-dimensional diagrams, which are often incorrectly perceived as ‘flat’ molecules. Models allow the pupils to visualise how molecules fill a certain shape in space, and also allow them to ‘experiment’ with molecules.

As well as commercial model kits, plastic building blocks, balloons, straws, cocktail sticks, plasticine etc. may also be used by the pupils to make three-dimensional models of the organic
compounds studied. The use of models helps to bridge the gap from the concrete level of cognitive ability to the formal operational stage necessary to understand reaction mechanisms.

As well as the specifically designed commercial Molymod® molecular modelling kits that were included in the teaching materials for this programme, other resources were also included. These included coloured paperclips to facilitate the concept of polymerisation, recognition of monomers etc. and plastic building blocks to introduce the concept of isomerism and limiting reagents. Figure 5.5 below illustrates the use of polystyrene spheres, included in the resource materials, to facilitate the introduction of the concept of an homologous series.

![Figure 5.5 A concrete representation of an homologous series.](image)

(Source: Unit 2, Lesson 1)

5. **Guided-Inquiry Learning.**

The main principles of the PIN-Concept for teaching Organic Chemistry was learning through inquiry and discovery (Barke et al. 2012). This approach was also integrated into the Organic Chemistry in Action! programme. Rather than simply providing all of the definitions for the pupils to learn or providing ‘recipe-style’ instructions for practical work, information was provided for the teachers to facilitate their guidance of the pupils. Prompting questions and points for discussion were included in the Pupil Workbooks also to initiate their thinking and help to direct their thoughts.

One example of where the guided-inquiry learning approach was used in the programme was in the learning of general formulas for hydrocarbons. Rather than providing the pupils with the general formula $C_nH_{2n+2}$ for alkanes, the pupils were guided to deduce this formula themselves. Through calculating and graphing the relative molecular masses of the consecutive alkanes, the pupils inferred that the differing unit of structure was CH$_2$. By
writing the molecular formulae of the first ten alkanes, the pupils were able to deduce the difference between each formula and hence ‘crack the code’ to recognise the general formula. This guided-inquiry approach was integrated into many of the lessons and activities in the intervention programme e.g. pupils deducing and exploring reaction mechanisms in a step-by-step manner rather than being given a summary of the four-step procedure. Through guided-inquiry, the pupils learn why each step of a mechanism is necessary. The aim is to promote deeper understanding through the pupils’ active involvement in learning rather than just rote-learning of the final idea.

6. **Visual Aids.**

Taagepera and Noori (2000) have looked at the patterns of how learners think in Chemistry. Although their study focused more closely on predicting electron densities in Organic Chemistry, the approach of mapping the pattern of how students think could allow for a broader hierarchy of topics to be developed. This would facilitate the learners’ interpretation of the multi-dimensional nature of Chemistry. Taagepera and Noori (2000) provided the comparison that an understanding of addition may be necessary before multiplication can be introduced in the Mathematics classroom. In the same manner, the use of visual aids may facilitate the learners’ ability to interpret the sub-microscopic apex of Johnstone’s triangle (Johnstone 1991). Having understood that the macroscopic substance is made up of microscopic molecules, the learner can then progress to understanding the symbolic and representational apex. As well as the use of molecular modelling kits (e.g. Molymod®) as outlined above, many studies have shown that computerised representations and animations of molecular models and reactions assists the learners’ understanding and ability to visualise electronegativity differences, bond polarities, partial charges, electron distribution as well as molecular shape and bond angles (Jones 2001, Fleming et al. 2000). Molecular-level animations can be effective learning resources, when they are designed and presented to encourage students to focus on the intended ‘key features’, and to avoid generating or reinforcing misconceptions (Tasker and Dalton 2006).

Ball and stick animations and three-dimensional molecular models are useful to illustrate the bond angles and to define the molecular shape. In comparison, the space filling animations are useful for space-filling representations. Visual aids are a key element when teaching the structure and bonding of molecules. As explained by Johnstone (2000b), it is easy for an expert to understand what chemical symbols represent. However, the two-dimensional
extended structural representation of a molecule may just be letters, numbers and lines without any physical meaning to the learner (Bodner and Domin 2000). Bodner and Domin (2000) found that learners who do poorly in Organic Chemistry cannot understand that letters, numbers and lines can have a physical meaning and that they represent and symbolise molecules. Organic Chemistry can lead to Memory Overload due to the large number of structures and formulae presented to the pupils.

For these reasons, relevant animations and video links are included in the *Organic Chemistry in Action!* PowerPoints, which were prepared in colour for all of the lessons. These facilitate the pupils’ ability to visualise and understand systems (e.g. fractional distillation), processes (e.g. HPLC, GC etc.) and mechanisms (free radical substitution), which have previously been identified as areas of difficulty when taught in the traditional theoretical manner. Appropriate presentation of new information is necessary so that it can be accurately perceived by the pupils, allowing them to develop a better understanding. Using a combination of visual aids facilitates the pupils’ development from concrete to abstract understanding of concepts.

7. **Integration of applications-led and context-based Chemistry.**

The spiralling structure of the *Organic Chemistry in Action!* programme has been outlined above. The order and sequencing of topics when teaching Chemistry should be determined by the learners’ needs and what is perceived by them to be relevant to their personal context and lifestyle (Reid 2009). In an applications-led curriculum, the destination is the same as the traditional curriculum but the route to the destination is totally different. This intervention programme is developed as an applications-led Organic Chemistry programme.

Each unit is firstly introduced to the pupils through a ‘Chemistry Chronicle’. Figure 5.6 shows an example of one of these Chemistry Chronicles. This Organic Chemistry storyline introduces each topic to the pupils in a real-life context in order to gain interest and stimulation for further learning. Introducing content that has social meaning and value to the learners assists their appreciation of the wonder and excitement of Chemistry. Reid (2000) has specified five dimensions that can improve the learners’ attitudes to studying Chemistry if incorporated in the teaching: These were the historical dimension, social impact, industrial implications, economic implications and socio-moral implications. These dimensions are part of the eight ‘Chemistry Chronicles’ introducing each unit. The approach to teaching Chemistry advocated by Reid (2000) involves the presentation of a problem, discussing the
problem and then unfolding the necessary Chemistry as it makes sense in the context of the application. Such problems included in this programme are the depletion of the ozone layer, development of anaesthetics, chemical pollutants, energy of fuels etc. These ‘real-life’ problems are used to define the Chemistry to be explored and then provide a framework for the traditional teaching that follows. This approach is similar to that used in context-based curricula discussed already e.g. SAC and ChiK.

**Figure 5.6. Example of a two-page Chemistry Chronicle – Everything Organic is not Organic**

(Source: Unit 1)

The titles of the eight Chemistry Chronicles in the *Organic Chemistry in Action!* programme are:

- Everything Organic is not Organic?
- From Grass to Gas.
- Fuel for the Future.
- A Radical Reaction!
- Making Sense of Scents.
- Polymers - In us and around us.
- Letting bugs take the strain.
- The Wonder Drug.
8. Integration of Practical Work.

Johnstone (1997, 2006) and many more have acknowledged the value of pre- and post-laboratory sessions. The pre-laboratory session provides a revision of theory and skills so that learners will be able to perceive the new information presented in the laboratory session through feedback from their Long Term Memory. Pre-laboratory exercises should include revision of theory, re-acquaintance with skills, planning the experiment to some extent and discussion about partition of labour etc. (Johnstone 1997). If the Long Term Memory is appropriately prepared before the laboratory session, the learners are then in a better position to distinguish the ‘signal from the noise’ in the laboratory and therefore, by making more space available in the Working Memory Space, to consider what they are doing at a microscopic level. The post-laboratory session is useful to ensure that the new information is anchored and understood clearly in the Long Term Memory.

An example of a pre-laboratory session in the Organic Chemistry in Action! programme is the use of molecular models, beginning with the reactants and changing the models to form the products to be formed. This approach is useful in the oxidation reactions, to allow the pupils to see the ‘removal of hydrogen atoms’ and ‘addition of oxygen atoms’ as the model of ethanol is changed into ethanoic acid. Such an activity allows the pupils to see and understand at a molecular level the oxidation reaction which happens during the reflux and distillation process (macroscopic level). The macroscopic skills are also prepared in some of the pre-laboratory sessions in this intervention programme e.g. pupils practice handling and setting up the apparatus for reflux and distillation. Teacher demonstrations are also included to ensure the pupils understand the principle of these laboratory techniques at a microscopic level.

As already discussed, there is a lack of evidence supporting the idea that traditional laboratories are effective in promoting meaningful learning (Greenbowe and Schroeder, 2008). For this reason, many of the practical activities in the Organic Chemistry in Action! programme are more open-ended activities. Rather than presenting the pupils with a “plethora of instructions” (Johnstone 1981) for a recipe-style practical experience, the pupils are allowed to work in a group to discuss a suitable method for investigation, list and prepare the necessary apparatus and then plan thier procedure before beginning their investigation. This approach gives the pupils more ownership of the investigation and allows them to develop as more independent learners.
Eight mandatory experiments from the Leaving Certificate Chemistry syllabus are included in the Organic Chemistry in Action! programme. Traditionally these experiments require a double class of 70-80 minutes to complete. The use of micro-scale apparatus is advised in the Organic Chemistry in Action! programme to reduce the time required for the experiments involving preparations, in particular those requiring refluxing and distillation set-ups (preparation of ethanal, ethanoic acid and soap). The advantages of micro-scale apparatus are numerous. They save time in preparation and reaction time; using less chemicals means there is less chemical waste to be disposed; and it is also safer for pupils to carry out the experiments themselves. This in turn allows for greater evaluation, discussion and communication about the reaction and the preparation. Alternative preparations of the ethene and ethyne gases are also included in the teaching materials for this programme. In response to the recent ban of sodium dichromate and potassium dichromate for use in Second-Level schools in Ireland (DES 2011a), other alternative methods for the preparation of ethanal and ethanoic acid are outlined in the Teacher Guide for this programme. Potassium permanganate and hydrogen peroxide are recommended as alternative oxidising agents.

The traditional methods may also be modified if the necessary laboratory equipment is not available for all pupils. Figure 5.7 shows the set-up for an alternative preparation and testing of ethyne gas using the cut-off ends of plastic pipettes as reaction vessels and a petri dish. Details of alternative preparation techniques and micro-scale preparations are included in the Teacher Guide. Quick and easy teacher demonstrations are used in many of the lessons. These are useful to probe pupil interest in a topic as well as for facilitating understanding.

![Figure 5.7 Alternative micro-scale preparation of ethyne gas and testing of its properties.](Source: Unit 2, Lesson 5)
Opportune teacher demonstrations, micro-scale preparations and alternative pupil experiments facilitate the integration of practical work with theory even in single class periods.

9. **Identify and Address Misconceptions.**

At the beginning of each lesson, possible learning difficulties (as identified in CER) are listed in the Teacher Guide. Many of the introductory activities in the lessons are useful to identify any previous misconceptions that the pupils may have before the concept is developed. Specific activities address these misconceptions, allowing pupils to discuss the wrong answers or explanations. Guidelines are provided for the teachers to re-explain the topic for correct understanding. An example is where the shape of alkanes is introduced. The teacher may firstly use balloons to illustrate the tetrahedral shape dictated by the central carbon atom.

The formative assessment tools that have been discussed above are useful in identifying pupil misconceptions while the topic is being introduced and the pupils are developing the new concept. Early identification of possible misconceptions is important to ensure that the pupils develop a solid foundational understanding. As well as addressing possible misunderstanding in Organic Chemistry, there are many exercises and assessments included in the Pupil Workbook to check their understanding of concepts from other areas of General Chemistry that are applicable to Organic Chemistry. This has already been discussed in Chapter Three (Section 3.4.3). For example the concepts of intermolecular forces, bonding and polarity need to be understood before pupils can learn to predict and understand the physical properties of organic compounds. Figure 5.8 below provides an example of how the pupils’ understanding of the concept of boiling can be assessed.

![Figure 5.8 Checking pupils’ understanding of what happens when something boils.](Source: Unit 3, Lesson 1)
10. Variety of teaching approaches.

The design criteria that have been outlined already illustrate the variety and diversity of teaching approaches integrated in the design of the *Organic Chemistry in Action!* programme. Through the use of the teaching resources provided for the teachers and pupils and also the lesson PowerPoints, incorporating videos and animations, there is opportunity for the teachers to use a variety of teaching methods within each lesson. The modified micro-scale practical activities and teacher demonstrations facilitate the integration of practical work in most of the lessons. The combined use of the assessment games and assignments make the lessons more interesting and enjoyable for the pupils.

Though many of these ideas described above are not entirely original, their combined use in a carefully structured teaching and learning package in *Organic Chemistry in Action!* is a unique feature of this programme, integrating findings from CER with the content of the prescribed Leaving Certificate Chemistry syllabus.

5.2.3. Sequence and Structure of the *Organic Chemistry in Action!* programme

As well as outlining the specific design criteria for the intervention programme, the structure of the content to be included had also to be considered. The spiral approach adapted and the drip-feed introduction of topics has been outlined and illustrated above (Figure 5.1 and Table 5.1). The programme was designed to specifically include all of the Organic Chemistry content of the Leaving Certificate Chemistry syllabus.

The total number of class periods (54 specified) is just less than the 57 class periods that are recommended in the syllabus guidelines for the sections covered (DES 1999a). This allows for three class periods to be used at the teacher’s discretion e.g. if a particular topic requires more class time, or for lost time. The number of lessons in each of the eight units of the programme is shown in Table 5.2. Given the standard school timetable of five periods per week (three singles and a double); this programme should take 11 and a half weeks to complete. However, the researcher did appreciate that the programme may take longer to complete as a result of everyday class interruptions in schools such as school sporting events, career days, retreats etc.
Table 5.2 Summary outline of the Organic Chemistry in Action! programme, with relevance to the Higher Level Leaving Certificate Chemistry syllabus.

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<th>Unit</th>
<th>Number of class periods required</th>
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<td>9</td>
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<td>Section 5 (Fuels) (except 5.4), all section 7 (Organic).</td>
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</table>

Table 5.3 provides an example of how the eight unit programme fits into five periods in a typical school timetable over 11 weeks. This would, of course have to be modified if a school had a different pattern of weekly class periods.

Table 5.3 Breakdown of eight units over an 11 week programme.

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<td>Unit 8</td>
<td>Unit 8</td>
</tr>
<tr>
<td>11</td>
<td>Unit 8</td>
<td>Unit 8</td>
<td>Unit 8</td>
<td>Pupil Questionnaire</td>
</tr>
</tbody>
</table>

Note: The Pupil Questionnaire used for evaluation of the Organic Chemistry in Action! Programme has been outlined in section 4.7 of Chapter Four. See Appendix H.

Table 5.4 that follows contains a detailed breakdown of the content covered in each of the eight units in the programme. It shows the topics covered and the number of lessons per unit. It also highlights the sections of the Leaving Certificate syllabus that are addressed in each unit and where the mandatory experiments are included.
### Table 5.4 Outline of the Organic Chemistry in Action! programme with reference to the Leaving Certificate syllabus content.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Unit Outline</th>
<th>Number of lessons</th>
<th>Syllabus content</th>
<th>Mandatory experiments</th>
</tr>
</thead>
</table>
| 1:   | **Every Living Thing** | − Recognise the presence of Carbon in all living things.  
− Identify Organic compounds and understand what they are.  
− Extract and separate chlorophyll from leaves.  
− Introduce the use of hydrocarbons as fuels. | 5 | 5.1 5.2 5.3 7.3(d) 7.4 7.5 | 7.7: Separation of mixtures using Paper Chromatography. |
| 2:   | **Chemistry in Chains** | − 3-D shape and structure of Alkanes, Alkenes and Alkynes.  
− Nomenclature and Structural formulae of Alkanes, Alkenes and Alkynes.  
− Isomerisation of Alkanes and Alkenes.  
− Physical properties (BP, MP) of Alkanes.  
− Polymerisation of Alkenes.  
− Classification of aromatic and aliphatic hydrocarbons.  
− Structure of Benzene. | 7 | 3.4 5.2 7.1 7.2 7.3(a) 5.3 | 5.2: Preparation and Properties of ethyne. |
| 3:   | **There’s no fuel like an old fuel** | − Oil Refining  
− Fractional distillation and uses of the fractions – fuels and petrochemicals.  
− Octane Number.  
− *Internal combustion engine  
− Auto-ignition and Knocking.  
− *Improving Octane Number.  
− Benzene – Physical properties and structure.  
− Renewable fuels- Hydrogen and Biofuels. | 7 | 5.1 5.3 5.5* 5.6 7.2 | |
| 4:   | **Changing the Chains** | − Solubility and physical state of Alkanes, Alkenes and Alkynes.  
− * Chloroalkanes.  
− *Substitution mechanism of Alkanes.  
− Addition Reactions of Alkenes – Hydration, formation of alcohols.  
− Alcohols: nomenclature, structure, physical properties, combustion.  
− Reaction as acids: ethanol reaction with sodium.  
− Stability of the benzene aromatic structure. | 7 | 5.2 5.3 7.1* 7.2 7.3(a) 7.3(b)* 7.3(e) | |
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Section</th>
<th>Summary</th>
</tr>
</thead>
</table>
| 5: Naturally Organic | - Structure and reactivity of aromatic compounds: benzene and esters.  
- Extraction techniques (distillation and solvent)  
- Separation Techniques (Chromatography and Recrystallisation)  
- Analytical Techniques (instrumentation *UV and IR)  
- Introduction of new functional groups: carbonyl compounds. | 8  
7.2  
7.4  
7.5* |
- Addition / removal of functional groups.  
- Elimination Reaction: dehydration of alcohols.  
- Addition Reactions – addition of halogens and HCl with ethane.  
- *Mechanism of ionic addition. | 5  
7.2  
7.3 (a)*  
7.3 (c)  
7.3 (f) |
| 7: Oxygenated Hydrocarbons | - Classification of alcohols.  
- Chemistry of Carbonyl group.  
- Aldehydes: formation, nomenclature, structure, physical properties.  
- *Ketones: formation, nomenclature, structure, physical properties.  
- *Calculation of percentage yield. | 6  
1.5  
2.6  
3.5  
7.1  
7.2*  
7.3(d)* |
| 8: Further oxidation | - Complete oxidation of primary and secondary alcohols.  
- Carboxylic acids: formation, nomenclature, structure, physical properties.  
- *Calculation of percentage yield.  
- *Reduction of carbonyl compounds.  
- *Substitution Reaction – formation of esters.  
- *Esters: formation, nomenclature, structure, physical properties.  
- *Substitution Reaction – Base hydrolysis  
- Formation of Soap. | 9  
4.2  
3.5  
7.2*  
7.3 (b)*  
7.3 (d)*  
7.3 (e)* |

Note: The syllabus content written in italics refers to content that is revised in the programme and not directly Organic Chemistry content.  
*The unit outline and syllabus content marked with the red asterix represents material that is in the Higher Level syllabus only.
5.2.4. *Organic Chemistry in Action! Materials*

This logo shown in Figure 5.9 above was used to brand and label all of the resource materials that were designed and developed. The development of the materials was partly supported and funded by *Merck Sharp and Dohme* in Ballydine, Co. Tipperary and *Eli Lilly* in Kinsale, Co. Cork. For these reasons, their company logos were included on all of the materials along with the University of Limerick logo. The researcher was funded by the Irish Research Council for Science Engineering and Technology (IRCSET).

*Figure 5.9 Organic Chemistry in Action! Logo*

The teachers participating in the trial implementation of the *Organic Chemistry in Action!* programme were provided with printed Pupil Workbooks for all pupils in their class, a Teacher Guidebook, PowerPoint presentations for all lessons and a Teaching Resource Kit of necessary teaching materials. The details of these materials are each outlined below. See Appendix J for PDF copies of the Teacher Guidebook, and Pupil Workbooks I and II. Due to restricted funds available, the printed Teacher Guide and Pupil Workbooks disseminated to the participating schools had to be printed in greyscale.

5.2.4.1. *Teacher Guidebook*

The Teacher Guidebook contained the learning outcomes and overall aims of each unit. For each lesson, the learning outcomes were listed along with an assessment for each outcome. Any possible learning difficulties or pupil misconceptions that may arise in the lesson were highlighted to the teacher. These were any known difficulties that have already been identified by CER and in Cycle One of this research project. Details of all activities, demonstrations and experiments for each lesson were provided (time required, necessary preparation before class, chemicals and apparatus required and appropriate safety precautions). Details and answers for the pupil activities were included in the lesson outline.
as well as further optional and modified activities that may be used as part of the lesson or for future lessons. The sources of any activities and resources used were listed at the end of each lesson for the teachers’ own discretion. A flowchart was illustrated on the first page of each lesson in the Teacher Guidebook. This provided a summary and sequence of the activities and topics included in the lesson. It also highlighted any preparatory work that needed to be carried out before the lesson e.g. preparing solutions or apparatus.

The teacher was informed at the beginning of each lesson how the content fitted into the spiral curriculum; reminders were included of previously developed concepts that the pupils would have to re-apply in the lesson; and references were made to future lessons where the content would be extended and further developed. It was the researcher’s intention that this would facilitate the teachers’ teaching of the lesson as well as the pupils’ overall understanding. The relevance and integration of the PowerPoint slides were outlined in each lesson. The material that was related to the Higher Level syllabus only was distinguished by use of a continuous grey bar on the margin.

5.2.4.2. Pupil Workbooks

There were two Pupil Workbooks. Pupil Workbook I includes the content for units One to Four, and Pupil Workbook II includes the content for units Five to Eight. At the beginning of each unit, a Chemistry Chronicle is included in the Pupil Workbook. This, as explained already, was a context-based storyline related to the content of the unit. The learning outcomes for the unit are then listed.

Much of the Pupil Workbooks were composed of skeletal notes which were completed by the pupils during the lessons. Results, findings and conclusions from the experiments and activities were also recorded in the Pupil Workbook. This Pupil Workbook contained all of the content necessary for the pupils to know in Organic Chemistry for the Leaving Certificate. The programme did not require the use of a textbook, but a textbook can be used as supplementary reading. The mandatory experiments were integrated into the Pupil Workbook with details of the procedures, space for recording results and observations as well as follow-up questions to assess pupil understanding. However, these experiments still had to be written up separately in the pupils’ mandatory laboratory notebooks.
The Pupil Workbooks were presented in such a way as to facilitate the pupils’ understanding, and to make them interesting. Special elements included differently designed text boxes to highlight Interesting Insights (applications of Chemistry), Safety Notes (before every practical activity) and Important Boxes (definitions that need to be learned). The Higher Level material was identified in the same way as in the Teacher Guidebook with a bolded grey line along the outside of the page. Other symbols were used to highlight new vocabulary as it was introduced, teacher demonstrations and times for discussion. These elements are illustrated in Figure 5.10 that follows.

![Figure 5.10 Symbols and elements of the Pupil Workbook.](image)
5.2.4.3. Teaching Resource Box

Participating teachers were provided with all necessary teaching materials and resources for the lessons. Figure 5.11 shows the contents of the Teaching Resource Box.

![Contents of the Teaching Resource Box](image)

*Figure 5.11 Contents of the Teaching Resource Box.*

The uses of the main contents of the box are outlined in Table 5.5 that follows. While some resources were particularly important for certain lessons, many of the resources e.g. Pupil Model Kits, Teacher Model Kits, Classroom Response Cubes and the Game cards were used in almost all of the lessons. Two types of molecular modelling kits were provided; one for the teacher for use in demonstrations of orbitals and another per every two pupils in the class. The Teacher Orbital Model Kits were commercial kits sourced from Molymod®. However, the Pupil Model Kits were custom-made with the appropriate number and types of atoms, bond linkages and orbitals necessary for the activities included in the Pupil Workbooks. These model kits were ball and stick type. They contained both four-holed and five-holed carbon atoms, oxygen atoms, halogen atoms and flexible bond linkages. These sets also included p orbitals.

The memory stick contained PowerPoint presentations which were specifically designed to address the teachers’ and learners’ needs for each lesson in the programme. These provided a strong visual aid for the pupils’ learning and helped to facilitate understanding of difficult concepts. The colour and animation of the PowerPoints were essential to enhance the greyscale printed Pupil Workbooks. These included video links and animations of reactions and processes that the pupils would not otherwise be able to see in the classroom. The PowerPoint presentations were an essential part of some lessons e.g. Instrumentation in Unit
5. The memory stick also included PDFs of the Teacher Guidebook and Pupil Workbooks to facilitate the teacher’s reproduction of certain pages or activity sheets if necessary. Software for PowerPoint-Viewer 2010 was also included for the teachers to download and to ensure the animations and illustrations in all PowerPoint presentations could be viewed as required by the pupils.

Table 5.5 Use of the Content of the Teaching Resource Box.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lego</td>
<td>To introduce the concepts of isomerisation and limiting reagents</td>
</tr>
<tr>
<td>Pupil Model Kits</td>
<td>To facilitate understanding of shape, structure and bond angles of organic compounds.</td>
</tr>
<tr>
<td>Teacher Model Kit</td>
<td>To illustrate the sigma and pi bonding in ethane, ethene, ethyne and benzene.</td>
</tr>
<tr>
<td>Labels</td>
<td>For use with activities identifying 3-D models and 2-D structures and other purposes.</td>
</tr>
<tr>
<td>Balloons</td>
<td>To illustrate the VSEPR theory to understand molecular shape of organic families.</td>
</tr>
<tr>
<td>Poppit beads and Paperclips</td>
<td>To illustrate the formation of polymers as chains of repeating units, to recognise the monomer units.</td>
</tr>
<tr>
<td>Polystyrene spheres (20mm, 25mm, 30mm)</td>
<td>To illustrate the homologous series.</td>
</tr>
<tr>
<td>6 sets x Game Card sets (printed on coloured card)</td>
<td>For assessment of topics e.g. reactions, reaction mechanisms.</td>
</tr>
<tr>
<td>Classroom response cubes</td>
<td>For use with multiple-choice questions on the lesson PowerPoints.</td>
</tr>
<tr>
<td>Compound concertina</td>
<td>To learn the IUPAC prefixes and to understand that each alkane differs by a CH$_2$ unit.</td>
</tr>
<tr>
<td>TLC sheet</td>
<td>For use with the TLC activities.</td>
</tr>
<tr>
<td>Classification Poster</td>
<td>To be completed as concepts are developed in each unit, for the classroom wall.</td>
</tr>
<tr>
<td>Memory Stick</td>
<td>PowerPoint presentations for each lesson and PDFs of the teacher and pupil materials.</td>
</tr>
</tbody>
</table>
5.3- Implementation of *Organic Chemistry in Action*!

The prepared teaching materials were reviewed by three practising Leaving Certificate Chemistry teachers in August 2011, in order to evaluate their appropriateness for use in a Leaving Certificate Chemistry class. The materials were also reviewed by a post-doctoral researcher in Chemistry Education. All recommendations made by this review team were taken on board and the corrected materials were made ready for the participants in the trial programme. The materials were ready for dissemination in the end of August 2011.

5.3.1. Participants involved in the Implementation

The participants involved in the implementation of the intervention materials were identified in Cycle One of the project. The methodology of Cycle One of this two-cycle project was detailed in Chapter Four (Section 4.6). In the Chemistry Teacher Questionnaires that were distributed in Cycle One, the teachers were asked to indicate at the end of the questionnaire if they would be interested in trialling the developed materials for teaching Leaving Certificate Organic Chemistry. Although a random sample of schools were selected for participation in Cycle One, the participating teachers in Cycle Two of this project were self-selected. In the time frame (November 2010 to July 2011) eight teachers remained committed to trialling the *Organic Chemistry in Action!* materials. Although a greater number of teachers had expressed interest in the materials in November 2010, for various different reasons many of these withdrew from the project. A ninth participating teacher was added after the exploratory workshop at the ISTA conference in April 2011. This teacher contacted the researcher after the workshop expressing an interest in the project and was enthusiastic to trial the materials.

The participating pupils were those in the Chemistry classes of the participating teachers. In total, this resulted in 151 pupils from the nine Chemistry classes. The researcher had to consider the high cost involved in providing the resource materials for nine schools and printing the workbooks for the pupils involved. For this reason, it was not feasible to involve more than these nine schools in the implementation phase. Pupil Model Kits could only be provided for every pair of pupils in each school due to the cost involved.

The details of the nine schools involved in the implementation phase of the intervention programme is summarised in Table 5.6. As can be seen from the table, not all of the schools completed the implementation of the programme within the given time-frame for this project.
Table 5.6 Participation in the Implementation of Organic Chemistry in Action!

<table>
<thead>
<tr>
<th>School I.D.</th>
<th>School Type</th>
<th>School Gender</th>
<th>Number of pupils (N)</th>
<th>Returned Pupil Questionnaires (n)</th>
<th>School Visit</th>
<th>Returned Teacher Diary</th>
<th>Returned Teacher Questionnaire</th>
<th>Teacher Interview</th>
<th>Complete participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Secondary</td>
<td>Girls</td>
<td>12</td>
<td>8</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>B</td>
<td>Community</td>
<td>Co-ed</td>
<td>15</td>
<td>7</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>C</td>
<td>Community</td>
<td>Co-ed</td>
<td>22</td>
<td>21</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>D</td>
<td>Community</td>
<td>Co-ed</td>
<td>24</td>
<td>19</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>E</td>
<td>Secondary</td>
<td>Girls</td>
<td>17</td>
<td>13</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>F</td>
<td>Community</td>
<td>Co-ed</td>
<td>12</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>-</td>
<td>✗</td>
</tr>
<tr>
<td>G</td>
<td>Secondary</td>
<td>Co-ed</td>
<td>21</td>
<td>19</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>H</td>
<td>Secondary</td>
<td>Boys</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✗</td>
</tr>
<tr>
<td>I</td>
<td>Secondary</td>
<td>Co-ed</td>
<td>18</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>-</td>
<td>✗</td>
</tr>
</tbody>
</table>

Nine schools  

N = 151  
n = 87  
n = 4  
n = 6  
n = 6  
n = 6  

Six Schools  

Note: * School F and School I trialled the materials with fifth year pupils. The findings from this trial investigation are not included in this thesis.
Due to change in circumstances, the teachers in School F and in School I decided to trial the materials with their fifth year Chemistry classes. The findings and feedback from these two schools will be used in the evaluation and modification of the teaching materials for future use. School H withdrew from their implementation of trial materials the in October 2011. Although Teacher H had attended the Introductory Training Workshop in August 2011, they withdrew because they were no longer able to fulfil the commitment to implement the programme as required.

In total six schools participated fully in the implementation phase of the programme. The number of pupils that completed questionnaires in each of these schools and the school types are shown in Table 5.6. Although more pupils participated in the programme and trialled the materials, the researcher only received feedback (Pupil Questionnaires) from 87 of the pupils in the six schools (N=151), a response rate of 57.6%. For this reason, the findings and feedback from the pupils that are presented in Chapter Eight are based on the feedback and performance of these 87 pupils only. The participating teachers in the six schools that completed the implementation of the programme within the specified time frame (September 2011 - February 2012) explained that many pupils were absent on the day when the questionnaires were distributed. The teachers explained that it is common for sixth year pupils to study from home, especially in the Spring and Summer term of sixth year.

The participants involved in the Control Group (n=117) were also selected from the original 100 schools selected for participation in Cycle One of the project (Table 4.11 in Chapter Four). As explained above, the teachers that participated in Cycle One of the project were invited to be involved in trialling the teaching materials. However, the teachers who were not interested in trialling the developed materials were instead asked to allow their pupils to participate as a Control Group for comparison in the evaluation of the intervention materials. In total 10 schools agreed to participate in the study as part of the Control Group. The teachers in these schools did not have to complete any questionnaire. The pupils had to complete the Control Group: Second-Level Pupil Questionnaire (II).

The response rate (73.1%) from the pupils in these control schools is shown in Table 5.7. Again, all of these pupils were in sixth year. Many of the teachers gave the same reason (non-attendance in school) for not all of the pupils in each class completing the questionnaires. In
total nine schools participated in the control group. As can be seen from Table 5.7, School M
did not complete their participation as a Control Group and did not return any questionnaires.

**Table 5.7 Participation in the Control Group**

<table>
<thead>
<tr>
<th>School I.D.</th>
<th>School Type</th>
<th>Gender</th>
<th>Number of Pupils (N)</th>
<th>Number of returned Pupil Questionnaires (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>Community</td>
<td>Co-Ed</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>K</td>
<td>Community</td>
<td>Co-Ed</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>L</td>
<td>Community</td>
<td>Co-Ed</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>M</td>
<td>Secondary</td>
<td>Girls</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>N</td>
<td>Secondary</td>
<td>Girls</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>O</td>
<td>Secondary</td>
<td>Girls</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>P</td>
<td>Secondary</td>
<td>Boys</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Q</td>
<td>Secondary</td>
<td>Co-Ed</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>R</td>
<td>Secondary</td>
<td>Girls</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>S</td>
<td>Secondary</td>
<td>Co-Ed</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Community – Co-Ed</th>
<th>Community – Girls</th>
<th>Secondary – Boys</th>
<th>Secondary – Co-Ed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intervention Group</strong></td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td><strong>Control Group</strong></td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

The type and gender of the schools in the Control Group are compared with the participating schools in Table 5.8. This shows that Control Group was representative of each school type involved in the implementation of the programme. The gender of the pupils in the Intervention Group and Control Groups will be outlined in detail in Chapter Eight with the results of Cycle Two.

**Table 5.8 Comparison of school type and gender of Intervention Group and Control Group**

**5.3.2. Teacher Induction and Training**

The participating teachers were invited to the University of Limerick for a half-day training workshop. This workshop was held on 23 August 2011. This date was selected as it was at the end of the teachers’ Summer holidays, and just before they returned to school. The attendance at this Teacher Training Workshop was compulsory for participation in the
implementation phase of the programme. One teacher was unable to attend due to personal reasons, but the other eight teachers attended the workshop. The workshop had four main aspects. The teachers were provided with a lunch as well as refreshments during the day. These breaks were useful for discussion among the participating teachers and with the researcher.

It began by the researcher outlining the design criteria (Section 5.2.2) and the philosophy of the project to the participating teachers. It was also important to acknowledge that the participants in this phase of the project were practitioners rather than researchers. For this reason, it was important to outline relevant CER to the teachers in order to inform their teaching. As outlined by Bodner and Orgill (2007) theory informs practice but practice refines theory. By sharing the CER findings and the findings from Cycle One of this project with the teachers, it was hoped that this would facilitate their experienced teaching strategies and approaches in the implementation of the *Organic Chemistry in Action!* programme.

As well as explaining the philosophy and design of the intervention materials, the teachers were given the opportunity to experience several of the activities included in the programme. Perceiving the perspective of a Leaving Certificate Chemistry pupil, they experienced some of the demonstrations to facilitate cognitive development and guided inquiry learning. These activities and ‘tasters’ of the programme were received very well by the teachers. The teachers were motivated and enjoyed the card games, model building and visual demonstrations. These activities were also useful in familiarising the teachers with the content of the Teacher Resource Box which they were collecting on the day of the workshop also.

The third part of the workshop was in the laboratory. In this short time, some of the difficult demonstrations included in the intervention materials were demonstrated for the teachers. Many of these were demonstrations which the teachers may not have seen or carried out before. This was an important aspect of the workshop as it was necessary that the teachers saw how the demonstrations were carried out safely and therefore would be confident to do the same in their own classrooms.

In the final part of the workshop all of the contents of the Teacher Resource Box (Figure 5.12 and Table 5.5) were shown to the teachers and the uses and purpose of each item outlined. The teachers then collected their Resource Box with the necessary number of items for the
number of pupils in their class. The teachers also collected the Pupil Workbooks and Teacher Guidebook.

5.3.3. Teacher Support

During the implementation phase, the teachers were not required to return to the University of Limerick for any review or appraisal of the programme. The teachers were happy with this as most of the teachers involved were teaching in counties outside of Munster and driving to Limerick would have been inconvenient. For these reasons, the researcher offered support to the participating teachers in a number of ways. These are outlined here.

5.3.3.1. Online Resource Forum

As mentioned already, the teachers received memory sticks containing all of the PowerPoints and materials required for the Organic Chemistry in Action! programme. Following recommendations by one of the teachers at the training workshop, an online file-sharing forum was set up. Sugar Sync was chosen by the researcher as a suitable online cloud for the intervention material. This database provides 5GB of free online storage. All of the resource materials were uploaded onto this forum and each of the participating teachers were invited to join as members. The teachers were given the opportunity to also upload and share additional resources of their own for use with Organic Chemistry.

5.3.3.2. Classroom Observations

The purpose of these school visits was two-fold. Their value in the evaluation of the intervention was explained in Section 4.7. The visits were useful in the implementation phase of the project to allow the researcher to gain an insight into how the programme was being implemented and to improve the level of communication with and support for the participating teachers.

The researcher in this project was not directly involved in the implementation of the programme. To provide support for the teachers and also to gain an insight into how the materials were perceived by pupils in the typical classrooms, the researcher offered to visit all of the participating schools. The researcher observed lessons in three of the participating schools (Schools C, E and G). In preparation for these visits the researcher designed a rubric to guide and facilitate their observation of the pupils and of the teachers. The same rubric was used to record the discussion, interest, participation and motivation in all of the classes.
observed. As well as recording the pupils’ and teachers’ use of the resource materials provided, the researcher was also interested to gain an insight into the attitudes of the pupils and their perception of what may have been perceived as a ‘non-traditional’ approach to teaching Chemistry. The researcher was interested in seeing whether the contextual examples and applications of the Chemistry included were actually relevant and recognisable by the pupils.

During these visits, the researcher recorded the pupil observations as well as an overall impression of the pupils’ positive and negative feedback about the programme, under the following headings:

- Use of models (working in pairs, involvement, enthusiasm)
- Interest in the lesson (inquiry, context)
- Involvement (active participation)
- Use and completion of workbooks.
- Help from the teacher.
- Practical work (integration, involvement, understanding)
- Group discussion and questions asked.
- Understanding lesson outcomes.
- Use of homework assignments.

The researcher used the following to guide their observation of the participating teachers:

- Teacher input.
- Demonstrations.
- PowerPoint (use and integration).
- Instruction.
- Promotion and evidence of inquiry learning.
- Links to previous lessons (spiral links).
- Use of assessment.
- Feedback given to pupils.
- Awareness of possible misconceptions.
- Variable teaching approaches.
- Homework assignments (use and correction).
- Use of additional resources in teacher Kit.
- Lesson completion and conclusion within class period.
These school visits also provided the opportunity for the teacher to provide informal (not recorded) feedback to the researcher. This provided the researcher with information to help prepare for the Teacher Questionnaire and Teacher Interviews in the evaluation of the programme, at the end of the implementation phase.

5.3.3.3. Focus Group

The researcher held a Focus Group in one of the participating schools (School B). This was a different school than those involved in the classroom observations. In this case, the teacher and pupils sat together in the classroom with the researcher. The Focus Group discussion was held with this class as the end of unit four. This was a half-way point in the eight-unit programme.

This informal (not recorded) discussion provided the researcher with the opportunity to get feedback from the pupils. The presence of the teacher in the Focus Group was helpful in reminding the pupils of particular elements that they enjoyed or found difficult. During this discussion, the pupils provided the teacher and researcher with insights that were not previously considered e.g. limited amount of space provided for answering in the Pupil Workbook, and difficulty in attending to the class activities and completing the workbook simultaneously. The pupils shared their insights of what they were learning from the course, elements that they enjoyed and elements that they found difficult. The pupils were given the opportunity to explain how the Organic Chemistry in Action! programme was relevant to aspects of their own lives and the world around them.

The structure and direction of the Focus Group was guided by the sequence of the lessons and units that the class had covered at the time of the Focus Group. In recalling the lessons, the teacher and pupils highlighted the effective demonstrations, animations and discussions that were had and also shared experiences with the researcher to advise improvements in the resource materials.

5.3.3.4. Email and Phone correspondence

As mentioned already, due to geographical location of the schools and participating teachers, it was not possible or realistic to expect the teachers to meet with the researcher during the intervention phase. As well as carrying out Classroom Observation, a Focus Group discussion and setting up an online forum as outlined above, the researcher also maintained continuous individual contact with the participating teachers. This was done by email mostly and also
through phone calls. Through this communication, the researcher was able to track the progress and participation of the teachers. Feedback from teachers about particular activities and lessons was sent to the researcher and the researcher was able to circulate any necessary modifications or recommendations about particular lessons or materials to the teachers. In some cases, the researcher acted as a facilitator to share useful tips between the participating teachers. By tracking each of the teachers’ progress in the programme, the researcher was able to organise school visits and Teacher Interviews as well as the appropriate timing of posting the Pupil Questionnaires and Teacher Questionnaires.

5.3.4. Third-Level Workshop

The main element of Cycle Two in this Action Research project involved the implementation and evaluation of the intervention materials in Second-Level schools. However, although the materials were prepared with a particular focus on the Leaving Certificate Organic Chemistry content, much of the programme materials were adaptable and suitable for use in teaching introductory or foundation level Organic Chemistry at Third-Level.

For this reason, an exploratory workshop was held in another Irish university in June 2011. This workshop was attended by those tutoring and lecturing Organic and also many of the Chemistry post-graduate researchers in this university. After outlining the CER findings and the findings from Cycle One of the project, a number of activities and elements of the programme were demonstrated to the participants in the workshop. Many of the participants found this part of the workshop helpful. They enjoyed the molecular modelling activities, modified practical work and the guided-inquiry approach to learning Organic Chemistry. By having the participants identify with the role of the learner throughout this workshop, and experience some of the activities, they became more aware of the possible learning difficulties and challenges faced by the novice learner when first introduced to Organic Chemistry.

The participants in the workshop felt that many of the elements of the programme could be integrated into lecture and tutorial settings at Third-Level. Some participants were eager to include the alternative laboratory activities in their programmes also.
Chapter 6
Cycle One
Results (I)-Second-Level Study
6.1- Introduction

As outlined in Chapter Four (Table 4.1), this research project had two cycles. Cycle One involved two separate studies; a study at Second-Level involving Leaving Certificate Chemistry pupils and teachers and a study at Third-Level involving foundation level Organic Chemistry students and lecturers. The findings and analysis from the Second-Level Study are outlined in this chapter. The findings from the Third-Level Study will be presented in Chapter Seven.

Cycle Two involved the development, implementation and evaluation of an intervention programme *Organic Chemistry in Action!*, for teaching Leaving Certificate Organic Chemistry. The findings and results from this cycle will be presented in Chapter Eight.

The Second-Level Pupil Questionnaire (I) was completed by 276 Leaving Certificate Chemistry pupils in 35 Second-Level schools. The Chemistry Teacher Questionnaire was completed by 79 teachers in 73 Second-Level schools. There were two parts in the Second-Level Pupil Questionnaire (I): part A and part B (Diagnostic Test). The findings from both of these parts are presented below along with the findings from the Chemistry Teacher Questionnaire. See Appendix F for complete copies of the Second-Level Pupil Questionnaire (I) and the Chemistry Teacher Questionnaire.

The main findings from the Second-Level study are summarised at the end of this Chapter (Section 6.4) and will be discussed further when addressing the research questions in Chapter Nine.

6.2- Second Level Pupil Questionnaire (I)

6.2.1. Part A - Results

6.2.1.1. Pupils’ Science and Mathematics background

The pupils’ ages ranged from 15 to 38 years with an average age of 18 years. Two pupils were 15 and one was 38. The majority of the pupils were 17 (n=107) or 18 (n=143) years of age.

All but four of the pupils in the study had studied Junior Certificate Science. 262 (95.0%) of the pupils had studied it at Higher Level and 7 (3.00%) had studied Ordinary Level.
Figure 6.1 shows the distribution of A, B, C and D grades at Higher Level Junior Certificate Science. 136 (49.3%) of the pupils did not answer this question about the grade received in their Junior Certificate Science. When asked about their preference for each category of Junior Certificate Science, Biology was listed as the topic that most (196, 73.2%) of the pupils enjoyed. Pupils were almost equally divided in their opinions towards Physics; 80 (29.0%) enjoyed it and 91 (33.0%) disliked it. 160 (59.6%) of the pupils enjoyed Chemistry in the Junior Certificate Science programme while just 16 (5.80%) said that they ‘disliked’ Junior Certificate Chemistry. This does suggest that these pupils had a relatively positive experience of Chemistry at Junior Cycle and so decided to continue to study it at Senior Cycle.

As well as choosing to study Chemistry for their Leaving Certificate course, many of the pupils in this study also studied another Science subject for their Leaving Certificate. These are listed in Figure 6.2. It is clear that Biology was the most popular second Science subject for these pupils with 166 (60.1%) of the pupils studying it as well as Chemistry.
156 (56.5%) of the pupils in this study had taken the Transition Year Programme in their school. Of these pupils, 140 (89.7%) of them studied Science during this year. 76 (54.2%) of these pupils experienced a sample of Biology, Physics and Chemistry during Transition Year. In addition, 11 (7.80%) listed Physics only, 25 (17.8%) listed Biology only and 23 (16.4%) listed Chemistry as the only Science topics that they covered during Transition Year. 8 (5.70%) of the pupils said that their Transition Year Science programme was focused on practical Science. 11 (7.90%) of the pupils did Forensic Science during this year. When asked about their participation in Science competitions, 48 (17.4%) of the pupils involved in the study had taken part in such events. Events listed by the pupils included the Science Olympiad, the ISTA Science Quiz, the Young Scientist Competition as well as other debating and environmentalist competitions and awards.

When asked about their study of Mathematics for their Junior Certificate, 244 (88.4%) of the pupils had studied Higher Level and 27 (9.78%) had studied Ordinary Level. Figure 6.3 shows the grade that the pupils attained at Higher Level and Ordinary Level Mathematics in their Junior Certificate. It should be noted that only 177 (64.1%) of the pupils involved in the study indicated their Mathematics grade from their Junior Certificate. 162 (58.7%) of the overall cohort of pupils studied Higher level Mathematics for their Leaving Certificate and 112 (40.6%) studied Ordinary level Mathematics. 82 (29.7%) of the pupils who had studied
Higher level of their Junior Certificate dropped to Ordinary Level Mathematics for their Leaving Certificate.

![Pupils' performance in Junior Certificate Mathematics (n=177)](image)

**Figure 6.3 Pupils’ performance in Junior Certificate Mathematics (n=177).**

### 6.2.1.2. Pupils’ attitudes to Leaving Certificate Organic Chemistry

The pupils were asked to indicate on a five-point Likert scale their attitudes towards Organic Chemistry in the Leaving Certificate Chemistry course. On the scale 1= Strongly Agree, 2= Agree, 3= Indifferent, 4= Disagree and 5= Strongly Disagree.

To summarise the pupils’ responses those who ‘strongly agreed’ and ‘agreed’ to each of the statements are grouped as Agree, and those who ‘disagreed’ and ‘strongly disagreed’ to each of the statements are grouped as Disagree in Table 6.1.

**Table 6.1 Pupils’ attitudes towards Organic Chemistry (n=276)**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Agree n (%)</th>
<th>Neutral n (%)</th>
<th>Disagree n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoy studying Organic Chemistry</td>
<td>158 (57.9%)</td>
<td>64 (23.4%)</td>
<td>51 (18.7%)</td>
</tr>
<tr>
<td>I find Organic Chemistry easy</td>
<td>75 (27.5%)</td>
<td>100 (36.6%)</td>
<td>98 (35.5%)</td>
</tr>
<tr>
<td>Organic Chemistry is one of the most interesting areas of the Leaving Certificate Chemistry course.</td>
<td>124 (45.6%)</td>
<td>74 (27.2%)</td>
<td>74 (27.2%)</td>
</tr>
</tbody>
</table>

It can be seen from Table 6.1 above that the majority of the pupils enjoy studying Organic Chemistry. In another question asking the pupils if they find Organic Chemistry easy or
difficult to learn, 94 (34.0%) found it easy to learn. The main reason given by 41 (44.0%) of these pupils was that Organic Chemistry is logical and can be learned systematically. Many of these pupils also found the subject interesting and relevant to their own lives. In comparison, the majority of pupils (165, 59.8%) found Organic Chemistry difficult to learn. The most common reason for finding Organic Chemistry difficult to learn for 52 (31.5%) of these pupils was due to the length and detail of the curriculum. These pupils felt overloaded with too much to remember and recall. Difficult topics listed here were differentiating the functional groups, naming and drawing compounds and organic formulae, as well as reactions and mechanisms. 17 (6.20%) of the pupils did not answer this question. Even though 165 (59.8%) of the pupils found Organic Chemistry difficult, only half that number of pupils (83, 30.1%) sought tutorial assistance with their study of Chemistry. Table 6.1 also shows that a majority (124, 45.6%) of the pupils find Organic Chemistry interesting.

The pupils were also asked about their attitudes towards the mandatory experiments in Organic Chemistry (listed in Section 2.3.2 of Chapter Two). 25 (9.1%) of the pupils misinterpreted this question, and listed other non-organic experiments as their favourite or least favourite. These responses have not been included in these results. The two most popular experiments amongst these pupils were the Preparation and properties of ethene (48, 21.0%) and the Preparation of soap (45, 20.3%). Interestingly the Preparation of soap was also listed as the least favourite mandatory experiment for 53 (23.2%) of the pupils. Other experiments which were not popular amongst the pupils were the Extraction of Clove Oil and the Preparation and properties of ethanal and ethanoic acid. The main reason given by the pupils for favouring the Preparation of soap was that it was easy, they could understand the process (17, 6.20%) and it involved everyday materials: lard, sunflower oil and soap (19, 6.90%). The main reason given by the pupils for disliking the Preparation of soap was that very little product was collected, setting up the apparatus was difficult (14, 5.10%), the reaction was difficult to understand and the equation was too long to learn (18, 6.50%). Pupils enjoyed the Preparation and testing the properties of ethene because it was quick and easy to understand. In general reasons given by the pupils for choosing their favourite experiment included an easy and quick set-up, a short experiment that worked and a reaction process that they could understand. In comparison, the reasons given for not liking other experiments were the contrary: long, slow boring methods, experiments that didn’t yield a product successfully and reactions that were hard to remember and understand.
The pupils were asked to rate on a five-point Likert scale their attitudes to the Organic Chemistry mandatory experiments. The pupils indicated their response to each of the statements in Table 6.2 where 1 = Strongly Agree, 2 = Agree, 3 = Indifferent, 4 = Disagree and 5 = Strongly Disagree. To summarise the pupils’ responses, ‘strongly agree’ and ‘agree’ are grouped here as ‘Agree’ while ‘disagree’ and strongly disagree’ are grouped as Disagree in Table 6.2. As can be seen by the percentages included for the pupils’ response to each statement in Table 6.2, the pupils had relatively positive attitude and experience of the practical work in Organic Chemistry.

Table 6.2 Pupils’ attitudes towards practical work in Organic Chemistry (n=276).

<table>
<thead>
<tr>
<th>The Organic Chemistry experiments are ....</th>
<th>Agree n (%)</th>
<th>Neutral n (%)</th>
<th>Disagree n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to understand.</td>
<td>129 (46.7%)</td>
<td>72 (26.1%)</td>
<td>67 (24.3%)</td>
</tr>
<tr>
<td>Interesting.</td>
<td>190 (68.8%)</td>
<td>54 (19.6%)</td>
<td>28 (10.1%)</td>
</tr>
<tr>
<td>Useful in facilitating my understanding of Organic Chemistry.</td>
<td>151 (54.7%)</td>
<td>63 (22.8%)</td>
<td>55 (19.9%)</td>
</tr>
</tbody>
</table>

Table 6.3 which follows shows how the pupils rated each of the Organic Chemistry topics on a five-point Likert scale where 1 = Really easy, 2 = Easy, 3 = Neutral, 4 = Difficult and 5 = Really Difficult. The results from this Likert scale were ordinal and non-parametric. For this reason the median value and percentiles are used to summarise the pupils’ responses. (The mean values have also been included in Table 6.3 as a point of interest, however the median values are more accurate). It can be seen that topics which the pupils found easy to learn included Drawing and Naming of organic compounds, as well as Oil refining, Oil products and Chromatography. The topics identified as difficult by the pupils were Organic Mechanisms and Synthesis.
To validate the findings shown in Table 6.3, the pupils were given an open ended question where they were asked to list the top five topics that they find most difficult in Organic Chemistry, with number one as the most difficult.

Figure 6.4 shows the top 11 topics listed by the pupils in this study when asked to identify Organic Chemistry topics that they find most difficult. It can be seen from Figure 6.4 that Organic Reactions, Synthesis, Mechanisms, Instrumentation and Functional groups were listed as the top five most difficult topics. The cumulative percentage of pupils that listed each of the topics as difficult is indicated by the value above each bar on the chart. Organic Mechanisms was listed as the number one most difficult topic by the highest number of pupils (53, 19.2%). However, Organic Reactions had the highest aggregate score as it was listed as difficult by 135 (48.9%) of the pupils.
Part A of the Second-Level Pupil Questionnaire (I) provided the researcher with information about the background of the pupils involved in the study. Almost two thirds (182, 65.9%) of the participants were female with 92 (33.3%) males. The majority of the pupils were in sixth year (258, 93.5%) of Second-Level school and just a small number (18, 6.50%) were in fifth year. 272 (98.6%) of the pupils involved had studied Junior Certificate Science although it is not a compulsory subject. This is above the national average of ~88% over the past 10 years (SEC 2011). Information was not gathered from the pupils about other Junior Cycle programmes (e.g. GCSE) that they may have studied if not studied Junior Certificate Science. The percentage of students that had studied Higher Level Junior Certificate Science (262, 95.0%) was also above the national average of 66.9% (SEC 2011). 226 (81.8 %) of the Chemistry pupils involved in the study were studying a second Science subject for their Leaving Certificate. The uptake of Biology, Physics, Agricultural Science and Physics & Chemistry were representative of the national trend, with Biology as the most popular second Science subject chosen by the Chemistry pupils.

244 (88.4%) of these students had studied Higher Level Junior Certificate Mathematics which is over double the national average of ~ 42% (SEC 2011). While 82 (29.7%) of the
pupils opted to study Ordinary Level Mathematics for their Leaving Certificate, 162 (58.7%) continued to study Higher Level Mathematics for their Leaving Certificate. This is over triple the national average uptake for Higher Level Leaving Certificate Mathematics of ~ 17% (SEC 2011).

The above average participation in Higher Level Mathematics and Science subjects suggests that the participants involved in this study may be pupils of higher cognitive ability, and that it is the academically better pupils who study Chemistry.

From the Likert scale questions, where the pupils had to tick a box indicating their attitude to learning Organic Chemistry and the value of the practical experiments, the pupils’ overall attitudes were relatively positive. A majority of pupils enjoyed learning Organic Chemistry and found it interesting. However, there were mixed responses to the statement ‘I find Organic Chemistry easy’. While some topics were identified as easy to learn by the Likert rating, Organic Mechanisms and Organic Synthesis were described as difficult to learn. These same topics along with Reactions, Instrumentation and Functional groups were listed as the most difficult topics to learn by the pupils in an open-ended question also.

6.2.3. Diagnostic Test- Results

Part B of the Second-Level Pupil Questionnaire (I) was a Diagnostic Test. The Diagnostic Test was composed of nine questions. The marking for each of the questions was evenly weighted with each question having a mark of 40. This resulted in an overall score of 360. The pupils’ performance in each question will be presented and briefly analysed in this Section. Each question from the Diagnostic Test is shown with the pupils’ responses to facilitate the comprehension of the results. The font size of snap-shots from the Diagnostic Test is small. A complete Second-Level Diagnostic Test is included in Appendix F.

6.2.3.1. Pupil responses to each of the questions in the Diagnostic Test

Question One - Drawing Organic Compounds

Figure 6.5 shows Question One from the Diagnostic Test. This question aimed to assess the pupils’ ability to draw organic compounds in the condensed and extended structure format. This question was the most popular question in the Diagnostic Test, attempted by 269 (97.5%) of the pupils. It was one of the best answered questions also, with a median percentage score of 80.0% (32/40). The mean percentage score was 77.0%. 
1. Drawing Organic Compounds

Fill in the blank boxes below accordingly.

You can see the first one, Butane, is done for you.

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>Condensed Structure</th>
<th>Extended Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane</td>
<td>CH₃CH₂CH₂CH₃</td>
<td></td>
</tr>
<tr>
<td>Hex-2-ene</td>
<td>CH₃CHCH₂CH₂CH₂H</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>H-C-O-H</td>
<td></td>
</tr>
<tr>
<td>Ethanal</td>
<td>CH₃CHO</td>
<td></td>
</tr>
<tr>
<td>Ethanoic acid</td>
<td>H-C-Ο-C</td>
<td></td>
</tr>
<tr>
<td>Methyl ethanoate</td>
<td>CH₃COOCH₃</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.5 Question One in the Second-Level Pupil Organic Chemistry Diagnostic Test - Drawing Organic Compounds.

It can be seen from Figure 6.6 that methanol and ethanoic acid were drawn correctly by a high percentage of pupils. This part of Question One was answered better than the extended structures.

Figure 6.6 Pupils’ performance in Question One - Drawing the condensed structure of organic compounds (n=276).
The pupils’ performance and attempts in drawing the extended structures is shown in Figure 6.7.

Hex-2-ene, ethanal and methyl ethanoate were attempted but answered incorrectly by 71 (25.7%), 43 (15.6%) and 80 (28.6%) of the pupils respectively. This suggests that the pupils may have more trouble with drawing the extended structural formulae rather than the condensed structural formulae. 18 (6.50%) of the pupils did not show the hydrogen atoms when drawing the extended structures. The most common mistakes when drawing hex-2-ene was not showing any double (C=C) bond (46, 64.8%), or drawing the double bond in the wrong position (10, 14.1%).

(Note in the discussion of pupils’ and students’ performances and responses in the Diagnostic Tests used in this research study, C=C is used to represent a carbon-carbon double bond, RC(O)R’ is used to represent a carbonyl group, RCO₂H is used to represent a carboxylic acid group etc. However, it is implied that from this notation that each carbon has a valency of four although it is not represented).

These mistakes suggest that the pupils did not correctly understand the IUPAC name given; i.e. recognising the ‘ene’ ending as an alkene and ‘-2-’indicating the correct position of the double bond between the second and third carbon atoms. 38 (88.0%) of the pupils who incorrectly attempted to draw the extended structure of ethanal drew the functional group RC(O)H group incorrectly. The most common mistake was omitting the double bond in the
carbonyl group. 48 (60%) of the pupils who drew the extended structure of methyl ethanoate incorrectly made a mistake when drawing the functional group (RC(O)OR') wrong. Some omitted the double bond in the carbonyl group drawing the carbon as an sp\(^3\) hybridised carbon instead of an sp\(^2\) carbon atom. These pupils did not know the ester functional group. 18 (23.0%) of the incorrect attempts were pupils who drew the structure of propanone with a central carbonyl group instead of methyl ethanoate. This suggests that these pupils may only have looked at the condensed structure (which does look similar to propanone with an extra oxygen atom) rather than the name to draw the extended structure and that they are unfamiliar with esters.

**Question Two - Naming Organic Compounds:**

![Figure 6.8 Question Two in the Second-Level Pupil Organic Chemistry Diagnostic Test- Naming organic compounds.](image)

Question Two (Figure 6.8) aimed to assess the pupils’ ability to name organic compounds. This question was attempted by 252 (91.3%) of the pupils. It was the second most popular question in the Diagnostic Test. It was the third best answered question with a median score of 50.0% (20/40). The mean percentage score was 44.9%. This question contained eight compounds to be named by the pupils. The first four compounds (A to D) were given in their condensed structure while the second four compounds (E to H) were given in their extended format. Overall, there was little difference in the pupils’ ability to name the compounds in the different structures, with an average of 128 (46.4%) correct responses to the condensed structures and an average of 111 (40.5%) correct responses to the extended structures.
It should be noted however that compounds B and H were both 2-methylpropan-2-ol. However, only 30 (10.9%) of the pupils correctly identified compound B (condensed formula) while over twice as many pupils (63, 22.9%) correctly named compound H (extended formula). Conversely, while compounds D and F were both propanoic acid, almost an equal number of pupils named both correctly; 148 (53.6%) and 154 (55.8%) respectively.

It is clear from Figure 6.9 that ethene (compound A) was answered correctly by the greatest number of pupils (224, 81.2%). Compound B (2-methylpropan-2-ol) was named correctly by the least number of pupils (30, 10.9%). The most common mistake made by 95 (61.7%) of the 154 (55.8%) incorrect attempts was not correctly identifying that there were three carbons in the longest carbon chain. Many of the incorrect responses were ethanol or methanol with an incorrect substituent. An additional 64 (41.6%) of the pupils did not recognise that this was a branched alcohol and instead named it as a straight-chained alcohol according to the molecular formula; butanol.

From Figure 6.10, it can be seen that the best named extended structure was compound F (propanoic acid). Compounds G (butanone) and H (2-methylpropan-2-ol) were the most poorly named. 12 (14.0%) of the 88 (31.6%) pupils who named butanone incorrectly named it as an aldehyde and a further 8 (9.00%) of the pupils named it as an ester. As in Question One, this suggests some confusion in the pupils’ ability to recognise and distinguish the
functional groups containing the carbonyl group. 67 (58.8%) of the 114 (41.3%) pupils who named compound H incorrectly did not recognise the correct longest continuous carbon chain and so named incorrect substituents. An additional 29 (25.4%) of the pupils gave the incorrect number to indicate the position of the -OH hydroxyl group in the alcohol. This mistake is related to the previous mistake. 34 (29.8%) of the pupils named this as a straight-chained alcohol.

![Figure 6.10 Pupils’ performance in Question Two: Parts E to H – Naming extended structures of organic compounds (n=276).](image)

**Question Three - Identification of Structural isomers:**

Question Three (Figure 6.11) aimed to assess the pupils’ ability to recognise structural isomers of different compounds. From the nine boxes in the grid, there were two possible isomers for compound A; E and I. There were also two possible isomers for compound C; B and G. F was the only isomer for compound H. This question was the third most popular question in the test, attempted by 246 (89.1%) of the pupils. It was the joint best answered question (along with Question One) with a median score of 80% (32/40)
Figure 6.11 Question Three in the Second-Level Pupil Diagnostic Test- Identification of structural isomers.

The mean percentage score in Question Three was 66.3%. The correct responses from the pupils for Question Three are shown in Figure 6.12.
191 (69.2%) of the pupils attempted to name an isomer of compound A. Figure 6.12 shows that 32 (11.6%) more pupils correctly recognised compound I (pentane) as an isomer of A (2-methylbutane), than E (2,2-dimethylpropane). 95 (34.4%) more pupils recognised compound G (hex-1-ene) as an isomer of C (hex-3-ene) than recognised B (cyclohexane) which was also a structural isomer of C. This suggests that the pupils were better able to identify isomers within the same family of compounds than between families. The recognition of the isomers of compound A were all within the alkane family. 189 (68.5%) of the pupils correctly identified F (2-methylpropan-2-ol) as an isomer of H (butan-1-ol). However, in comparison to the other isomers, this part of the question had the most incorrect attempts. 28 (10.1%) of the pupils incorrectly listed D (butanal) as the only isomer of H while an additional 45 (16.3%) of the pupils who correctly listed F as an isomer of H, also listed D. Naming D as an isomer of H was the most consistent incorrect answer in this question (73, 26.4%). This may have been due to the presence of oxygen in the compound. It suggests that the pupils may have seen the RC(O)H group at the end of the compound but did not count the hydrogen atoms accurately.
Question Four - Electron Density and Electrophilic attack:

4. **Electron Density – Electrophilic attack.**

Use the table of Electronegativity values provided on pg.10 to answer this question. **Example:** Electronegativity values Oxygen = 3.4, Hydrogen = 2.2.

Since Oxygen is more electronegative than Hydrogen, it has a greater affinity for the shared electrons.

\[ \delta^- \quad \delta^+ \]

\[ H - O - H \]

i) Clearly place ‘\( \delta^- \)’ next to the atom with the highest concentration of electron density and ‘\( \delta^+ \)’ next to the atom with the lowest concentration of electron density.

\[ H - C = C - H \]

ii) Indicate with an arrow where \( Br^+ \) atom would attack this molecule:

\[ Br^+ \]

\[ H - C = C - H \]

Explain why the \( Br^+ \) ion attacks the atom that you choose.

Draw how you think the ethene molecule would look after the \( Br^+ \) ion has attacked. Include the partial charges.

*Figure 6.13 Question Four in the Second-Level Pupil Diagnostic Test- Electron density and electrophilic attack.*

Question Four (Figure 6.13) aimed to assess the pupils’ ability to identify areas of electron density on a compound and also the site of electron density where an electrophile would attack. This question was attempted by 229 (83.0%) of the pupils. It was the third best answered question with a median score of 50% (20/40). The mean percentage score was 50.7%. The pupils’ performance in Question Four is summarised in Figure 6.14.
Figure 6.14 Pupils’ performance in Question Four- Electron Density and Electrophilic attack (n=276)

Figure 6.14 shows that most (182, 65.9%) pupils were able to identify the regions of high and low electron density on the ethene molecule and the site on the ethene molecule where the bromine electrophile would join the ethene molecule. 33 (12.0%) of the pupils incorrectly identified one of the hydrogen atoms as the site where the bromine ion would join. An arrow pointed to the C=C double bond was accepted as a correct answer for 108 (60.0%) of the correct responses to identifying the site of electrophilic attack. An arrow pointed directly to either of the carbon atoms in the ethene was also accepted as a correct response from 69 (38.3%) of these pupils. The specific language used in the question ‘where the Br\(^+\) ion would attack’, may have encouraged these pupils to draw the arrow from the bromine ion to the ethene molecule. Only three pupils drew the arrow of attack as coming from the carbon double bond in the ethene molecule. This response indicates that this minority of pupils understood that the electrons moved from an area of high electron density to an area of low electron density. However, since it was not specified in the question that the arrow was a curly arrow (mapping electron movement), it is understood that the use of the arrow in these responses was solely to indicate the area of the ethene molecule which the bromine ion would bond to.
Even though about two-thirds of the pupils identified the areas of high and low electron density and where the electrophile would attack, only one third of the pupils were able to draw how the ethene molecule would look after the attack. Two correct answers were accepted from the 92 (33.3%) pupils who answered the final part (iv) of the question correctly. 48 (52.0%) of them drew the intermediate bromonium ion and the remaining 44 (48.0%) drew the bromine atom attached to one carbon forming a carbocation at the other carbon atom. 92 (33.3%) of the pupils answered this part of the question incorrectly. 15 (16%) of these pupils drew a negative charge on the carbocation, while 30 (33.0%) of these pupils did not give any charge to the second carbon (carbon that the bromine was not joined to). An additional 27 (29.3%) of these pupils drew the product of the reaction as bromoethene (substituting the bromine atom for one of the hydrogen atoms instead of as an addition reaction across the double bond).

**Question Five- Organic Chemical Reaction types**

![Diagram of chemical reactions](image)

*Figure 6.15 Question Five in the Second-Level Pupil Diagnostic Test- Organic chemical reaction types.*
Question Five (Figure 6.15) aimed to assess the pupils’ ability to complete the products of the different reaction types and also to classify the different reactions. This question was the fourth most popular question in the Diagnostic Test and was attempted by 231 (83.7%) of the pupils. It was also the fourth best answered question with a median score of 40% (16/40). The mean percentage score was 45.6%. The first part of this question; completing the reaction, was attempted by 149 (54.0%) of the pupils. Figure 6.16 shows the pupils’ performance in completing each reaction (a to e) in part (a) of Question Five.

A large number of pupils did not attempt to complete any of the five reactions. The reaction completed correctly by the greatest number of pupils (108, 39.1%) was the addition of water to ethene to form ethanol. The reaction which was most poorly completed by the pupils was the reaction of ethanol with sodium, where ethanol reacts as an acid. Only 53 (19.2%) of the pupils completed this reaction correctly. The reaction which the least number of pupils attempted to complete was the oxidation of propanol. Only 80 (28.6%) of the pupils attempted to complete this reaction with 59 (74.0%) of these pupils completing the reaction correctly. Of these 59 pupils, 12 (20.0%) put propanoic acid as opposed to propanal as the product. This was accepted as a correct answer as further oxidation of the propanal would result in the production of propanoic acid.
The second part of Question Five, classifying the reaction type was attempted by more of the pupils (229, 83.0%), indicating greater confidence in this content. Figure 6.17 shows the pupils’ responses when asked to classify each of the reaction types presented in Question Five.

Figure 6.17 Pupils’ performance in part b) of Question Five, - Classification of reaction types (n=276).

The correct classification for each reaction is given on the x-axis in Figure 6.17. As in part (a) of this question, reaction a (addition of water to ethene) was the best answered, with 203 (73.6%) of the pupils classifying it correctly as an addition reaction. Hydration and hydrolysis were also accepted as correct answers for this part. 25 (69.0%) of the 36 (13.0%) of incorrect classifications of reaction d (substitution of ethane) were addition. It is evident that these pupils did not recognise ethane as an alkane or understand that alkanes must undergo substitution reactions. 23 (41.0%) of the 56 (20.3%) pupils who incorrectly classified reaction c classified it as an addition reaction instead of a reaction as an acid. Of the 135 (48.9%) of pupils who correctly answered reaction c, 51 (37.8%) of them classified the reaction as a substitution reaction. This was taken as a correct answer by the researcher as the hydrogen in the hydroxyl group of the ethanol is substituted by the sodium to form sodium ethoxide. The reactions classified correctly by the least number of pupils were the reaction as an acid (135, 48.9%) and the oxidation (redox) reaction (134, 48.6%). 22 (39.0%) of the 56 (20.3%) incorrect responses classified reaction e as a reaction as an acid. Perhaps in this case,
the presence of an alcohol and the sodium in the sodium dichromate (as given in the question) may have distracted the pupils.

Comparing Figures 6.16 and 6.17, it is clear that more pupils attempted to classify the reactions than complete the reaction equations. Also there was an average of over twice as many correct responses for classifying the reactions (166, 60.2%) than for completing the reaction equations (81, 29.3%). The example of classifications given in the question may have encouraged more pupils to attempt to answer this part of the question. In comparison, no clue was given to encourage completion of the reaction equations.

**Question Six- Synthesis of Ethanal from Ethene**

![Diagram of ethene to ethanal conversion](image)

<table>
<thead>
<tr>
<th>Step</th>
<th>Reaction Type</th>
<th>Name of the Reactant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 6.18 Question Six in the Second-Level Pupil Diagnostic Test- Synthesis of ethanal from ethene.*

Question Six (Figure 6.18) assessed the pupils’ ability to draw the structures of ethanol and ethanal and also to recognise the reactants needed for both steps of the synthesis and to classify each type of reaction. This question was the second least popular question in the Diagnostic Test, and was attempted by only 188 (68.1%) of the pupils. However, it was one of the third-best answered questions with an average score of 50% (20/40). The mean percentage score was 46.5%. This suggests that most of the pupils who did attempt the question did have some understanding of the synthesis and the reaction steps involved. The
preparation of ethanal by oxidation of ethanol is one of the mandatory experiments on the Leaving Certificate course. Having completed their study of Leaving Certificate Organic Chemistry, the pupils should have carried out this experiment. The pupils should also have carried out the mandatory experiment of dehydrating ethanol to produce ethene. From these experiences, the pupils should be able to deduce the two steps outlined in the synthesis of ethanol from ethene.

The first part of the question simply asked the pupils to draw the structures of ethanol and ethanal in the respective labelled boxes. This part only assessed their ability to draw the named alcohol and aldehyde, as the names of each were given. 151 (54.7%) of the pupils drew the correct structure of ethanol and fewer pupils (142, 51.4%) drew the correct structure of ethanal. In part (b) of the question, the pupils had to classify the type of reaction involved in each step and also a suitable reactant to be used. The pupils’ performance in part (b) is summarised in Figure 6.19.

![Figure 6.19 Pupils’ performance in Question Six, Part (b) - naming the reaction types and reactants (n=276).](image)

Figure 6.19 shows that more pupils (31, 11.3%) identified the hydration reaction (step 1) than identified the oxidation reaction (step 2) correctly. Almost an equal number of pupils identified the correct reactant used in each step. It should be noted that 16 (35%) of the 46 (16.7%) pupils who incorrectly attempted to classify the type of reaction for step 2 gave
elimination as the reaction type. Although this is an oxidation reaction, classification of it as an elimination, does suggest that the pupils understand there is a loss of hydrogen from the ethanol to form ethanal. 35 (12.7%) of the pupils gave an incorrect reactant for step 1 (hydration of ethene). The most popular incorrect response by 14 (40%) of these pupils was aluminium oxide. This is the dehydrating agent that the pupils would have used for the preparation of ethene from ethanol. It is apparent that these pupils may not have realised that the formation of ethanol from ethene is a reverse of that reaction and would thus require hydration by addition of water. This incorrect answer suggests that the pupils may have just memorised the name of the reactant without understanding its properties and uses.

Question Seven- Mechanism of a reaction:

7. Mechanism of a reaction
   a) Fill in the products in the equation for the reaction below.

   \[
   \begin{align*}
   \text{C} & \equiv \text{C} \\
   \text{H} & \quad \text{H} \\
   \text{H} & \quad \text{H}
   \end{align*}
   \hspace{1cm} + \hspace{1cm} \text{HCl} \quad \rightarrow
   \]

   b) Show the mechanism of the reaction.
   o Show the steps clearly.
   o Use arrows to show the transfer of electrons.

Figure 6.20 Question Seven in the Second-Level Pupil Diagnostic Test- Mechanism of reaction.

Question Seven (Figure 6.20) again assessed the pupils’ ability to complete a reaction equation (as was also assessed in Question Five). Part (b) of this question asked the pupils to clearly outline the mechanism for the addition of HCl to ethene. This question was the least popular question in the Diagnostic Test. The first part of the question was attempted by 141 (51.1%) of the pupils, while only 103 (37.3%) pupils attempted the second part. This question was also the most poorly answered question, resulting in a median score of 0% (0/40). The mean percentage score was 28.6%

121 (43.8%) of the pupils correctly completed the reaction equation drawing 1-chloroethane as the product. This was slightly more than the number (108, 39.1%) of pupils who correctly
completed the similar addition reaction of water to ethene in Question Five. 79 (65.3%) of those that completed the reaction correctly in Question Seven completed reaction a correctly in Question Five also. Pupils’ performance in part (b) is shown in Figure 6.21.

![Figure 6.21 Pupils’ attempt to draw the reaction mechanism (n=276)](image)

**Figure 6.21 Pupils’ performance in Question Seven, Part (b) - showing the mechanism of a reaction (n=276).**

Figure 6.21 summarises the pupils’ attempts to show the mechanism of the given reaction. Only 12 (4.3%) of the pupils answered this part of the question completely correctly by showing the mechanism and using arrows correctly to show the transfer of electrons. The incorrect attempts made by the pupils are illustrated and the percentage breakdown in given in Figure 6.21. 48 (17.4%) of the pupils were given partial credit for their attempt to show the mechanism of the reaction. These pupils drew out the different steps in the reaction, showing the correct intermediate compounds etc. but with incorrect use of the arrows suggesting that they did not have a clear understanding of what direction the electrons were moving or why. Other (25, 9.1%) pupils drew the correct intermediates but without any arrow signalling to show how the compounds were formed. It was clear that some of these pupils may have been writing what they could recall from a similar mechanism which they had learned. A small number of pupils (5, 1.8%) just named the four steps of the reaction mechanism without any
further explanation. The poor performance in this question is a clear indication that this is a particular area of difficulty or unfamiliarity for the Leaving Certificate pupils.

**Question Eight - Classification of Organic Compounds**

8. **Classification of Organic Compounds**  
   Can you classify the structures below?  
   Please indicate the letter of the appropriate structure in the box below:

   ![Chemical structures]

   A
   B
   C
   D
   E
   F

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Aldehyde</th>
<th>Ketone</th>
<th>Ester</th>
<th>Carboxylic acid</th>
</tr>
</thead>
</table>

*Figure 6.22 Question Eight in the Second-Level Pupil Diagnostic Test - Classification of organic compounds.*

Question Eight (Figure 6.22) assessed the pupils' ability to recognise the functional groups of the compounds, and classify them appropriately. An extra compound (Alkane D) was also included to reduce the possibility of pupils using an elimination process to classify the compounds. This question was attempted by 214 (77.5%) of the pupils. It was the second-best answered question with a median score of 60% (24/40). The mean percentage score for this question was 56.5%. The pupils' performance in this question assessing classification of the organic compounds is summarised in Figure 6.23.
The compound identified correctly by the greatest number of pupils was the alcohol (188, 68.1%), and the compound that the least number of pupils identified correctly was the ketone (129, 46.7%). The most common incorrect responses in the classification of each group are included with the percentage of incorrect responses in the red sections of the bars in Figure 6.23. However, it should be noted that some other incorrect responses were given in each of the cases; the responses named in the Figure 6.23 are only the most common responses. 19 (6.80%) of the same pupils incorrectly identified the ketone as an aldehyde and the aldehyde as a ketone. It is clear that many pupils cannot distinguish between these functional groups, as was also found in Questions One and Two.
Question Nine- Properties of Organic Compounds


Circle which one of the compounds below has the higher boiling point:

\[ \text{CH}_3\text{OH} \quad \text{or} \quad \text{CH}_3\text{CH}_3 \]

Explain why?

________________________

b) Circle which one of the compounds below would be more soluble in H\textsubscript{2}O:

\[ \text{CH}_3\text{OH} \quad \text{or} \quad \text{CH}_3\text{CH}_3 \]

Explain why?

________________________

Figure 6.24 Question Nine in the Second-Level Pupil Diagnostic Test- Properties of organic compounds.

Question Nine (Figure 6.24) assessed the pupils’ knowledge of the physical properties of organic compounds, comparing alcohols and alkanes. This question was attempted by 205 (74.3%) of the pupils and had the third-best median score of 50% (20/40). The mean percentage score for this question was 55.0%. The performance in Question Nine is summarised in Figure 6.25.

Figure 6.25 Pupils’ performance in Question Nine – Properties of Organic compounds (n=276).
Overall, the pupils were better able to identify the alcohol as having a higher boiling point (178, 64.5%) than it being more soluble in water (168, 60.9%). Also more pupils were able to provide a valid explanation for choosing methanol as having the higher boiling point (135, 48.9%) than for being more soluble (126, 45.6%). In both cases just over 41 (15.0%) of pupils identified the correct compound, without an accurate and correct explanation. This suggests that these correct responses may have been guesses, or maybe facts that the pupils had rote learned without understanding. The most common of the incorrect reasons (46, 16.7%) for methanol having a higher boiling point than water was ‘due to the -OH group’ (14, 30.0%) and ‘alcohols have a higher boiling point than alkanes’ (7, 15.0%). Neither of these reasons were marked as correct as they only partially explain the reason. These pupils did not mention that the intermolecular bonds (hydrogen bonding) in the alcohol are stronger than the intermolecular bonds (van der Waals) in the alkane.

Similar incorrect responses were given by the pupils to explain why methanol is more soluble in water than the alkane. These included ‘alcohols are more soluble in water’ (9, 20.0%) and simply ‘the OH group’ (16, 35.0%).

6.2.4. Diagnostic Test- Summary and Analysis

The pupils’ performance in each of the questions on the Diagnostic Test has been discussed and outlined in Section 6.2.3. This section will summarise the pupils’ overall performance in the Diagnostic Test and also investigate any factors that may have contributed to their overall performance and response to the questions.

6.2.4.1. Summary of pupils’ performance in the Diagnostic Test

There were nine questions in the Second-Level Diagnostic Test. Only 5 (1.8%) of the pupils did not attempt to answer any of the questions in the Diagnostic Test. 122 (44.2%) of the pupils attempted to answer all nine of the questions. Pupils attempted to answer an average of seven questions out of nine. This was a good level of attempt by the pupils with only 46 (16.7%) of the pupils attempting less than five of the questions.

Table 6.4 provides a summary of the number and percentage of pupils that attempted each question. Each question is marked according to its popularity. It can be seen that Question One was the most popular question (attempted by 269, 97.5%) and Question Seven was the least popular question (attempted by just 153, 55.4%). Reaction mechanism is only on the
Higher Level Leaving Certificate syllabus. Therefore, it is not surprising that only 6 (22.0%) of the 27 Ordinary Level pupils attempted this question. However, 99 (80.5%) of the Higher Level pupils made no attempt to answer this question.

Table 6.4 Summary of the pupils’ attempt per question in the Second-Level Diagnostic Test (n=276).

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Percentage Attempted (%)</th>
<th>Attempt Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing</td>
<td>269 (97.5%)</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Nomenclature</td>
<td>252 (91.3%)</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Isomerism</td>
<td>246 (89.1%)</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Electron Density</td>
<td>229 (83.0%)</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Reaction types</td>
<td>231 (83.7%)</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Organic synthesis</td>
<td>188 (68.1%)</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Organic mechanism</td>
<td>153 (55.4%)</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>Classification</td>
<td>214 (77.5%)</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Physical Characteristics</td>
<td>205 (74.3%)</td>
<td>7</td>
</tr>
</tbody>
</table>

There was a large drop-off in the percentage of attempts at Question Six. 88 (31.9%) of the pupils did not attempt this question. Half (45, 51.0%) of these 88 pupils did not attempt any of the remaining questions in the test (Questions Seven, Eight and Nine). It is unknown whether these pupils may not have had enough time to complete the Diagnostic Test (beyond Question Five) or whether they lost their concentration or interest in completing the test. However, it is worth noting that the majority of the pupils ~75% had sufficient time and maintained their interest in the Diagnostic Test to complete Questions Eight and Nine. Of those that attempted questions Eight and Nine, 199 (72.1%) of the same pupils attempted both of these questions. The poor level of attempt in Questions Six and Seven in comparison to the increased level of attempt in Questions Eight and Nine indicates that these questions were deliberately avoided by some pupils and thus reinforces that Synthesis and Mechanisms are difficult topics for learners.

The scores (as percentage values) for each question were analysed and tested using the Kolmogorov-Smirnov Test. It was found that the distribution of scores for all of the questions was not normal (p < 0.001). For this reason, the median score for each question along with the interquartile range is given in Table 6.5. The interquartile range describes the dispersion.
in the pupils’ scores between the upper (75\textsuperscript{th}) and lower (25\textsuperscript{th}) quartiles. The mean percentage scores are also included in Table 6.5 as a point of interest. The final column ‘Mark order’ summarises the highest and lowest scoring questions.

Table 6.5 Summary of the pupils’ performance per question in the Second-Level Diagnostic Test (n=276).

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Mean score (%)</th>
<th>Inter Quartile Range</th>
<th>Median score (%)</th>
<th>Mark Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing</td>
<td>77.0</td>
<td>40</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Nomenclature</td>
<td>44.9</td>
<td>62</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Isomerism</td>
<td>66.3</td>
<td>60</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Electron Density</td>
<td>50.7</td>
<td>50</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Reaction types</td>
<td>45.6</td>
<td>50</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Organic synthesis</td>
<td>46.5</td>
<td>100</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Organic mechanism</td>
<td>28.6</td>
<td>50</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>Classification</td>
<td>56.5</td>
<td>100</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Physical Characteristics</td>
<td>55.0</td>
<td>100</td>
<td>50</td>
<td>3</td>
</tr>
</tbody>
</table>

As well as being the most popular question, Question One was also one of the best answered questions along with Question Three. Question Seven was the least popular question and the worst answered. The median score of zero here is because when marking the Diagnostic Test, the pupils who did not attempt a question or answered incorrectly were marked a score of zero. All pupils were marked out of a total of 360 marks (nine questions x 40 marks) and not just on the questions that they attempted. This should be kept in mind when looking at the median scores for all of the questions. The questions with a poor attempt rate also have a low median score due to this factor.

Table 6.6 shows the performance of the pupils in each of the questions with the omission of the non-attempts.
Table 6.6 Summary of the pupils’ performance per question in the Second-Level Diagnostic Test with omission of the non-attempts.

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Attempts n (%)</th>
<th>Mean score (%)</th>
<th>Median score (%)</th>
<th>Median score (out of 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing</td>
<td>269 (97.5%)</td>
<td>79.0</td>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>Nomenclature</td>
<td>252 (91.3%)</td>
<td>49.2</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Isomerism</td>
<td>246 (89.1%)</td>
<td>74.4</td>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>Electron Density</td>
<td>229 (83.0%)</td>
<td>61.0</td>
<td>75</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Reaction types</td>
<td>231 (83.7%)</td>
<td>54.2</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>Organic synthesis</td>
<td>188 (68.1%)</td>
<td>68.3</td>
<td>83</td>
<td>33.2</td>
</tr>
<tr>
<td>7</td>
<td>Organic mechanism</td>
<td>153 (55.4%)</td>
<td>51.6</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>Classification</td>
<td>214 (77.5%)</td>
<td>72.9</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>9</td>
<td>Physical Characteristics</td>
<td>205 (74.3%)</td>
<td>74.0</td>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>

The median scores in Table 6.6 are based solely on the number of pupils that attempted each of the questions. In comparison to the scores given in Table 6.5, it can be seen that there are no differences in the median scores for Questions One to Three, since these questions were all highly attempted. However, when pupils who didn’t attempt questions (zero marks) are omitted from the analysis, it can be seen that the performance in Questions Four to Nine is different than that outlined in Table 6.5. In particular, it is worth noting the median score for Question Seven (50%, 20/40) when the non-attempts are omitted. It is also interesting to observe that the median scores in Questions Eight and Nine were both 100% (40/40). It is clear that the pupils (~75% of the total cohort) who continued to complete the Diagnostic Test and attempt these questions performed very well. This suggests that if all of the pupils had attempted these questions (assessing Classification and Physical Characteristics) these topics may have resulted in having a higher overall score than Drawing or Isomerism.

The Kolmogorov-Smirnov Test was also used to test the distribution of the pupils’ overall performance in the Diagnostic Test. The distribution was found to be not normal (p < 0.001). The histogram is shown in Figure 6.26. The mean score was 52.58% and the median score was 51.5%. For this reason, any of the hypothesis tests used to investigate factors contributing to the pupils’ performance in the Diagnostic Test were non-parametric tests. The tests used have been explained in Chapter Four (Section 4.3.1).
6.2.4.2. Analysis of pupils’ performance in the Diagnostic Test

The pupils involved in this study were from 35 different Second-Level schools around Ireland. There were five different types of Second-Level schools involved in the study; boys’ secondary (median score = 71.5%), girls’ secondary (median score = 59.0%), co-educational secondary (median = 49.0%), community (median = 44.5%) and vocational (median = 27.0%). The boys’ secondary schools had the highest median score, while the vocational schools had the lowest score in the Diagnostic Test. However, the Kruskal-Wallis Test found no significance in this difference in performance between the school types (H (4) =7.306, p=.0121).

In total, 92 (33.3%) of the participants were male and 182 (65.9%) were female (two of the participants did not give their gender in the questionnaire). Even though the females (median score = 53.0%, IQR= 45.25) performed better than the males (median score = 49.0%, IQR= 51.75), the Mann-Whitney U Test did not find this difference to be significant (U=7504.000, p=0.161).
Most of the pupils participating were in sixth year (258, 93.5%). These pupils (median score = 54.0%, IQR= 48.25) did perform better than the fifth year pupils (median score = 16.0%, IQR= 25.50). This difference was significant using the Mann-Whitney U Test (U=900.000, p <0.001). These differences were as expected as the sixth year pupils had a broader knowledge of Chemistry as they had studied the subject for longer. These pupils would have had a greater knowledge of other areas of the Chemistry course which contribute to their understanding of Organic Chemistry. The sixth year pupils attempted an average of five more questions than the fifth year pupils.

246 (89.1%) of the pupils in the study were studying Higher Level Chemistry while 27 (9.8%) were studying Ordinary level. The Higher Level pupils (median score= 54%, IQR=46.00) performed better than the Ordinary Level pupils (median score =18%, IQR=15.00). This difference was found to be significant using the Mann-Whitney U Test (U= 1037.000, p<0.001). The Higher Level pupils attempted an average of three more questions than those studying Ordinary Level. The Higher Level pupils would have been expected to have a deeper understanding of Chemistry than the Ordinary Level cohort. Figure 6.27 provides a comparison of performance in each test questions by the Higher and Ordinary Level Chemistry pupils.

![Figure 6.27 Pupils’ performance per question and level of Leaving Certificate Chemistry (n=273).](image)

*Note: The median percentage scores of zero for the Ordinary Level pupils in Questions Three, Four, Six, Seven and Eight is because a score of zero was given when no attempt was made to answer the question.*
The Higher Level pupils performed significantly better than the Ordinary Level pupils in all questions. The Mann-Whitney U Test statistics and level of significance are listed in Table 6.7 below.

Table 6.7 Mann-Whitney U Test statistics and significance for influence of Level of Chemistry studied and performance in each test question.

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Mann-Whitney U Test statistic</th>
<th>Level of significance</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1014.000</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>2</td>
<td>1103.500</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>3</td>
<td>1023.500</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>4</td>
<td>1549.500</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>5</td>
<td>1578.000</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>6</td>
<td>1473.000</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>7</td>
<td>2048.500</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>8</td>
<td>1424.000</td>
<td>p &lt; 0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>9</td>
<td>2151.000</td>
<td>p = 0.002</td>
<td>✔ ✔</td>
</tr>
</tbody>
</table>

Note: As can be seen in Table 6.7 ✔ ✔ ✔ is used to indicate the level of significance where p<0.001. These ‘ticks’ will be used for the remainder of results presented in this thesis. ✔ ✔ will be used to indicate where the level of significance is p < 0.01 and ✔ will be used to indicate where the level of significance is p <0.05.

223 (80.8%) of the Chemistry pupils in this study were studying a second Leaving Certificate Science subject. Table 6.8 provides a summary of the pupils’ performance according to the other Science subjects they were studying for their Leaving Certificate.

Table 6.8 Pupils performance in the Diagnostic Test and study of other Science subjects (n=273).

<table>
<thead>
<tr>
<th></th>
<th>Number of pupils (% of total)</th>
<th>Median Test score (%)</th>
<th>Interquartile range</th>
</tr>
</thead>
<tbody>
<tr>
<td>One other Science subject</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biology</td>
<td>140 (50.7%)</td>
<td>54</td>
<td>50.75</td>
</tr>
<tr>
<td>Physics</td>
<td>50 (18.1%)</td>
<td>64</td>
<td>43.50</td>
</tr>
<tr>
<td>Agricultural Science</td>
<td>4 (1.4%)</td>
<td>40.5</td>
<td>44.00</td>
</tr>
<tr>
<td>Two other Science subjects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics and Biology</td>
<td>20 (7.2%)</td>
<td>77.5</td>
<td>52.75</td>
</tr>
<tr>
<td>Agricultural Science and Biology</td>
<td>4 (1.4%)</td>
<td>42</td>
<td>27.5</td>
</tr>
<tr>
<td>No other Science subject</td>
<td>55 (19.9%)</td>
<td>38</td>
<td>39</td>
</tr>
</tbody>
</table>
The Kruskal-Wallis Test found that pupils studying a second Science subject performed significantly better than those that were only studying Chemistry ($H (8) = 21.566, p = 0.006$). Three pupils are omitted from the results in Table 6.8 as they were the only pupils studying their combination of subjects. The results in Table 6.8 show that the pupils studying one or more other Science subjects as well as Chemistry performed better than those studying Chemistry alone. The pupils studying another physical science i.e. Physics performed better than those studying a life science subject as their second subject i.e. Biology or Agricultural Science. This trend may suggest that the pupils studying the physical sciences are operating at a higher level of cognitive ability and so have a better understanding of Organic Chemistry.

Figure 6.28 shows the pupils’ performance in the Diagnostic Test with respect to their study of Junior Certificate Science. While it is surprising to see that the pupils who hadn’t studied any Junior Certificate Science had a higher median score than those that had studied the subject, it is important to note that only four pupils had not studied the subject. The numbers of pupils in each category are listed in the box beside the bar chart in Figure 6.28. The Kruskal-Wallis Test showed that the study of Junior Certificate Science had a significant effect on the pupils’ performance in the Diagnostic Test ($H (2) = 10.288, p = 0.006$).

![Study of Junior Certificate Science and Diagnostic Test performance (n=273)](image)

*Figure 6.28 Pupils’ performance in the Diagnostic Test and study of Junior Certificate Science (n=273).*

The box plot in Figure 6.29 illustrates the average percentage score and dispersion of scores attained by the pupils who achieved the different grades at Higher Level and Ordinary Level Junior Certification Science.
The Kruskal-Wallis Test found that the difference in Diagnostic Test performance (Figure 6.29) was also significant ($H(7) = 41.874$, $p < 0.001$). The Jonckheere-Terpsta Test observed a significant trend of decreasing performance in the Diagnostic Test in concurrence with decreasing Junior Certificate Science examination results (Std. J-T statistic $= -4.872$, $p < 0.001$). The pupils Diagnostic Test scores are listed in Table 6.9 with details of their performance in Junior Certificate Science.

**Table 6.9 Performance details of pupils’ score in the Diagnostic Test and grade in Junior Certificate Science ($n=140$)**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Median Test score (%)</th>
<th>Interquartile range</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>76</td>
<td>29.75</td>
<td>56</td>
</tr>
<tr>
<td>B</td>
<td>53.5</td>
<td>42.5</td>
<td>58</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>54.00</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>26.75</td>
<td>6</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>
In summary, Figure 6.29 and Table 6.9 show that pupils who studied Junior Certificate Science at Higher Level and performed better in the examination performed significantly better in the Organic Chemistry Diagnostic Test also. In addition to investigating the effect of studying other Science subjects as well as participation and performance in Junior Cycle Science, it is important also to consider the pupils’ level of Leaving Certificate Mathematics and their performance in the Junior Certificate Mathematics examination.

Table 6.10, which follows summarises the pupils’ performance in the Diagnostic Test with reference to the level of Mathematics that they studied for their Junior Certificate and the level that they were studying for their Leaving Certificate.

<table>
<thead>
<tr>
<th>Level</th>
<th>No. of pupils (% of total)</th>
<th>Median score (%)</th>
<th>Interquartile range</th>
<th>Mann-Whitney U Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Junior Certificate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>244 (88.4%)</td>
<td>56</td>
<td>49.00</td>
<td>U= 11308.000 p &lt;0.001</td>
</tr>
<tr>
<td>Ordinary</td>
<td>27 (9.8%)</td>
<td>21</td>
<td>27.00</td>
<td></td>
</tr>
<tr>
<td><strong>Leaving Certificate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher</td>
<td>162 (58.7%)</td>
<td>67</td>
<td>44.25</td>
<td>U= 5544.500 p &lt;0.001</td>
</tr>
<tr>
<td>Ordinary</td>
<td>112 (40.6%)</td>
<td>39</td>
<td>32.50</td>
<td></td>
</tr>
</tbody>
</table>

The Mann-Whitney U Test was used to investigate if the level of Mathematics studied had a significant effect on the pupils’ performance in Organic Chemistry. The test statistics and significance level included in Table 6.10 show that the level of Mathematics studied at Junior and Senior Cycle did have a significant effect on the pupils’ overall performance.

Figure 6.30 shows a breakdown of performance in each of the test questions with respect to the level of Leaving Certificate Mathematics studied. The Higher Level Mathematics pupils performed significantly better than the Ordinary Level pupils in all of the nine questions. The best questions answered by the Ordinary Level pupils were Questions One (Drawing organic compounds) and Three (Isomerism). Question One was also one of the best answered questions by the Higher Level pupils along with Question Nine (Physical Characteristics of organic compounds).
CHAPTER SIX  CYCLE ONE: RESULTS (I) - SECOND-LEVEL STUDY

Figure 6.30 Pupils’ performance per question and level of Leaving Certificate Mathematics (n=274).
Note: The median scores of zero for the Ordinary Level pupils in questions six and seven is because a score of zero was given when no attempt was made to answer the question.

The Mann-Whitney U Test statistics and level of significance for the results shown in Figure 6.10 are listed in Table 6.11.

Table 6.11 Mann-Whitney U Test statistics and significance for influence of level of Mathematics studied and performance in each test question.

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Mann-Whitney U Test statistic</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6224.500</td>
<td>p &lt;0.001</td>
</tr>
<tr>
<td>2</td>
<td>5297.500</td>
<td>p &lt;0.001</td>
</tr>
<tr>
<td>3</td>
<td>6424.000</td>
<td>p &lt;0.001</td>
</tr>
<tr>
<td>4</td>
<td>6685.500</td>
<td>p &lt;0.001</td>
</tr>
<tr>
<td>5</td>
<td>6949.000</td>
<td>p =0.001</td>
</tr>
<tr>
<td>6</td>
<td>5759.000</td>
<td>p &lt;0.001</td>
</tr>
<tr>
<td>7</td>
<td>7349.000</td>
<td>p =0.003</td>
</tr>
<tr>
<td>8</td>
<td>6660.000</td>
<td>p &lt;0.001</td>
</tr>
<tr>
<td>9</td>
<td>5966.000</td>
<td>p &lt;0.001</td>
</tr>
</tbody>
</table>

Figures 6.27 and 6.30 show that pupils studying Higher Level Chemistry and Higher Level Mathematics for their Leaving Certificate performed better in all questions in the Diagnostic Test. When reading these results, it is important to understand that 156 (56.5%) of the overall cohort were studying both Mathematics and Chemistry at Higher Level.
The box plot in Figure 6.31 shows the median score and dispersion of performance of the pupils in the Diagnostic Test with respect to their Junior Certificate Mathematics grade. It can be seen that the pupils who performed better in their Junior Certificate Mathematics also performed better in Organic Chemistry. The box plot in Figure 6.31 provides an illustration to support the summary of findings in Table 6.10. The Kruskal-Wallis Test found that this difference in performance in Organic Chemistry in the Diagnostic Test according to Junior Certificate Mathematics performance was also significant ($H(8)= 41.982$, $p <0.001$). The Jonckheere-Terpstra Test observed a trend of decreasing performance in the Organic Chemistry Diagnostic Test as the performance and level of Junior Certificate Mathematics decreased (Std. J-T statistic = -4.651, $p <0.001$).

![Performance in the Diagnostic Test and Junior Certificate Mathematics grade](image)

**Figure 6.31 Comparison of pupils’ performance in the Diagnostic Test and performance in Junior Certificate Mathematics ($n=177$).**

Note: There is a large dispersion in the median scores of the pupils who scored an Ordinary Level D in their Junior Certificate Science because there were just two pupils within that specific cohort; one had a median score of 13% and the other was 59%.

In this section, a number of factors have been investigated to identify the dynamics contributing to the non-parametric nature of the distribution of results in the Diagnostic Test. Table 6.12 provides a summary of the variables that have been discussed so far.
Table 6.12 Summary of factors contributing to the pupils’ performance in the Diagnostic Test.

<table>
<thead>
<tr>
<th>Variable Factor</th>
<th>Hypothesis Test used</th>
<th>Level of Significance</th>
<th>Concluding trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>School Type</td>
<td>Kruskal-Wallis Test</td>
<td>✓</td>
<td>Boys’ secondary schools had the highest average score and the vocational schools had the lowest, no significant difference between schools.</td>
</tr>
<tr>
<td>Gender</td>
<td>Mann-Whitney U Test</td>
<td>✓</td>
<td>The females’ average test score was 4% greater than males’, but not significant.</td>
</tr>
<tr>
<td>Year of study</td>
<td>Mann-Whitney U Test</td>
<td>✓ ✓ ✓</td>
<td>6th years performed significantly better than 5th years.</td>
</tr>
<tr>
<td>Level of Chemistry</td>
<td>Mann-Whitney U Test</td>
<td>✓ ✓ ✓</td>
<td>HL pupils had a significantly higher overall score than the OL pupils. HL pupils attempted more of the test questions. HL pupils performed significantly better than the OL pupils in all of the questions in the Diagnostic Test.</td>
</tr>
<tr>
<td></td>
<td>Mann-Whitney U Test</td>
<td>✓ ✓ ✓</td>
<td></td>
</tr>
<tr>
<td>Study of other Science subjects</td>
<td>Kruskal-Wallis Test</td>
<td>✓ ✓ ✓</td>
<td>Pupils studying any second Science subject performed significantly better than those just studying Chemistry. Pupils with Physics as the second subject performed better than those studying a life science subject with Chemistry.</td>
</tr>
<tr>
<td>Junior Certificate Science Level</td>
<td>Kruskal-Wallis Test</td>
<td>✓ ✓ ✓</td>
<td>Pupils who had studied HL Science performed significantly better than those that had studied OL.</td>
</tr>
<tr>
<td>Junior Certificate Science Grade</td>
<td>Kruskal-Wallis Test</td>
<td>✓ ✓ ✓</td>
<td>Pupils who achieved higher grades in the JC examination scored higher in the Diagnostic Test.</td>
</tr>
<tr>
<td></td>
<td>Jonckheere-Terpsta Test</td>
<td>✓ ✓ ✓</td>
<td></td>
</tr>
<tr>
<td>Junior Certificate Mathematics Level</td>
<td>Mann-Whitney U Test</td>
<td>✓ ✓ ✓</td>
<td>Pupils that had studied HL performed significantly better than those with OL Mathematics.</td>
</tr>
<tr>
<td>Junior Certificate Mathematics Grade</td>
<td>Kruskal-Wallis Test</td>
<td>✓ ✓ ✓</td>
<td>Pupils who achieved higher grades scored higher in the Diagnostic Test.</td>
</tr>
<tr>
<td></td>
<td>Jonckheere-Terpsta Test</td>
<td>✓ ✓ ✓</td>
<td></td>
</tr>
<tr>
<td>Leaving Certificate Mathematics</td>
<td>Mann-Whitney U Test</td>
<td>✓ ✓ ✓</td>
<td>Pupils studying HL had a higher score in the Diagnostic Test. HL pupils performed better than the OL in all of the questions.</td>
</tr>
</tbody>
</table>

In a part A of the Pupil Questionnaire, the pupils were asked to mark on a Likert rating scale their attitude towards learning a number of Organic Chemistry topics. A five point scale was
used: 1= Really easy, 2= Easy, 3= Neutral, 4=Difficult and 5= Really difficult. Figure 6.32 provides a summary of the average rating for each of the topics listed.

Figure 6.32 Pupils’ median Likert rating of Organic Chemistry topics (n=276).

The topics that are shown with hashed bars in Figure 6.32 are topics that were directly assessed in the Diagnostic Test. The pupils’ performance in each of these topics in the Diagnostic Test is shown in Figure 6.33. Electron Density is shown with a solid bar in Figure 6.33. This is the only topic that was assessed in the Diagnostic Test but was not directly listed in the topics for the pupils to rate on the Likert scale.
Comparing Figures 6.32 and 6.33, it can be seen that Drawing and Isomerism were the best answered questions. These topics were respectively rated as easy and neutral by the pupils in the Likert scale. The most poorly answered topics (with the lowest median percentage scores) were Organic Mechanism and Organic Reactions. These topics were rated as difficult and neutral respectively by the pupils on the Likert scale.

Due to the non-parametric results in the test questions and the ordinal data from the Likert scale, the Kruskal-Wallis Test was used to investigate if the pupils’ rating of the topics had a significant relationship with the score achieved when answering a question on the topic. Before carrying out these tests, the Likert rating results were grouped into three categories as shown in Table 6.13. Really easy and Easy were grouped as ‘Easy’, while difficult and really difficult were simple grouped as ‘Difficult’. The Jonckheere-Terpsta Trend test was used to investigate the significance of the trend observed. The test statistics for both of these tests and the levels of significance are given in Table 6.13 which follows. Table 6.13 also highlights the most common trend of attitude toward each topic as expressed by the pupils. This is given as the number of pupils (and percentage of the total, n= 276). The median percentage score for the test question for each topic is also given for comparison with the attitudes shown.
Table 6.13 Comparison of pupils’ attitudes to Organic Chemistry topics and test performance in the topics (n=276).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Easy</th>
<th>Neutral</th>
<th>Difficult</th>
<th>Median Percentage score (%)</th>
<th>Kruskal-Wallis Test H (2) =</th>
<th>Level of significance</th>
<th>Johckheere-Terpsta Trend Test Statistic</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td>201 (72.8%)</td>
<td>45 (16.3%)</td>
<td>28 (10.1%)</td>
<td>80</td>
<td>25.815</td>
<td>P &lt; 0.001</td>
<td>-5.058</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Nomenclature</td>
<td>163 (59.1%)</td>
<td>65 (23.6%)</td>
<td>46 (16.7%)</td>
<td>50</td>
<td>21.434</td>
<td>P &lt; 0.001</td>
<td>-4.443</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Classification</td>
<td>130 (47.1%)</td>
<td>76 (27.5%)</td>
<td>59 (21.4%)</td>
<td>60</td>
<td>27.538</td>
<td>P &lt; 0.001</td>
<td>-5.109</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Isomerism</td>
<td>121 (43.8%)</td>
<td>81 (29.3%)</td>
<td>65 (23.6%)</td>
<td>80</td>
<td>20.356</td>
<td>P &lt; 0.001</td>
<td>-4.426</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Characteristics</td>
<td>80 (20.0%)</td>
<td>120 (43.5%)</td>
<td>63 (22.8%)</td>
<td>50</td>
<td>6.777</td>
<td>P = 0.034</td>
<td>-2.313</td>
<td>P = 0.021</td>
</tr>
<tr>
<td>Organic Reactions</td>
<td>65 (23.6%)</td>
<td>82 (29.7%)</td>
<td>112 (40.6%)</td>
<td>40</td>
<td>3.538</td>
<td>P = 0.171</td>
<td>-0.977</td>
<td>P = 0.329</td>
</tr>
<tr>
<td>Organic Mechanism</td>
<td>54 (19.6%)</td>
<td>70 (25.4%)</td>
<td>138 (50.0%)</td>
<td>0</td>
<td>5.664</td>
<td>P = 0.059</td>
<td>-1.288</td>
<td>P = 0.198</td>
</tr>
<tr>
<td>Organic Synthesis</td>
<td>53 (19.2%)</td>
<td>76 (27.5%)</td>
<td>132 (47.8%)</td>
<td>50</td>
<td>5.439</td>
<td>P = 0.066</td>
<td>-1.6441</td>
<td>P = 0.101</td>
</tr>
</tbody>
</table>
From Table 6.13, it can be seen there was a significant relationship between the topics described as easy or neutral and the pupils’ test performance in these topics. The Jonckheere-Terpsta Trend Test statistics are negative and significant for each of these topics also. These topics (Drawing, Nomenclature, Isomerism, Classification and Characteristics) which were rated low on the Likert scale (1, 2, 3- indicating that they were not difficult) were the same topics that the pupils scored well on in the Diagnostic Test (median percentage score 50-80%). In these cases, the pupils had an accurate perception of the ‘easy’ topics. However, it can be seen that the pupils’ rating on the Likert scale for their attitudes to the remaining topics (Organic Reactions, Mechanism and Synthesis) did not have a significant effect on the pupils’ performance in these topics in the Diagnostic Test. Given the low median scores for these topics, this suggests that performance in these questions was not dependent on whether the pupils rated the topics as easy or difficult. These findings reinforce previous evidence that Reactions, Mechanism and Synthesis are among the most difficult topics in Organic Chemistry.

There was no significant correlation between the pupils’ attitudes to the topics and their level of attempt of the questions assessing the topics. However a trend was observed where the topics that had been rated as really easy or easy were attempted by higher numbers of pupils.

The main findings from parts A and B of the Second-Level Pupil Questionnaire (I) are summarised at the end of this chapter (Section 6.4.1).
6.3 - Chemistry Teacher Questionnaire

The Chemistry Teacher Questionnaire was distributed to 79 Second-Level Chemistry teachers in 73 different schools teaching Leaving Certificate Chemistry. This questionnaire was distributed in May and November 2010. Details of the design and distribution of the questionnaire are outlined in Section 4.6 of Chapter Four. The Chemistry Teacher Questionnaire is included in Appendix F.

It can be seen from Table 6.14 that the 73 participating schools were representative of all schools in Ireland teaching Leaving Certificate Chemistry.

Table 6.14 Gender and type of the 73 schools in the Second-Level Teacher Study.

<table>
<thead>
<tr>
<th>SCHOOL GENDER</th>
<th>SCHOOL TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Girls</td>
</tr>
<tr>
<td>Schools teaching Leaving Certificate Chemistry (546)</td>
<td>136 (24.9%)</td>
</tr>
<tr>
<td>Schools randomly chosen and asked to participate. (N=100)</td>
<td>33 (33.0%)</td>
</tr>
<tr>
<td>Schools where teachers participated in the study. (n=73)</td>
<td>18 (24.6%)</td>
</tr>
</tbody>
</table>

Six of the 73 schools returned two Chemistry Teacher Questionnaires. The gender of one teacher was not given, however, of the remaining 78 teachers, the gender breakdown was as follows: 19 male (26%) and 59 female (81%).

Leaving Certificate Chemistry is a two-year course. Figure 6.34 below shows the stage of the two year course when the teachers generally teach the Organic section of the course. Organic Chemistry accounts for ~20% of the Leaving Certificate and so deserves approximately one fifth of the class time in the two-year syllabus.

The majority of teachers (29, 37.0%) teach Organic Chemistry in one term; Autumn in 6th year. In total 46 (58.0%) of the teachers spread the teaching of the Organic course over two school terms. The most popular two terms were Summer of 5th year and Autumn of 6th year (27, 34.0%). Most teachers indicated that they introduce
Organic Chemistry through fuels, heats of reaction and oil refining in Summer of fifth year and move onto the Organic families in Autumn of 6th year.

The teachers indicated their attitudes towards Organic Chemistry, by responding to three statements on a five point Likert rating scale. On the scale 1 = Strongly agree, 2= Agree, 3= Neutral, 4= Disagree and 5 = Strongly Disagree. The teachers were also asked to indicate what they think most closely represents their pupils’ attitudes towards Organic Chemistry. The teachers’ attitudes as well as their perception of their pupils’ attitudes to Organic Chemistry are shown in Table 6.15. Due to the non-parametric nature of the ordinal data from the Likert scales used, the median ratings for each of the statements are included.

**Table 6.15 Chemistry teachers’ own attitudes and perceptions of their pupils’ attitudes to teaching and learning Organic Chemistry on a five-point Likert scale (n=79).**

<table>
<thead>
<tr>
<th>Organic Chemistry is…</th>
<th>Teachers’ own perspective</th>
<th>General Trend</th>
<th>Teachers’ perspective of their pupils’ attitudes</th>
<th>General Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interesting</td>
<td>1</td>
<td>Strongly Agree</td>
<td>2</td>
<td>Agree</td>
</tr>
<tr>
<td>Enjoyable</td>
<td>2</td>
<td>Agree</td>
<td>3</td>
<td>Unsure</td>
</tr>
<tr>
<td>Easy to teach /learn</td>
<td>2</td>
<td>Agree</td>
<td>4</td>
<td>Disagree</td>
</tr>
</tbody>
</table>
Most of the teachers agreed that Organic Chemistry is interesting and enjoyable to teach. However, the teachers were undecided whether Organic Chemistry was easy to teach or not. This was highlighted in their response to an open-ended question after the Likert scale rating. Of the 67 teachers who answered the open-ended question about Organic Chemistry being easy or difficult to teach, 42 (63.0%) of these said it was easy to teach with fewer (25, 38.0%) finding Organic Chemistry difficult to teach. The main reasons given by teachers who found Organic Chemistry easy to teach was that it is a logical topic (22, 54.0%) and also interesting and relevant to everyday life (16, 39.0%). The main reason given by the teachers who found it difficult to teach was the large amount of information to be taught in the syllabus (17, 68.0%).

Even though the teachers felt that the pupils found Organic Chemistry interesting, they also acknowledged that the pupils don’t find it easy to learn. 70 (87.0%) of the teachers answered the open-ended question about their pupils’ perspective of learning Organic Chemistry. 53 (76.0%) of these teachers felt that their pupils find Organic Chemistry difficult to learn mainly due to the overload of information they are expected to learn (27, 51.0%), and also the difficulty of distinguishing the functional groups (10, 19.0%). 16 (21.0%) of the teachers felt their pupils find Organic Chemistry easy to learn because of the logical nature of the organic families (12, 75.0%).

The mandatory experiments are numbered 1 to 8 on the x-axis in Figure 6.35. These experiments are named and listed in Table 6.16 that follows. Table 6.16 can be used as a legend for Figure 6.35.
Figure 6.35 Completion of Organic Chemistry mandatory experiments (n=79).

Table 6.16 List of Organic Chemistry Mandatory Experiments.

<table>
<thead>
<tr>
<th>Mandatory Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Preparation and properties of ethyne</td>
</tr>
<tr>
<td>2 Preparation and properties of ethene</td>
</tr>
<tr>
<td>3 Preparation and properties of ethanal</td>
</tr>
<tr>
<td>4 Preparation and properties of ethanoic acid</td>
</tr>
<tr>
<td>5 Extraction of clove oil from cloves by steam distillation.</td>
</tr>
<tr>
<td>6 Preparation of soap.</td>
</tr>
<tr>
<td>7 Separation of a mixture of indicators using paper chromatography or thin-layer chromatography or column chromatography.</td>
</tr>
<tr>
<td>8 Recrystallisation of benzoic acid and determination of its melting point.</td>
</tr>
</tbody>
</table>

Figure 6.35 above shows the breakdown of how the mandatory experiments were carried out in the schools involved in the study. The pupils carried out the experiments themselves in most cases (average = 66.0%). The experiments carried out by the pupils themselves in most cases were the Separation of mixtures by chromatography (71, 90.0%) and the Recrystallisation of benzoic acid (67, 86.0%). The experiment not carried out at all in the highest number of schools (15, 20.0%) and carried out by the pupils themselves in the least number of schools (15, 20.0%) was the Extraction of Clove Oil using steam distillation. Reasons given by the teachers for experiments that were not carried out included a lack of equipment (36, 46.0%), time limitations (17, 22.0%) and the safety (26, 33.0%) of some of the set-ups and apparatus. One teacher described the experiments as “a waste of time, and they [the pupils] get confused”
(School R). Due to lack of resources, the pupils needed to work in large groups rather than pairs in many of the schools. Some teachers suggested and recommended the use of videos of the experiments that they cannot carry out in the laboratories (13, 17.0%). Other teachers explained how demonstrating the experiments rather than having the pupils carrying them out themselves allows the teacher to explain what is happening more clearly and facilitates pupil understanding.

Table 6.17 shows the topics listed in the Leaving Certificate Organic Chemistry course. The teachers were asked to indicate the difficulty of teaching each topic on a five-point Likert scale ranging from 1 = Very Easy to 5 = Very Difficult. Due to the non-parametric nature of the ordinal data, the median score as well as the 25th and 75th percentiles are included in the table. The mean scores from the Likert ratings are also included as a point of interest.

<table>
<thead>
<tr>
<th>Table 6.17 Likert rating of teaching the different Organic topics (n=79).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drawing Organic Compounds</strong></td>
</tr>
<tr>
<td>Mean: 1.78</td>
</tr>
<tr>
<td>25th Percentile: 1</td>
</tr>
<tr>
<td>50th Percentile: 2</td>
</tr>
<tr>
<td>Median: 2</td>
</tr>
<tr>
<td>75th Percentile: 2</td>
</tr>
<tr>
<td>General Trend: Easy</td>
</tr>
<tr>
<td><strong>Nomenclature</strong></td>
</tr>
<tr>
<td>Mean: 1.94</td>
</tr>
<tr>
<td>25th Percentile: 1</td>
</tr>
<tr>
<td>50th Percentile: 2</td>
</tr>
<tr>
<td>Median: 2</td>
</tr>
<tr>
<td>75th Percentile: 2</td>
</tr>
<tr>
<td>General Trend: Easy</td>
</tr>
<tr>
<td><strong>Classification of Organic Compounds</strong></td>
</tr>
<tr>
<td>Mean: 2.18</td>
</tr>
<tr>
<td>25th Percentile: 1</td>
</tr>
<tr>
<td>50th Percentile: 2</td>
</tr>
<tr>
<td>Median: 3</td>
</tr>
<tr>
<td>75th Percentile: 3</td>
</tr>
<tr>
<td>General Trend: Easy</td>
</tr>
<tr>
<td><strong>Isomerism</strong></td>
</tr>
<tr>
<td>Mean: 2.51</td>
</tr>
<tr>
<td>25th Percentile: 2</td>
</tr>
<tr>
<td>50th Percentile: 2</td>
</tr>
<tr>
<td>Median: 3</td>
</tr>
<tr>
<td>75th Percentile: 3</td>
</tr>
<tr>
<td>General Trend: Easy</td>
</tr>
<tr>
<td><strong>Characteristics of Organic Compounds</strong></td>
</tr>
<tr>
<td>Mean: 2.81</td>
</tr>
<tr>
<td>25th Percentile: 2</td>
</tr>
<tr>
<td>50th Percentile: 3</td>
</tr>
<tr>
<td>Median: 4</td>
</tr>
<tr>
<td>75th Percentile: 4</td>
</tr>
<tr>
<td>General Trend: Indifferent</td>
</tr>
<tr>
<td><strong>Organic Reactions</strong></td>
</tr>
<tr>
<td>Mean: 3.09</td>
</tr>
<tr>
<td>25th Percentile: 2</td>
</tr>
<tr>
<td>50th Percentile: 3</td>
</tr>
<tr>
<td>Median: 4</td>
</tr>
<tr>
<td>75th Percentile: 4</td>
</tr>
<tr>
<td>General Trend: Indifferent</td>
</tr>
<tr>
<td><strong>Organic Mechanisms</strong></td>
</tr>
<tr>
<td>Mean: 3.52</td>
</tr>
<tr>
<td>25th Percentile: 3</td>
</tr>
<tr>
<td>50th Percentile: 4</td>
</tr>
<tr>
<td>Median: 4</td>
</tr>
<tr>
<td>75th Percentile: 4</td>
</tr>
<tr>
<td>General Trend: Difficult</td>
</tr>
<tr>
<td><strong>Organic Synthesis</strong></td>
</tr>
<tr>
<td>Mean: 3.39</td>
</tr>
<tr>
<td>25th Percentile: 2</td>
</tr>
<tr>
<td>50th Percentile: 4</td>
</tr>
<tr>
<td>Median: 4</td>
</tr>
<tr>
<td>75th Percentile: 4</td>
</tr>
<tr>
<td>General Trend: Difficult</td>
</tr>
<tr>
<td><strong>Organic Natural Products</strong></td>
</tr>
<tr>
<td>Mean: 2.68</td>
</tr>
<tr>
<td>25th Percentile: 2</td>
</tr>
<tr>
<td>50th Percentile: 3</td>
</tr>
<tr>
<td>Median: 3</td>
</tr>
<tr>
<td>75th Percentile: 3</td>
</tr>
<tr>
<td>General Trend: Indifferent</td>
</tr>
<tr>
<td><strong>Oil Refining and Products</strong></td>
</tr>
<tr>
<td>Mean: 2.28</td>
</tr>
<tr>
<td>25th Percentile: 1</td>
</tr>
<tr>
<td>50th Percentile: 2</td>
</tr>
<tr>
<td>Median: 3</td>
</tr>
<tr>
<td>75th Percentile: 3</td>
</tr>
<tr>
<td>General Trend: Easy</td>
</tr>
<tr>
<td><strong>Chromatography</strong></td>
</tr>
<tr>
<td>Mean: 1.95</td>
</tr>
<tr>
<td>25th Percentile: 1</td>
</tr>
<tr>
<td>50th Percentile: 2</td>
</tr>
<tr>
<td>Median: 2</td>
</tr>
<tr>
<td>75th Percentile: 2</td>
</tr>
<tr>
<td>General Trend: Easy</td>
</tr>
<tr>
<td><strong>Instrumentation</strong></td>
</tr>
<tr>
<td>Mean: 3.43</td>
</tr>
<tr>
<td>25th Percentile: 2</td>
</tr>
<tr>
<td>50th Percentile: 3</td>
</tr>
<tr>
<td>Median: 5</td>
</tr>
<tr>
<td>75th Percentile: 5</td>
</tr>
<tr>
<td>General Trend: Indifferent</td>
</tr>
</tbody>
</table>

The most difficult topics to teach were Organic Synthesis and Organic Mechanisms. As can be seen in Table 6.17, the teachers listed many of the topics as easy to teach. 73 of the 78 teachers answered an additional open-ended question identifying the most difficult topics to teach. The Organic Chemistry topics that the teachers find most difficult to teach are presented in Figure 6.36 as the teachers’ top three most difficult topics to teach.
Figure 6.36 Organic Chemistry topics that teachers find most difficult to teach (n=73).

Reasons given by the teachers for the difficulty with teaching Instrumentation included the load of information for the pupils to memorise, as well as difficulties in distinguishing between the principles and processes of the different instrumentation techniques. 31 (74.0%) of these teachers who listed Instrumentation, alluded to the difficulty of teaching the topic with the fact that many of themselves or the pupils had never used or even seen the processes. Vague syllabus description of the topic made Instrumentation difficult to teach also. The second overall most difficult topic to teach was Organic Mechanisms. The main reason given by teachers for this was the difficult concepts to be understood (16, 38.0%) and the difficulty the pupils have in visualising the steps of the mechanisms (13, 35.0%). Mechanisms, Synthesis and Reactions are difficult to teach, as are Reaction Schemes as they rely on the pupils’ full and clear understanding of the functional groups of the different families of compounds and their characteristics. Many teachers have recognised the high cognitive demand of Organic Reactions, Mechanisms and Synthesis as they integrate everything else that the pupils have learned in Organic Chemistry. This is the stage of the course where pupil misconceptions become evident to the teacher. Many of the
teachers recognised the pupils’ attempt to ‘learn off’ reactions and mechanisms because they have no understanding of the functional groups and transfer of electrons etc., they cannot comprehend the abstract concept, ‘there is nothing concrete for the students to grasp’ (School T). Other Organic Chemistry topics identified as difficult to teach by less than 9 (12.0%) of the teachers were Organic Schemes, Classification of Organic compounds, Drawing Organic compounds, Nomenclature, Isomerisation and Mathematics calculations in Organic Chemistry.

Figure 6.37 shows the topics that the teachers thought their pupils have difficulty learning. Some similarities can be found between Figures 6.36 and 6.37.

![Figure 6.37 Organic Chemistry topics that teachers perceive pupils find difficult to learn (n=79).](image)

A common top four difficult topics can be identified from both Figure 6.36 and 6.37: Organic Mechanisms, Synthesis, Reactions and Instrumentation. While Instrumentation was the number one most difficult topic to teach, Organic Mechanisms was the topic that 59 (75.0%) of the teachers thought their pupils found most difficult to learn. Overall Figures 6.36 and 6.37 suggest that the topics that
teachers consider most difficult to teach are also the topics that they perceive their pupils have difficulty learning. Perhaps this suggests that if better teaching strategies or approaches were available for and used by these teachers, these topics may become easier to teach, and in turn easier for the pupils to learn and understand. However, it is also important to acknowledge that the topics identified as most difficult to teach and learn in Figure 6.36 and 6.37 respectively are topics that require high cognitive demand and abstract thought (Shayer and Adey 1981). Therefore, these findings should not be surprising and are in-line with previous literature.

64 (81.0%) of the teachers involved in the study used the ‘Chemistry Live!’ textbook written by Declan Kennedy (2000). 10 (13.0%) of the teachers used ‘Understanding Chemistry’ written by Jim McCarthy and Terence White (2004). One teacher used ‘Chemistry for Today’ by Randal L. Henly (1979). 14 (18.0%) of the teachers followed the sequence of the Leaving Certificate Chemistry syllabus when teaching Organic Chemistry, and 44 (56.0%) of the teachers followed the sequence in their respective textbooks. Of these, 39 (87.0%) were following the sequence of the ‘Chemistry Live!’ textbook, and 4 (9.00%) were following the sequence of the ‘Understanding Chemistry’ book. The order of the Organic Chemistry content of both these text-books and the syllabus is outlined in Table 6.18 which follows. The Chapter titles are written in bold and underlined, and the main topics covered in each chapter are listed below each heading. There is little variation in the sequencing of the topics in both textbooks used by the Chemistry teachers. The syllabus content is listed sequentially in Table 6.18 with the omission of intervening topics that are not classified as ‘Organic Chemistry’ in this research project i.e. Heats of reaction. It can be seen that both books loosely follow the order of topics in the syllabus: beginning with hydrocarbons, oil refining and fuels and progressing to other families of organic compounds. The reactions, mechanisms and synthesis are all included together as a unit. Chromatography and instrumentation are taught as separate topics at the end of the Organic Chemistry section. It is important to consider the order in which teachers are teaching Organic Chemistry. As discussed in Chapter Three, what may appear logical and understandable to the expert (teacher) may not be logical for the novice learner. It is important that Organic Chemistry is taught in a psychological order to allow the pupils to develop and progress their knowledge of the organic families, reactions and mechanisms in an understandable and contextual manner.
Table 6.18 Sequencing of Organic Chemistry topics in two Leaving Certificate text-books and the Leaving Certificate Chemistry syllabus.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 5.1 Sources of Hydrocarbons</td>
<td>Fuels and Heats of Reaction</td>
<td>Fuels and Heats of Reactions</td>
</tr>
<tr>
<td>Section 5.2 Structure of Aliphatic hydrocarbons</td>
<td></td>
<td>- Hydrocarbons</td>
</tr>
<tr>
<td></td>
<td>Some families of Organic Compounds</td>
<td>- Oil Refining and Products</td>
</tr>
<tr>
<td>Section 5.3 Aromatic Hydrocarbons</td>
<td>- Tetrahedral Carbon compounds</td>
<td>Organic Compounds</td>
</tr>
<tr>
<td>Section 5.5 Oil Refining and its products</td>
<td>- Planar Carbon compounds</td>
<td>- Tetrahedral Carbon compounds</td>
</tr>
<tr>
<td>Section 5.6 Other Chemical Fuels</td>
<td>- Organic Natural Products</td>
<td>- Planar Carbon compounds</td>
</tr>
<tr>
<td>Section 7.1 Tetrahedral Carbon</td>
<td>Types of Reactions in Organic Chemistry</td>
<td>- Organic Natural Products</td>
</tr>
<tr>
<td>Section 7.2 Planar Carbons</td>
<td>- Substitution reactions</td>
<td>Organic Chemical Reactions</td>
</tr>
<tr>
<td>Section 7.3 Organic Chemical Reaction Types</td>
<td>- Addition reactions</td>
<td>- Addition reactions</td>
</tr>
<tr>
<td>Section 7.4 Organic Natural Products</td>
<td>- Elimination reactions</td>
<td>- Substitution reactions</td>
</tr>
<tr>
<td>Section 7.5 Chromatography and Instrumentation in Organic Chemistry</td>
<td>- Organic Synthesis</td>
<td>- Elimination reactions</td>
</tr>
<tr>
<td></td>
<td>- Organic Synthesis</td>
<td>- Chromatography and Instrumentation in Organic Chemistry</td>
</tr>
</tbody>
</table>

20 (26.0%) of the teachers did not strictly follow the sequencing of either the syllabus or textbook, but instead used a combination of the syllabus and their textbook (10, 13.0%) or their own unique approach (10, 13.0%). These teachers used the textbook and syllabus as a guideline and also their own discretion. Several teachers indicated that they adapted their teaching approach to accommodate to the ability of their class group. Functional groups, the mandatory experiments and Fuels and Heats of reaction were common starting points for many of these teachers. Some teachers also tended to
teach each homologous group separately and then use their own reaction schemes to facilitate the pupils’ overall understanding. An important factor raised by many of these teachers was that the sequence of teaching the Organic Chemistry topics was dependent on the pupils’ level of ability. These teachers also left the teaching of Organic Mechanisms until the last to teach, as they felt it culminates other knowledge learned in Organic Chemistry.

As well as investigating the sequence of teaching and textbooks used by the Leaving Certificate Chemistry teachers, information was also sought from the teachers (n=44) about what resources they use to facilitate their teaching of organic compounds. (It was explained in Chapter Four (Section 4.8.1.1) why only 44 of the teachers were asked this question).

The most common resource used by 19 (43.0%) of the teachers who were asked this question was molecular models. Such models are useful to illustrate molecular shape and bonding. This in turn can facilitate the comprehension of different characteristics and functional groups of the families of organic compounds. 9 (20.0%) of the teachers used PowerPoint presentations to facilitate their teaching of Organic Chemistry.

In an open-ended question at the end of the questionnaire, further suggestions were made by the teachers for resources that they felt would facilitate their teaching of Organic Chemistry in the Leaving Certificate. These included a visit to an industry or Third-Level laboratory to facilitate the pupils’ understanding of the instrumentation learned in Organic Chemistry, as most of the equipment that the pupils learn about is not seen in Second-Level school laboratories. The availability of a laboratory technician was recommended to assist the teachers in the time-consuming set-ups and practical work, which is an important and time-consuming part of Organic Chemistry. Micro-scale laboratory equipment would also increase the possibility of teachers completing the practical work within the double class periods. Many teachers asked for ‘visual aids’ to facilitate their teaching and increase the level of pupil understanding. Visual aids suggested included: Power-Point illustrations (22, 28.0%), posters, and animations of reaction schemes and mechanisms (18, 23.0%), DVD’s and videos of experiments that they cannot carry out in the laboratory and of oil refining etc. (25, 32.0%). Many of the teachers suggested the need for Organic Chemistry to
become more ‘hands-on’ to boost the level of pupil understanding e.g. the use of models to represent the three-dimensional structures (22, 28.0%). Worksheets for formative assessment were suggested as exam questions are only useful towards the end of the course for revision. Some teachers recognised the need to link Organic Chemistry learned in school with the pupils’ lives as well as the context and applications of Chemistry in the broader world. The value of an Organic Chemistry workshop for the teachers was also mentioned in order to learn procedural tips and alternative methods using the apparatus actually available in schools. Other suggestions made by individual teachers included the colour coding of reactions and reaction types, mini-whiteboards and pens for students when doing mechanisms, educational board games and relevant newspaper / magazine articles about the applications of Organic Chemistry e.g. pharmaceutical links.

The main findings from the Chemistry Teacher Questionnaire are summarised in Section 6.4.2 that follows.

6.4 Summary of findings from the Second-Level Study

The findings from the Second-Level study have been presented in detail in this chapter. The main findings from the participating pupils and teachers are summarised below.

6.4.1. Main findings from Second-Level Pupil Questionnaire (I)

Part A of this questionnaire provided the researcher with information about the pupils’ Science and Mathematics background as well as their attitudes to studying Organic Chemistry in the Leaving Certificate:

- Almost all of the pupils had studied Junior Certificate Science.
- The Chemistry pupils’ study of other Leaving Certificate Science subjects was in line with the national trend (Biology being the most popular).
- The percentage of pupils that had studied Higher Level Junior Certificate Mathematics and continued to study Higher Level Leaving Certificate Mathematics was above the national trend.
- Although most of the pupils found Organic Chemistry for the Leaving Certificate enjoyable, the majority of pupils found it difficult to learn and understand.
• The pupils had a positive attitude towards the practical work in Organic Chemistry.
• Topics that were identified as difficult to learn included Organic Reactions, Organic Synthesis, Organic Mechanisms, Instrumentation and Functional Groups.
• Topics that were identified as easy to learn included Drawing organic compounds, Nomenclature, Oil refining and products and Chromatography.

Part B of the Second-Level Pupil Questionnaire (I) was a Diagnostic Test. Analysis of test performance showed that:
• The median test percentage score was 51.5%.
• The best answered questions were those assessing Drawing of organic compounds and Isomerism.
• The worst answered question was the question assessing Organic Mechanism.
• In comparison to findings from part A, pupils had an accurate perception of the topics predicted as ‘easy’ as these were the best answered topics in the Diagnostic Test.
• However, many pupils had a false perception of their understanding of the more difficult topics. Pupils performed poorly in these topics whether they were rated as easy or difficult (Reactions, Mechanisms and Synthesis).
• Factors that had a significant effect on pupils’ performance in the Diagnostic Test included the pupils’ year of study, current level of Leaving Chemistry and Mathematics, study of other Science subjects as well as their level and grade in Junior Certificate Mathematics and Science.
• The type of school that the pupils were attending and their gender did not have a significant effect on pupils’ performance in the Diagnostic Test:

6.4.2. Main findings from Chemistry Teacher Questionnaire
The main findings from the Chemistry Teacher Questionnaire are listed here:
• Most teachers teach Organic Chemistry in the Summer term of fifth year and in the Autumn term of sixth year.
• Most teachers showed a positive attitude towards Organic Chemistry; finding is interesting, enjoyable and easy to teach.
• The main reasons given by teachers for not carrying out practical work or for doing demonstrations instead of allowing pupils to carry out the work were related to limited availability of equipment, limited time and the safety of some preparations.

• Topics that the teachers rated as easy to teach included: Drawing organic compounds, Nomenclature, Classification of organic compounds, Isomerism, Oil refining and products and Chromatography.

• Topics that the teachers rated as difficult to teach included: Organic Mechanisms, Organic Synthesis, Organic Reactions and Instrumentation. The teachers predicted that the pupils find these same topics difficult to learn.

• Most teachers follow the sequence of their textbook when teaching Organic Chemistry. The majority of teachers use the same textbook- *Chemistry Live!* (Kennedy, 2000), which follows a sequence of topics similar to the Leaving Certificate Chemistry syllabus.

• Teachers expressed the need for more Organic Chemistry teaching resources; posters, summary charts, animations, videos, hands-on activities for pupils and tools for formative assessment.

These findings will be discussed in Chapter Nine along with the findings from the Third-Level study also carried out in Cycle One of this research project.
Chapter 7
Cycle One
Results (II)-
Third-Level Study
7.1 - Introduction

As explained in Chapter Four, two separate studies were carried out in Cycle One of the research project: the Second-Level study and the Third-Level study. The results and findings of the Second-Level study have been presented in Chapter Six.

The Third-Level study was also part of Cycle One of the research project. The Third-Level study consisted of a Third-Level Student Questionnaire and an Organic Chemistry Lecturer Questionnaire. The Third-Level Student Questionnaire was made up of two parts. The results and analysis of part A, which sought information about the students’ Science and Mathematics background is presented in Sections 7.2.1 and 7.2.2. Part B of the questionnaire was a Diagnostic Test. The students’ performance in each question as well as an analysis of overall performance in the Diagnostic Test is presented in Sections 7.2.3 and 7.2.4 respectively. The findings from the Organic Lecturer Questionnaire are presented in Section 7.3 of this chapter. The main findings from the Third-Level study are summarised in the final Section of this chapter (7.4).

7.2 – Third-Level Student Questionnaire

121 students completed the Third-Level Student Questionnaire. 55 (45.5%) of the participants were male and 62 (51%) were female. This cohort consisted of three class groups from the one university (participating class sizes of 26, 21 and 39) and one class group each from two Institutes of Technology (participating class sizes 17 and 18). In total, five class groups completed the Third-Level Student Questionnaire. Within each of the class groups, there was a combination of students from different courses of study. The course of study and previous study of Chemistry of the participants is outlined in Table 7.1. It should be noted that the number of students from each course as listed in Table 7.1 refers to the number of students in that course and class group that participated in the research study. Not all of the students in all of the courses and classes completed the Third-Level Student Questionnaire. Leaving Certificate Chemistry was not a compulsory entry requirement for any of these courses. The number of students in each course of study that had studied Leaving Certificate Chemistry at Higher and Ordinary level is outlined Table 7.1 also. The CAO points-system for entry to Third-Level education has been outlined in Chapter 2 (Section 2.2.1). The entry point required for the courses of study are included in Table 7.1 also.
Table 7.1 Breakdown of the institutes, courses of study, and previous chemistry experience of the participating students (n=121).

<table>
<thead>
<tr>
<th>Third Level Institution</th>
<th>Course of study (Bachelor of Science)</th>
<th>Number of students (% of total sample)</th>
<th>Year of study</th>
<th>Previous Chemistry studied at third level</th>
<th>Leaving Certificate Chemistry</th>
<th>CAO entry points</th>
</tr>
</thead>
<tbody>
<tr>
<td>University (Class 1)</td>
<td>Environmental Science</td>
<td>12 (9.9)</td>
<td>2</td>
<td>General Inorganic</td>
<td>4 x HL, 1 x OL, 7 x None</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>Health and Safety</td>
<td>10 (8.3)</td>
<td>2</td>
<td>General Inorganic</td>
<td>1 x HL, 1 x OL, 8 x None</td>
<td>320</td>
</tr>
<tr>
<td></td>
<td>Physical Education and Chem</td>
<td>3 (2.5)</td>
<td>1</td>
<td>General Inorganic</td>
<td>3 x HL</td>
<td>495</td>
</tr>
<tr>
<td>University (Class 2)</td>
<td>Biological Science with Chemistry</td>
<td>16 (13)</td>
<td>2</td>
<td>General Inorganic</td>
<td>11 x HL, 5 x None</td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>Chemistry and Physics</td>
<td>5 (4.1)</td>
<td>2</td>
<td>General Inorganic and Analytical</td>
<td>4 x HL, 1 x None</td>
<td>460</td>
</tr>
<tr>
<td>University (Class 3)</td>
<td>Food Science and Health</td>
<td>18 (15)</td>
<td>2</td>
<td>General (1and2) Organic (1) Analytical</td>
<td>5 x HL, 1 x OL, 12 x None</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>Industrial Biochemistry</td>
<td>13 (11)</td>
<td>2</td>
<td>General (1and2) Organic (1) Analytical</td>
<td>8 x HL, 1 x OL, 4 x None</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td>Pharmaceutical and Industrial Chemistry</td>
<td>8 (6.6)</td>
<td>2</td>
<td>General Organic (1) Analytical Physical (1and2) Inorganic(1and2)</td>
<td>7 x HL, 1 x None</td>
<td>365</td>
</tr>
<tr>
<td>Institute of Technology 1</td>
<td>Pharmaceutical and Forensic analysis</td>
<td>9 (7.4)</td>
<td>2</td>
<td>General Inorganic</td>
<td>5 x HL, 4 x None</td>
<td>390</td>
</tr>
<tr>
<td></td>
<td>Drug and Medicinal analysis</td>
<td>6 (5.0)</td>
<td>2</td>
<td>General Inorganic</td>
<td>1 x OL, 5 x None</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Environmental and Chemical analysis</td>
<td>1 (0.8)</td>
<td>2</td>
<td>General Inorganic</td>
<td>None</td>
<td>240</td>
</tr>
<tr>
<td>Institute of Technology 2</td>
<td>Forensic and Environmental Analysis</td>
<td>10 (8.3)</td>
<td>2</td>
<td>General Environmental Forensic</td>
<td>3 x HL, 2 x OL, 5 x None</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>Science with Nanotechnology</td>
<td>8 (6.6)</td>
<td>2</td>
<td>General Inorganic</td>
<td>4 x HL, 4 x None</td>
<td>315</td>
</tr>
</tbody>
</table>
7.2.1. Section A- Results

7.2.1.1. Students’ Science and Mathematics background

As can be seen in Figure 7.1, Biology was the most popular choice of Science subject studied at Second-Level by these students. This conforms to the national trend. In total 63 (52.1%) of the students had studied Chemistry at Second-Level. (56, 89% at Higher Level and 7, 11% at Ordinary Level). 58 (47.9%) of the students had not studied any Chemistry at Second-Level.

![Science subjects studied at Second Level](n=109)

There were 12 students who had not studied any Science subject for their Leaving Certificate. For 6 of the 63 (52.1%) of students who had studied Chemistry at Second-Level, Chemistry was the only Science subject that they had studied. Table 7.2 that follows shows the other Science subjects studied by the remaining 57 students who studied Leaving Certificate Chemistry.

*Table 7.2 Other Science subjects studied by students at Second-Level as well as Chemistry (n=63).*

<table>
<thead>
<tr>
<th></th>
<th>Higher Level Chemistry (n=56)</th>
<th>Ordinary Level Chemistry (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>36 (64.0%)</td>
<td>2 (29.0%)</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>-</td>
<td>2 (29.0%)</td>
</tr>
<tr>
<td>Physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>21 (38.0%)</td>
<td></td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>-</td>
<td>2 (29.0%)</td>
</tr>
<tr>
<td>Agricultural Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>11 (20.0%)</td>
<td>-</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>1 (2.00%)</td>
<td>-</td>
</tr>
<tr>
<td>Physics and Chemistry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>1 (2.00%)</td>
<td>-</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>-</td>
<td>1 (14.0%)</td>
</tr>
</tbody>
</table>
Figure 7.2 shows the students’ performance in their Leaving Certificate Chemistry examination.

![Figure 7.2 Students’ performance in Leaving Certificate Chemistry examination (n=63).](image)

It is assumed that most of this cohort of students sat the Leaving Certificate examination in June 2009. Based on this assumption, the percentage of Higher Level A’s was below the national average of 21.9% for 2009 (Duane and Regan 2009). However, the overall percentage of A,B,C grades was 89.0% which was above the average of 77.6% for the same year (Duane and Regan 2009). However, the percentage of A grades at Ordinary Level was above the national average of 9.20% for 2009, as was the percentage achieving A,B,C grades, where the national average was 63.2% for 2009 (Duane and Regan 2009).

51 (41.1%) of the students had studied Higher Level Mathematics for their Leaving Certificate and 60 (49.6%) had studied Ordinary Level Mathematics. The national percentage of students studying Higher Level Mathematics in 2009 was 18.4% (SEC 2009), so the percentage of students in this cohort that studied Higher Level Mathematics for their Leaving Certificate was much higher (41.1%). The students’ performance in their Leaving Certificate Mathematics is summarised is Figure 7.3.
Figure 7.3 Students’ performance in Leaving Certificate Mathematics examination (n=111).

The percentage of students achieving an A in Higher Level Mathematics (5.8%) was below the national average of 15% for 2009 (SEC 2009). However, the percentage of students in this cohort that achieved an A in Ordinary Level Mathematics (44%) was much higher than the national average of just 12.7% for 2009 (SEC 2009).

7.2.1.2. Students’ attitudes to Organic Chemistry at Third-Level

The students were asked to indicate on a five-point Likert scale their attitude towards different Organic Chemistry topics. On the scale 1 = really easy, 2 = easy, 3 = neutral, 4 = difficult and 5 = really difficult. A summary of the findings from this question are included in Table 7.3. The distribution of the ordinal data from the Likert scales for each of the 10 topics was found to be not normal using the Kolmogorov-Smirnov Test, as the data was non-parametric. For this reason, the median and percentile values are shown in Table 7.3. The mean scores are also included as a point of interest.
As can be seen from Table 7.3, Drawing organic compounds was the only topic that the students described as easy. The topics described as particularly difficult by the students were Reaction Types, Reaction Mechanisms and Organic Synthesis.

Table 7.1 showed the breakdown of the students in the 5 class groups that completed the questionnaire. As outlined in Table 7.1, one of these class groups from the university had studied a previous module of Organic Chemistry. For each of the other four class groups, this questionnaire was distributed towards the end of their first module of Organic Chemistry at Third-Level. In answering this question, the students were specifically asked about their attitudes to Organic Chemistry at Third-Level. However, these attitudes to the specific topics may have been developed from their study of Chemistry at Second-Level (63 (52.1%) of the students).
7.2.2. Part A-Analysis

Third-Level students from five different class groups completed the Third-Level Student Questionnaire. Second-Level Chemistry was not a specific entry requirement for any of the courses of study. Some (12, 9.9%) of the students had not studied any Science subject for their Leaving Certificate while 63 (52.1%) had studied Chemistry. Many of the students that had studied Chemistry also studied other Science subjects at Second-Level (Table 7.2).

The Leaving Certificate grades achieved in Chemistry and Mathematics among participating students was compared with the national averages for 2009 (SEC 2009). The percentage of students achieving an A grade and the percentage of those achieving A, B, C grades in Chemistry was much higher than the national average. This may suggest that many of these students who had studied Leaving Certificate Chemistry are operating at the formal stage of cognitive development, since Chemistry is identified as a multi-dimensional subject with a high cognitive demand (Johnstone 2000a).

A greater percentage (41.1%) of students in this sample group had studied Higher Level Mathematics than was observed in the national average (18.4%) for 2009 (SEC 2009). Again this suggests that the many of the students involved in this study may have been operating at the formal stage of cognitive development. However, when the students’ grade performance in Higher Level Mathematics was compared with the national average, the percentage achieving an A grade was below the national average. In comparison, the percentage achieving an A grade at Ordinary Level greatly exceeded the national average.

As well as the diverse study of Science and Chemistry at Second-Level, the students from the different course groups had studied Chemistry to a different extent at Third-Level. One of the university classes were studying their second module of Organic Chemistry while each of the other four participating class groups were at the end of their first module of Organic Chemistry at Third-Level.

The questionnaire was distributed at the end of the students’ study of Introductory Organic Chemistry at Third-Level to investigate the particular topics that the pupils find difficult at this stage. It should be noted also that some of the class groups had studied more Chemistry at Third-Level than others. The Chemistry modules covered by each participating group are outlined in Table 7.1. The students’ understanding of General, Inorganic, Physical and
Analytical Chemistry should contribute to their understanding of Organic Chemistry. Many difficulties and misconceptions in Organic Chemistry stem from prior misconceptions developed from other areas of Chemistry e.g. bonding, physical properties, particulate nature of matter etc. The effect of such prior misconceptions has already been discussed in Chapter Three (Section 3.4.4).

These participating students make up a diverse group due to their level of and study of Science and Chemistry at both Second-Level and Third-Level. While the same questionnaire and Diagnostic Test was distributed to all participants, the influence of their diverse backgrounds will be investigated in Section 7.2.4 with respect to their performance in the Diagnostic Test and attitudes to Organic Chemistry. Section 7.2.3 which follows will outline the students’ performance in each of the questions in the Third Level Diagnostic Test.

7.2.3. Diagnostic Test – Results

The Third-Level Diagnostic Test was made up eight questions. Each question assessed the students’ understanding of a different Organic Chemistry topic. The eight questions were evenly weighted. Each question was worth five marks, resulting in an overall test score of 40 marks (8 questions x 5 marks each). In this section, each question will be presented with an individual analysis of the students’ attempt and performance in each question. A snapshot of each question is shown to facilitate the reader’s understanding of the results. The complete Third-Level Diagnostic Test is included in Appendix G.
Question One- Drawing organic compounds:

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>Condensed Structure</th>
<th>Extended Structure</th>
<th>Skeletal Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane</td>
<td>( \text{CH}_3(\text{CH}_2)_2\text{CH}_3 )</td>
<td>![Extended Structure for Butane]</td>
<td>![Skeletal Structure for Butane]</td>
</tr>
<tr>
<td>3-methylhex-2-ene</td>
<td>( \text{CH}_3\text{CH} = \text{C(CH}_3)_2\text{CH}_2\text{CH}_3 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>![Condensed Structure for Ethanol]</td>
<td>![Extended Structure for Ethanol]</td>
<td></td>
</tr>
<tr>
<td>Cyclohexene</td>
<td>( \text{C}<em>6\text{H}</em>{10} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanoic acid</td>
<td>![Condensed Structure for Ethanoic acid]</td>
<td>![Extended Structure for Ethanoic acid]</td>
<td></td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>( \text{C}_8\text{H}_5\text{CHO} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7.4 Question One in the Third-Level Organic Chemistry Diagnostic Test – Drawing organic compounds.

Figure 7.4 shows Question One of the Diagnostic Test. A half mark was given for each correctly drawn structure. This resulted in a total of 5 marks for the question (10 x 0.5 marks). In this question, the IUPAC names of six organic compounds were presented to the
students. The condensed, extended and skeletal structures of the first compound, butane, were completed for the students. One type of structure for each of the other five compounds was included for the students. This question assessed the students’ ability to draw the named organic compounds using the three different methods of two-dimensional representation. The students had to draw the condensed structure for two compounds, the extended structure for four compounds and the skeletal structure for four compounds. The students could use the IUPAC name of the compound or the type of structure that was given to draw the other two structures.

This question was attempted by 119 (98.3%) of the students. It was the most popular question in the Diagnostic Test. However, it was only one of the third-best answered questions with a median score of 30% (1.5/5). The mean percentage score for Question One was 36.4%.

As can be seen in Figure 7.5, more students attempted to draw the condensed structure of ethanol than ethanoic acid and more students drew it correctly.

![Figure 7.5 Students’ attempt and performance in drawing the condensed structures of ethanol and ethanoic acid (n=121).](image)

9 (24.0%) of the students (84, 30.6%) who attempted to draw the condensed structure of ethanoic acid, but answered incorrectly wrote the molecular formula (C2H4O2) instead of the condensed structural formula representing the RCO2H functional group. A further 8 (22%) of the students answered this part of the question incorrectly by not taking account of the carbon
in the –RCO₂H carboxyl functional group. These students incorrectly gave the condensed structure of propanoic acid (C₂H₅COOH) instead of ethanoic acid (CH₃COOH).

Figure 7.6 shows that the students’ ability to correctly draw the extended structures of the given organic compounds was generally poor, even though this part of Question One was well attempted by the students.

![Figure 7.6 Students’ attempt and performance in drawing the extended structures of 3-methylhex-2-ene, cyclohexene, ethanoic acid and benzaldehyde (n=121).](image)

The extended structure which was drawn correctly by the greatest number of students was ethanoic acid. The extended structure drawn correctly by the least number of students was benzaldehyde. The most common mistake made by 31 (40%) of the 78 (64.4%) students who incorrectly drew the extended structure of 3-methylhex-2-ene was omitting the methyl substituent from the alkene.

In both of the cyclic structures (cyclohexene and benzaldehyde) omission of the carbon and hydrogen atoms was a mistake made by many of the students. This may suggest that the students did not understand clearly how to represent the extended structure of a cyclic compound. 18 (22%) of the 83 (68.6%) students who drew cyclohexene incorrectly did not show any double carbon (C=C) bond. 34 (41%) of the students attempted to draw
cyclohexene as a linear structure. 68 (56.2%) of students attempted to draw the extended structure of benzaldehyde but answered it incorrectly. 16 (24%) of these students did not represent any double bonded carbons in the benzene ring. A further 24 (35%) of the students attempted to draw benzaldehyde as a linear structure.

The part assessing the students’ ability to draw the skeletal structure of the four given compounds was the most poorly attempted part of Question One (Figure 7.7).

![Figure 7.7 Students’ attempt and performance in drawing the skeletal structures of 3-methylhex-2-ene, ethanol, cyclohexene, and benzaldehyde (n=121).](image)

As when drawing the extended structure, the least number of students attempted to draw the skeletal structure of benzaldehyde and it also had the least percentage of correct attempts for the skeletal structure. Only 57 (47.1%) of the students attempted to draw the skeletal structure of benzaldehyde with 21 (17.4%) of the students drawing it correctly. 13 (36.0%) of the 36 (29.8%) who attempted it but answered incorrectly did not show the benzene ring structure. 13 (36.0%) other students attempted to represent it as a linear compound. The skeletal structure that most students drew correctly was ethanol.

54 (44.6%) of the students attempted to draw the skeletal structure of 3-methylhex-2-ene but were incorrect. 34 (63.0%) of these students did not show the methyl group in their skeletal representation. A further 14 (26.0%) of these 54 students did not show the carbon double bond in the skeletal structure. 48 (39.7%) of the students incorrectly attempted to draw the
skeletal structure of cyclohexene. 22 (46.0%) of these students did not show any carbon double bond in their structure. 18 (38.0%) of these 48 students attempted to represent the skeletal structure of cyclohexene as a linear structure.

**Question Two – Identifying organic species**

![Figure 7.8](image.png)

Question Two is shown in Figure 7.8 above. This question assessed the students’ ability to identify different organic species. There was more than one possible correct answer for three of the species to be identified. One mark was given for each of the species identified (4 x 1 marks). A fifth mark was given for correctly identifying a second nucleophile, electrophile or radical.

114 (94.2%) of the students attempted at least part of Question Two. This was the second most popular question in the Diagnostic Test. It was the best answered question with a median score of 60% (3/5). The mean percentage score was 53.3%. The students’ performance in part a) of Question Two is shown in Figure 7.9.
Figure 7.9 Question Two, Part a) Identification of a nucleophile (n=121).

Part a) of question two was attempted by 67 (55.4%) of the students. There were two correct answers to this part; D and F. 54 (44.6%) of the students correctly identified the hydroxyl group as a nucleophile. However, only 13 (10.7%) of the students recognised the C=C carbon double bond in ethene as a nucleophile. The most popular incorrect answer was B. This is surprising as B is a positively charged NO$_2$ ion. Figure 7.10 shows the students’ performance in part b) of Question Two; identification of an electrophile.

Figure 7.10 Question Two, Part b) Identification of an electrophile (n=121).
Part b) of question two was attempted by 66 (54.5%) of the students. There were three correct answers for this part of the question. As can be seen in Figure 7.10, the electrophile correctly identified by the greatest number of students was the positively charged NO$_2$ ion. Fewer students identified the secondary carbocation (28, 23.1%) and the chlorine radical (10, 8.20%) as electrophiles. The most common incorrect answer was the hydroxyl group (F). This is surprising as this is clearly negatively charged. Parts (a) and (b) of Question Two had the highest level of non-attempts. A greater percentage of pupils attempted to identify the carbocation and radical than attempted to identify the nucleophile and electrophile. This can be seen in Figures 7.11 and 7.12 that follow.

![Identifying a Carbocation (n=121)](image)

*Figure 7.11 Question Two, Part c) Identification of a carbocation (n=121).*

Figure 7.11 shows the students’ response to part c) of Question Two. 107 (88.4%) of the students attempted this part of the question with 58 (47.9%) correctly identified the secondary carbocation. The most popular incorrect response was D (ethene). Perhaps this may have been due to the presence of two carbon atoms in the species. 18 (16.8%) of the students who attempted this part of Question Two listed C (methyl radical) as a carbocation. Perhaps this was because the methyl group looked similar to a primary carbocation. This suggests that the students have a poor understanding or recognition of the free radical symbol, •.
Figure 7.12 shows the students’ performance in part d) of Question Two.

![Graph showing identification of radicals](image)

**Figure 7.12 Question Two, Part d) Identification of a radical (n=121).**

Part d) of Question Two was attempted by 89 (73.6%) of the students. There were two radicals to be identified; an atomic radical and an alkyl radical. 86 (71.1%) of the students correctly identified the chlorine radical. Fewer (51, 42.1%) of the students identified the methyl radical correctly. This was the best answered part of Question Two, suggesting that radicals and atomic radicals in particular are the organic species that the students can most easily and correctly identify.
Question Three- Electron Density

Q3. Electron Density

Electronegativity values for use with Question 3:
EN Carbon = 2.5, Hydrogen = 2.2, Oxygen = 3.4, Chlorine = 3.1, Bromine = 2.9.

i) Clearly place ‘δ−’ next to the atom of greatest electron density around it, and ‘δ+’ next to the atom of least electron density around it in each of the two molecules shown below.

\[ \text{H} \overset{\cdot}{\text{C}} \overset{\cdot}{\text{H}} \]

\[ \text{H}_3\text{C} \overset{\cdot}{\text{C}} \overset{\cdot}{\text{H}} \]

ii) Use curly headed arrows to show how propan-2-one (acetone) will react with a proton H⁺.

\[ \text{H}_3\text{C} \overset{\cdot}{\text{C}} \overset{\cdot}{\text{H}} \]

iii) Draw the structure formed from this reaction.

*Hint: There may be a resonance structure involved.*

Figure 7.13 Question Three in the Third-Level Organic Chemistry Diagnostic Test – Electron Density.

Question Three (Figure 7.13) was made up of three parts. In the first part, the electronegativity values were given for the students to use to identify the atom of highest and lowest electron density in both of the compounds shown. A half mark was given for the correct assignment of the δ− and δ+ signs on each compound. This gave a total of 2 marks (4 x 0.5 marks) for part i). One mark was given for part ii) showing the curly arrow to represent the transfer of electrons from one of the lone pairs on the oxygen atom to the positively charged hydrogen atom (electrophile). Two marks were given for part iii); one mark for each of the possible resonance structures. In total 110 (90.9%) of the students attempted at least some part of Question Three. This was the fourth most popular question in the Diagnostic Test, but it was one of the third-best answered questions. The median score was 30% (1.5/5).
The mean percentage score for Question Three was 29.3%. Figure 7.14 shows the students’ performance in part i) of Question Three.

![Graph](image)

**Figure 7.14 Students’ performance in part i) of Question Three –Electron density (n=121).**

A greater percentage of students correctly identified the atoms of highest and lowest electron densities in hydrogen chloride than in ethanal. This may have been because there are just two atoms in hydrogen chloride, and so, reduced the possibility of an incorrect answer even if the students did guess. 22 (18.2%) of the students gave an incorrect answer when identifying the electron density in hydrogen chloride. 9 (41.0%) of these students incorrectly identified the hydrogen atom as the area of greatest electron density while 14 (64.0%) of the students who answered incorrectly listed the chlorine atom as the area of lowest electron density.

65 (53.7%) of the students did not correctly identify oxygen as the area of highest electron density and the hydrogen atom as the area of lowest electron density in the molecule of ethanal. 48 (74.0%) of these students who answered incorrectly identified the central carbon atom as the area of lowest electron density. Even though this was not the atom of lowest electron density in the molecule, these (48) students were correct in suggesting that the carbon atom in the carbonyl group had a lower electron density than the oxygen atom joined to it.
The students’ performance in part ii) of Question Three is shown in Figure 7.15.

Figure 7.15 Students’ performance in Part ii) of Question Three – Movement of electrons (n=121).

The students’ ability to map electron movement by use of curly arrows is dependent on their ability to correctly identify the area of high electron density in ethanal. As seen from Figure 7.14, only 38 (31.4%) of the students correctly identified the areas of highest and lowest electron density in ethanal. In some of the incorrect responses, the students had drawn in more than one incorrect arrow of electron movement. In total 68 (56.2%) of the students answered this part of Question Three incorrectly. 44 (65.0%) of these students drew an arrow coming from the double bond in the carbonyl group. Even though this arrow was incorrect, it does suggest that these students did recognise the double bond as an electron rich area. However, 40 (59.0%) of the students drew an arrow coming from the positive hydrogen atom towards the carbon or oxygen in the ethanal. This incorrect response indicates a misunderstanding of the meaning of curly arrows or the meaning of electron density.

Figure 7.16 shows the students’ poor attempt and poor performance in part iii) of Question Three. The ability to answer part iii) correctly was dependent on the students’ ability to correctly answer the previous two parts of this question. The poor performance in part ii) of the question highlights the students’ misunderstanding of how ethanal will react with a proton. Without being able to answer part ii) of the question correctly, it is not surprising that only a low percentage of students correctly answered part iii) of this question. Only 14 (11.6%) of the students correctly drew the structure formed after the appropriate electron movement and 8 of these students correctly drew the resonance structure of the product formed after the electron movement from the oxygen atom to the proton (H\(^+\)).
Figure 7.16 Students’ performance in Part iii) of Question Three – Structure formed after electron movement (n=121).

Even though 54 (44.6%) of the students did not attempt to draw either resonance structure formed, 53 (43.8%) did attempt to draw the structure but were incorrect. 24 (36%) of these students who were incorrect in their attempt did not show the positive charge on the central carbon atom or on the newly formed hydroxyl group. 15 (22%) of these students did not show the electron pairs on the oxygen atom.

Figure 7.17 shows a grid of organic compounds that was included in the Third-Level Diagnostic Test. This grid of organic compounds labelled A to P was included in the Diagnostic Test after Question Three. Questions Four, Five and Six were based on the compounds in this grid. The students were able to refer to each of the 16 compounds using the letters in the boxes.
Figure 7.17 Grid of compounds in the Diagnostic Test – used with Questions Four, Five and Six.
Question 4 – Naming organic compounds

Figure 7.18 Question Four in the Third-Level Organic Chemistry Diagnostic Test – Naming organic compounds.

Question Four (Figure 7.18) was answered with reference to the grid of 16 organic compounds in Figure 7.17. The students were asked to give the IUPAC name of the five compounds represented by the given letters. One mark was given for each compound that was correctly named (5 x 1 marks). Even though this question was attempted by 95 (78.5%) of the students, it was one of the most poorly answered questions in the Diagnostic Test. The median score was 0% (0/5). The mean percentage score was 16.0%.

Figure 7.19 shows the students’ performance in Question Four.

Figure 7.19 Students’ performance in Question Four of the Diagnostic Test – Naming organic compounds (n=121).
As can be seen in Figure 7.19, compound A (2-methylbutane) was the compound named correctly by the greatest percentage of students. Naming this compound required the students to correctly identify and number the longest continuous carbon chain so that the substituent (methyl) was given the lowest possible number. 56 (47.1%) of the students attempted to name this compound but were incorrect. The most common mistake made by 41 (73.0%) of these students was not identifying the longest chain. Many of these students named the compound as 2-ethylpropane. In the incorrect attempts to name compounds I, M and O, it is clear that the students had some difficulty in differentiating some functional groups. Compound I was an ester (methyl ethanoate) with the functional group $RC(O)OR'$. However, this was incorrectly named as a carboxylic acid and a ketone by many students. Likewise, compound M was a ketone (butan-2-one), but was identified as an aldehyde by many students. 57 (47.1%) of the students named compound N incorrectly. 10 (18.0%) of these students incorrectly identified the aldehyde as a carboxylic acid, and a further 10 (18.0%) of the students named the compound butanol (an alcohol) instead of an aldehyde.

The low percentage of students attempting Question Four (Naming organic compounds) is surprising since this topic was not identified as a difficult topic in part A of the Third-Level Student Questionnaire. It is clear from the similarity between the incorrect responses that the functional groups of esters ($RC(O)OR'$), ketones ($RC(O)R'$), aldehydes ($RC(O)H$), carboxylic acids ($RCO_2H$) and alcohols ($ROH$) are a point of much confusion for many of the students. This issue will be discussed in more detail in Chapter Nine as the same difficulty has been observed with the Second-Level pupils (Chapter Six).

**Question Five – Classification of organic compounds:**

<table>
<thead>
<tr>
<th>FAMILIES OF ORGANIC COMPOUNDS</th>
<th>COMPOUND LETTER(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td></td>
</tr>
<tr>
<td>Aldehyde</td>
<td></td>
</tr>
<tr>
<td>Halalkane</td>
<td></td>
</tr>
<tr>
<td>Alkene</td>
<td></td>
</tr>
<tr>
<td>Cycloalkene</td>
<td></td>
</tr>
<tr>
<td>Alkane</td>
<td></td>
</tr>
<tr>
<td>Cycloalkane</td>
<td></td>
</tr>
<tr>
<td>Ketone</td>
<td></td>
</tr>
<tr>
<td>Carboxylic acid</td>
<td></td>
</tr>
<tr>
<td>Ester</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7.20 Question Five in the Third-Level Organic Chemistry Diagnostic Test – Classification of organic compounds.
Question Five (Figure 7.20) in the Diagnostic Test assessed the students’ ability to recognise, identify and name functional groups. This question was answered with reference to the grid of compounds shown in Figure 7.17. The organic families for 14 of the compounds were listed. The number of correctly classified compounds were calculated as a percentage of 14 to determine the mark for the question out of a total of 5. For some of the families of compounds there was more than one compound that contained the particular functional group. Two of the compounds, F and O were not classified in the list given in the table for Question Five. These variables aimed to limit the possibility of the students answering by elimination and guessing.

113 (93.4%) of the students attempted this question. This was the third most popular question in the Diagnostic Test but it had the highest median score (equal to Question Two). The median score was 60% (3/5). The mean percentage score for this question was 52.7%.

Figure 7.21 shows the percentage of students that classified the compounds into the given list of organic families correctly.

![Classification of organic compounds](image)

*Figure 7.21 Students’ correct responses to Question Five – Classification of organic compounds (n=121).*

From Figure 7.21, it can be seen that the cyclic compounds were classified correctly by the greatest percentage of students. 26 (21.5%) more students identified compound H (butan-1-
ol) as an alcohol than recognised compound D (2-methylpropan-2-ol) as an alcohol. 85 (70.2%) of the students recognised compound C as an alkene. However, much fewer students classified compounds G (43, 35.5%) and L (41, 33.9%) correctly as alkenes. The presence of bromine in both of these compounds may have distracted the students from the central carbon C=C double bond.

Figure 7.22 shows the most common incorrect classifications made by the students who attempted Question Five. The organic families are listed on the x-axis.

The letter in brackets (in Figure 7.22) represents the compound that was most commonly classified incorrectly in that family of compounds i.e. compound J (1-2-dibromoethane) was classified as an alkane by 12 (9.90%) of the students. Compound J should have been classified as a haloalkane. Compounds F (ether) and M (ketone) were incorrectly classified as esters by 14 (11.6%) of the students. Compound P (carboxylic acid) was incorrectly classified as an alcohol (7, 5.8%) and an aldehyde (6, 5.0%) suggesting that the students did not recognise the complete RCO₂H functional group. These students may have recognised either the terminal RC(O) carbonyl group, similar to the functional group of an aldehyde (RC(O)H) or the ROH part of the carboxyl group suggesting an alcohol. Compound N (aldehyde) was incorrectly classified as ketone (5, 4.1%) and a carboxylic acid (5, 4.10%) by the students. This suggests again that the students may have only recognised half or part of the RC(O)H
functional group and also not observed its terminal position. The confusion between functional groups has been identified in Question Four also.

**Question Six – Isomerism:**

![Figure 7.23 Question Six in the Third-Level Organic Chemistry Diagnostic Test – Isomerism.](image)

Figure 7.23 shows Question Six in the Diagnostic Test. The question was answered with reference to the grid of compounds in as shown in Figure 7.17. This question assessed the students’ understanding of Isomerism. The students had to identify structural and geometric isomers. One mark was given for each correctly identified isomer. There were two possible isomers of compound H, so this allowed for a total of five marks for the question (5 x 1 marks). This question was only attempted by 66 (54.5%) of the students. It was the least popular question in the Diagnostic Test. The median score was 20% (1/5). The mean score was 31.1%. Figure 7.24 shows the percentage of students who correctly identified the isomers for each of the compounds given in Question Six.

![Figure 7.24 Students’ correct responses to Question Six – Isomerism (n=121).](image)
CHAPTER SEVEN

CYCLE ONE: RESULTS (II): THIRD-LEVEL STUDY

From Figure 7.24, it can be seen that the greatest percentage of students (61, 50.4%) correctly identified 2, 2-dimethylpropane as a structural isomer of 2-methylbutane. 56 (46.3%) of the students recognised compounds G and L as a pair of geometric isomers. 24 (19.8%) more students recognised compound D (2-methylpropan-2-ol) as an isomer of compound H (butan-1-ol), than recognised compound F as an isomer also.

Figure 7.25 shows the most common incorrect answers given by the students who attempted Question Six.

![Incorrect identification of isomers (n=121)](chart)

**Figure 7.25 Students’ incorrect responses to Question Six – Identification of isomers (n=121).**

22 (18.2%) of the students incorrectly identified compound K (cyclohexene) as an isomer of compound B (cyclohexane). It is clear from this incorrect answer that the pupils did not account for the double carbon C=C bond in the cyclic structure. 16 (13.3%) of the students incorrectly identified compound N (butanal) as an isomer of compound H (butan-1-ol). These students have just recognised the same carbon back-bone on both of these structures. The presence of one oxygen atom in both structures also makes them look similar. However, it is clear that the students did not count the number of hydrogen atoms in each of the compounds.

7 (5.80%) of the students incorrectly identified compound J (1,2-dibromoethane) as an isomer of compound L (1,2-dibromoethene). These students may just have looked for the presence two bromine atoms in an isomer for L, and ignored the carbon C=C double bond.
Question Seven – Shape and structure of hydrocarbons:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of compound</strong></td>
<td><strong>Name of compound</strong></td>
</tr>
<tr>
<td>C-H Bond Angle</td>
<td>C-H Bond Angle</td>
</tr>
<tr>
<td>Molecular shape</td>
<td>Molecular shape</td>
</tr>
<tr>
<td>Hybridisation of the Carbon atom</td>
<td>Hybridisation of the Carbon</td>
</tr>
</tbody>
</table>

**Figure 7.26 Question Seven in the Third-Level Organic Chemistry Diagnostic Test- Shape and structure of hydrocarbons.**

Question Seven (Figure 7.26) assessed the students’ understanding of the shape of hydrocarbons. The simplest alkane (methane) and simplest alkyne (ethyne) were used to assess the students’ understanding of the structure of hydrocarbons from an orbital level (hybridisation) to the shape that they occupy in space.

A flat two-dimensional representation of both structures was given to assess if the students had an understanding of the actual bond angle and shape of the molecules. This bond angle is dictated by the hybridisation of the s and p orbitals. Five marks were given for this question; 2.5 for each hydrocarbon. The marks were divided as 0.5 for the name, 0.5 for the bond angle, 0.5 for the molecular shape and 1 mark for the hybridisation of the carbon atom. Overall 107 (88.7%) of the students attempted part of Question Seven. It was the second best answered question with a median score of 50% (2.5/5). The mean score was 50.4%.

The part of the question assessing the shape and structure of methane was attempted by 102 (84.3%) of the students. However, fewer students (93. 76.9%) attempted the part assessing the understanding of ethyne. Figure 7.27 shows the students’ performance in the assessment of the shape and structure of methane.
44 (36.4%) of the students gave an incorrect answer for the H-C-H bond angle in methane. 13 (30.0%) of these students gave 120° as the bond angle and a further 7 (16.0%) of students said that the bond angle in methane was 90°. These students showed a misunderstanding of the actual shape of methane. 14 (78.0%) of the students who gave an incorrect response for the molecular shape of methane thought that the shape of the molecule was trigonal planar instead of tetrahedral. There were 20 (16.5%) incorrect responses given for the hybridisation of the carbon atom in methane. These included sp² (5, 25.0%) and sp (7, 35.0%) hybridisation of the carbon atom. Figure 7.28 shows the students’ level of understanding of the shape and structure of ethyne.
23 (19.0%) of the students gave an incorrect answer for the molecular shape of ethyne. 17 (74.0%) of these students said that ethyne was planar. 27 (22.3%) of the students gave an incorrect response to the hybridisation of the carbon atom in ethyne. 13 (48.0%) of these 27 students said that the carbon was sp² hybridised, while a further 8 (30.0%) of these incorrect responses were indicating that the carbon was sp³ hybridised.

Comparing the students’ responses to the question assessing shape and structure of methane and ethyne, there is no common trend in the students’ responses to both hydrocarbons. More students may have known the bond angle of ethyne than methane correctly, as the two-dimensional structure of ethyne suggests the 180° angle, while the two-dimensional structure of methane is more misleading. The students showed a poor understanding of the hybridisation of the carbon atom in both compounds. From the incorrect responses given for both compounds, it is clear that there was no common incorrect response among the students. This may suggest that hybridisation is a particular area of difficulty for the students. A common incorrect response could indicate a common misconception, but no common incorrect response is identifiable in this case.

**Question Eight – Mechanism of reactions**

**Figure 7.29 Question Eight in the Third-Level Organic Chemistry Diagnostic Test – Mechanism of reactions.**
Question Eight (Figure 7.29) was the final question on the Diagnostic Test. This question assessed the students’ understanding of organic Reaction Mechanisms. Part a) of question eight assessed the understanding of electron density and movement of electrons. The concept being assessed was similar to part ii) of Question Three. In this case, the students had to use a double-headed arrow to show the electron movement from the double bond in benzene towards the positive electrophile. The students had then to draw the intermediate that was formed. One mark was given for part a) of Question Eight. Parts b), c) and d) assessed the addition reaction to an alkene. One mark was given for drawing the major and minor products formed correctly (part b). One mark was given for naming the reactants and products correctly (part c). Two marks were given for showing the mechanism for the formation of the major product (2,2-bromomethylbutane).

This question was the second poorest attempted question, with only 79 (65.3%) of the students attempting to answer at least some part of Question Eight. It was also the joint worst-answered question, along with Question Four. The median score for Question Eight was 0% (0/5). The mean score was 6.28%. Figure 7.30 shows the students’ poor performance in Question Eight.

![Figure 7.30 Students’ performance in Question Eight – Mechanism of reactions.](image)

Question Eight was poorly attempted and poorly answered by the students. This reinforces previous evidence that reaction mechanisms are a particularly difficult topic for those...
learning Organic Chemistry. 43 (35.5%) of the students attempted part a) of the question but answered incorrectly. 12 (28.0%) of these students drew the arrow for electron movement incorrectly coming from the nitrite electrophile towards the benzene ring. 17 (63.0%) of the incorrect attempts had shown the arrow of electron movement in the correct direction from a double bond in the benzene ring towards the electrophile. However, when drawing the immediate product formed from this electron movement, these students omitted the resonance positive charge on the carbon ring or the hydrogen atom still present at the carbon where the \( \text{NO}_2 \) had joined to. Other attempts were marked as incorrect because the students only drew the correct product of the first step of the reaction (11, 26.0%) or the final product, nitrobenzene (10, 23.0%) without using any arrow to represent electron movement to show how the new products were formed.

In part b) 41 (33.9%) of the students attempted to draw the major product formed but were incorrect. 13 (37.0%) of these incorrect attempts were structures that included a double carbon \( \text{C} = \text{C} \) bond. From these incorrect answers, it suggests that these students (41, 33.9%) did not understand the product of an addition reaction to an alkene would result in a saturated product.

In part b) also, 34 (28.1%) of the students incorrectly attempted to draw the structure of the minor product formed. 22 (65.0%) of these students drew small (diatomic) molecules such as hydrogen, bromine as the minor products. Perhaps, the title ‘minor product’ may have misled these students to thinking that the minor product was smaller than the major product.

As can be seen in Figure 7.30, more students were able to name the reactants than were able to correctly name the products of the reaction. This is not surprising as the correct structures of the reactants were given in the question and the ability to name the products correctly was dependent on the students’ ability to draw the products correctly (part b).

Part d) was the most poorly attempted part of the question with only 15 (12.4%) of the students attempting to answer it. 12 (9.90%) of the students were incorrect when showing the mechanism. These incorrect attempts involved inaccurate use of the curly arrows to map the electron movement. Six students drew an arrow coming towards the carbon double \( \text{C} = \text{C} \) bond from the \( \text{H-Br} \) bond. Nine other students drew an arrow from the hydrogen atom in the 2-methylbut-2-ene towards the hydrogen bromide.
7.2.4. Diagnostic Test- Summary and Analysis

7.2.4.1. Summary of Student Performance in the Diagnostic Test

This section looks at the students’ overall performance in the Diagnostic Test. Table 7.4 summarises the percentage of students that attempted at least some part of each question. It can be seen that Question One was the most popular question and Question Six was the least popular question.

Table 7.4. Summary of the students’ attempt per question in the Diagnostic Test (n=121).

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Percentage Attempt n (%)</th>
<th>Attempt Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing</td>
<td>119 (98.3%)</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Organic species</td>
<td>114 (94.2%)</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Electron Density</td>
<td>110 (90.9%)</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Nomenclature</td>
<td>95 (78.5%)</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Classification</td>
<td>113 (93.4%)</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Isomerism</td>
<td>66 (54.5%)</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Shape and Structure</td>
<td>107 (88.7%)</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>Mechanism</td>
<td>79 (65.3%)</td>
<td>7</td>
</tr>
</tbody>
</table>

Only 11 (9.1%) of the students that didn’t attempt Question Six did not attempt the remaining questions (Seven and Eight). It can be seen from the percentages included in Table 7.4 that although Question Six was poorly attempted, the majority (107, 88.7%) of the students continued with the Diagnostic Test and attempted Question Seven. Although Question Eight (final question on the test) was poorly attempted also, it was not the least popular question. The tendency for the greatest number of students to avoid the question, assessing Isomerism suggests that this is a topic that the students find difficult or the presentation of the question may have affected the attempt rate.

The Kolmogorov-Smirnov test was used to investigate the distribution of the students’ performance in each of the test questions. The distribution for each question was not normal. For this reason, the median score for each question and the inter quartile ranges are given in Table 7.5. The inter quartile range illustrates the measure of variability about the median.
between the first and third quartile. The mean percentage scores are also included as a point of interest.

Table 7.5 summarises the students’ performance in the Diagnostic Test. As explained at the beginning of section 7.2.3, each question in the Diagnostic Test was worth five marks giving a total overall score of 40 marks for the Diagnostic Test. The median percentage score for each question is given in Table 7.5. It should be noted that a score of zero was given when a student did not attempt any part of the question or the attempt was completely incorrect. This explains the median score of zero for Question Eight. The ‘Mark Order’ column lists the order of the questions from the best answered question with the highest median percentage scores (Questions Two and Five) to the poorest answered questions with the lowest median score (Questions Four and Eight). The best answered questions were those which assessed the students’ ability to recognise and classify different organic species, and classify organic compounds according to their functional groups. The questions attempted by the least number of students (Questions Four, Six and Eight, Table 7.4) were the poorest answered questions.

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Mean score (%)</th>
<th>Inter Quartile Range</th>
<th>Median score (%)</th>
<th>Mark Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing</td>
<td>36.4</td>
<td>45</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Organic species</td>
<td>53.3</td>
<td>40</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Electron Density</td>
<td>29.3</td>
<td>30</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Nomenclature</td>
<td>16.0</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Classification</td>
<td>52.7</td>
<td>30</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Isomerism</td>
<td>31.1</td>
<td>60</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Shape and Structure</td>
<td>50.4</td>
<td>60</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Mechanism</td>
<td>6.28</td>
<td>10</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

It is worth commenting on the median percentage scores for these questions with omission of the non-attempts (zero marks). The students who attempted Question Four (95, 78.5%) had a median score of 20% (1/5), and the students who attempted Question Six (66, 54.5%) had a median score of 60% (3/5). This suggests that the students who did attempt these questions (assessing Nomenclature and Isomerism) did have a higher median score than the overall median (included in Table 7.5) suggests.
However, the same was not observed for Question Eight. When the non-attempts (zero marks) were omitted from the analysis of Question Eight, the median score of the 79 (65.3%) who attempted the question was still 0% (0/5). This suggests that unlike Nomenclature and Isomerism, even the students who attempted the question assessing Reaction Mechanism performed poorly.

The overall median score in the Diagnostic Test was 34.2% (14/40). Taking the standard pass-rate as 40%, only 44 (36.4%) of the students passed the Diagnostic Test and scored above 40%. The highest score achieved in the Diagnostic Test was 94% (37.5/40). Only one student achieved this score. The histogram in Figure 7.31 shows that the distribution of the score in the Diagnostic Test. As can be seen from the distribution curve, the results in the Diagnostic Test are almost parametric.

![Figure 7.31 Histogram of the students’ performance in the Diagnostic Test (n=121).](image)

The data was found to have a normal distribution using the Kolmogorov-Smirnov test for normality (p=0.2). The mean score (34.2%) compares well with the median score (34%). For this reason the appropriate parametric tests were used to investigate the factors that
influenced the students’ overall performance in the Diagnostic Test. The tests used have been outlined in Chapter Four (Section 4.3.1).

7.2.4.2. Analysis of students’ performance in the Diagnostic Test.

A number of factors were analysed using SPSS to investigate if they had a contribution to the students’ performance in the Diagnostic Test.

The investigation of the effect of the students’ course of study is summarised in Table 7.6.

**Table 7.6 Comparison of students’ performance in the Diagnostic Test with different courses of study.**

<table>
<thead>
<tr>
<th>Course of Study</th>
<th>Number of students</th>
<th>Mean Test Score (%</th>
<th>Percentage of students passed (n)</th>
<th>Percentage of students failed (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Science</td>
<td>12</td>
<td><strong>33.5</strong></td>
<td>33% (4)</td>
<td>66% (8)</td>
</tr>
<tr>
<td>Health and Safety</td>
<td>10</td>
<td><strong>31.1</strong></td>
<td>30% (3)</td>
<td>70% (7)</td>
</tr>
<tr>
<td>Physical Education with Chemistry</td>
<td>3</td>
<td><strong>60.0</strong></td>
<td>100% (3)</td>
<td>-</td>
</tr>
<tr>
<td>Biological Science with Chemistry Education</td>
<td>16</td>
<td><strong>37.3</strong></td>
<td>44% (7)</td>
<td>56% (9)</td>
</tr>
<tr>
<td>Physics Education with Chemistry</td>
<td>5</td>
<td><strong>41.0</strong></td>
<td>60% (3)</td>
<td>40% (2)</td>
</tr>
<tr>
<td>Food Science and Health</td>
<td>18</td>
<td><strong>16.2</strong></td>
<td>6% (1)</td>
<td>94% (17)</td>
</tr>
<tr>
<td>Industrial Biochemistry</td>
<td>13</td>
<td><strong>36.7</strong></td>
<td>38% (5)</td>
<td>62% (8)</td>
</tr>
<tr>
<td>Pharmaceutical and Industrial Chemistry</td>
<td>8</td>
<td><strong>33.1</strong></td>
<td>38% (3)</td>
<td>62% (8)</td>
</tr>
<tr>
<td>Pharmaceutical and Forensic Analysis</td>
<td>9</td>
<td><strong>54.8</strong></td>
<td>67% (6)</td>
<td>33% (3)</td>
</tr>
<tr>
<td>Drug and Medicinal analysis</td>
<td>6</td>
<td><strong>33.8</strong></td>
<td>33% (2)</td>
<td>66%(4)</td>
</tr>
<tr>
<td>Forensic and Environmental Analysis</td>
<td>10</td>
<td><strong>40.6</strong></td>
<td>20%(2)</td>
<td>80% (8)</td>
</tr>
<tr>
<td>Forensic and Nanotechnology</td>
<td>8</td>
<td><strong>29.6</strong></td>
<td>50% (4)</td>
<td>50% (4)</td>
</tr>
</tbody>
</table>

The course Environmental and Chemical analysis in the Institute of Technology 1 is omitted from the analysis shown in Table 7.6 as there is only one student from the participating cohort (n=121) in that course of study. It can be seen from Table 7.6 that students in the
Physical Education and Chemistry course (n=3) and the Pharmaceutical and Forensic Analysis course (n=9) performed the best. The Food Science and Health course (n=18) and the Science with Nanotechnology course (n=8) had the lowest average score in the Diagnostic Test. The percentage and number of students in each course that passed and failed the Diagnostic Test are also included in the last two columns in Table 7.6.

The one-way ANalysis Of VAriance (ANOVA) analysis showed a significant difference in the Diagnostic Test performance between each of the five class groups, \( p=0.003 \). The Bonferroni post hoc test found that the only significant difference between the individual class groups was between university class 3 (lowest mean score) and Institute of Technology 1 (highest mean score). It is interesting to note that the students in the courses with the lowest average scores had studied more modules of Chemistry at Third-Level than the students in the courses with the highest average scores (Table 7.1). Students in these courses had also studied a previous Organic Chemistry module. This suggests that other factors such as gender, age and study of Leaving Certificate Chemistry and Mathematics may have a greater influence on the students’ performance in the Diagnostic Test than their course of study and study of Chemistry at Third-Level.

Table 7.7 shows how the students’ performance in the Diagnostic Test varied in accordance with their age. Seven of the total cohort (n=121) were omitted from Table 7.7, because these students were the only students of their age in the whole cohort. Six other students were omitted because they did not give their age.

**Table 7.7 Students’ performance in the Diagnostic Test according to their age (n=108).**

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Mean Score (%)</th>
<th>Standard Deviation</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>34.8</td>
<td>14.7</td>
<td>8</td>
</tr>
<tr>
<td>19</td>
<td>34.0</td>
<td>18.3</td>
<td>36</td>
</tr>
<tr>
<td>20</td>
<td>32.7</td>
<td>18.2</td>
<td>37</td>
</tr>
<tr>
<td>21</td>
<td>30.0</td>
<td>18.3</td>
<td>10</td>
</tr>
<tr>
<td>22</td>
<td>36.7</td>
<td>16.9</td>
<td>3</td>
</tr>
<tr>
<td>25</td>
<td>38.5</td>
<td>10.6</td>
<td>2</td>
</tr>
<tr>
<td>26</td>
<td>29.2</td>
<td>9.80</td>
<td>3</td>
</tr>
<tr>
<td>32</td>
<td>39.3</td>
<td>4.60</td>
<td>2</td>
</tr>
<tr>
<td>34</td>
<td>23.0</td>
<td>32.5</td>
<td>2</td>
</tr>
<tr>
<td>35</td>
<td>43.8</td>
<td>3.18</td>
<td>2</td>
</tr>
<tr>
<td>36</td>
<td>48.7</td>
<td>17</td>
<td>3</td>
</tr>
</tbody>
</table>

**Standard students:**
- n= 91
- Mean = 32.9%
- Std. Dev. = 17.38

**Non-Standard students:**
- n= 17
- Mean = 37.0%
- Std. Dev. = 13.51
The top score in the Diagnostic Test (94%) was achieved by a 33 year old student. The students’ ages are listed in chronological order, from the youngest (18 years) to the oldest (36 years) in Table 7.7. The students aged 18 to 21 years are categorised here as ‘standard students’ while the mature students are categorised as ‘non-standard’. The mean scores and standard deviations for these groups are summarised in the last column of Table 7.7. The number of students at each age should be considered when analysing Table 7.7. The students’ performance in the Diagnostic Test was slightly positively related to the students’ age with a Spearman’s correlation coefficient of $r=0.059$. However, this was not significant, $p=0.528$. The Independent Samples T-test also showed no significant difference in performance between the standard and non-standard students.

The overall mean score in the Diagnostic Test was 34.2%. On average, the males had a higher mean score (37.6%, standard deviation = 17.36) than the females (31.2%, standard deviation = 18.00). However, using the Independent Samples T-test, this difference between the genders was not significant; $t (115) =1.937$, $p = 0.055$. This gender difference might have been significant if there was a larger sample size.

56 (46.3%) of the students had studied Higher Level Chemistry, and 7 (5.80%) of the students had studied Ordinary Level Chemistry for their Leaving Certificate. 58 (47.9%) of the students had not studied any Chemistry for their Leaving Certificate. Figure 7.32 shows how the students’ performance in the Diagnostic Test differs in relation to their study of Leaving Certificate Chemistry. The number of students in each cohort is also given.
Figure 7.32 Mean Score (%) of students in the Diagnostic Test in comparison with their study of Leaving Certificate Chemistry (n=121).

Using a one-way ANOVA and the Bonferroni post hoc tests, it was found that there was a significant difference (p=0.001) between the performance of the students that had studied Higher Level Chemistry (mean score = 40.4%, standard deviation = 19.32) and the students who had not studied any Leaving Certificate Chemistry (mean score = 28.9%, standard deviation = 13.99). Only 7 (5.80%) of the students studied Ordinary Level Chemistry. It can be seen from Figure 7.32, that there is very little difference in the mean scores of the students who studied Ordinary Level Leaving Certificate Chemistry and those that did not study Chemistry for their Leaving Certificate at all. This difference was not significant (p=1.00). There was no significant difference in performance between students who had studied Higher Level and Ordinary Level Chemistry for their Leaving Certificate (p=0.304).

Figure 7.33 and Table 7.8 show the students’ performance (mean score %) in the Diagnostic Test in comparison to their grade and level of Leaving Certificate Chemistry. The box plot in Figure 7.33 shows that the higher performing students at Higher Level performed better in the Diagnostic Test. It also shows the range of the students’ scores in the Diagnostic Test. The students who got a B and C at Ordinary Level performed better in the Diagnostic Test than the students that got a D in Higher Level Chemistry for their Leaving Certificate. Overall there was a significant difference (p=0.002) observed between the students’ performance in the Diagnostic Test and their performance in their Leaving Certificate Chemistry examination using the one-way ANOVA hypothesis test.
Figure 7.33 Boxplot of students’ performance in the Diagnostic Test in comparison with their performance in Leaving Certificate Chemistry (n=57).

The number of students that achieved each grade is included with the standard deviation in Table 7.8.

Table 7.8 Statistical data of students’ performance in the Diagnostic Test in comparison to their Leaving Certificate Chemistry grade (n=57).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mean score (%)</th>
<th>Standard Deviation</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>50.89</td>
<td>21.12</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>42.30</td>
<td>15.37</td>
<td>22</td>
</tr>
<tr>
<td>C</td>
<td>37.53</td>
<td>19.13</td>
<td>19</td>
</tr>
<tr>
<td>D</td>
<td>17.83</td>
<td>12.72</td>
<td>3</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>16.00</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>40.75</td>
<td>18.74</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>20.00</td>
<td>28.28</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>36.00</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

From Figures 7.32 and 7.33, it can be seen that the students who studied Higher Level Chemistry for their Leaving Certificate and students who performed better at this level had a greater mean score in the Diagnostic Test.
The distribution of the students’ performances in each of the test questions was not normal. The p values were below 0.05 in all cases using the Kolmogorov-Smirnov Test. Figure 7.34 shows a breakdown of the students’ median percentage score in each question in the Diagnostic Test with reference to their study of Chemistry for their Leaving Certificate.

In Questions Two, Five, Six and Eight, the students who had not studied Leaving Certificate Chemistry performed better than those that had studied Ordinary Level Chemistry. The number of students in each cohort is listed under the legend at the right of the bar chart. The small number of students that had studied Ordinary Level Chemistry should be noted. Question Two (assessing recognition of organic species) was the overall best answered question in the Diagnostic Test. It can be seen from Figure 7.34 that all three groups of students performed reasonably well in this question. Question Eight (assessing mechanism of reactions) was the overall most poorly answered question in the Diagnostic Test. As can be seen in Figure 7.34, all three groups performed very poorly in this question (median percentage score = zero for each group).
The Kruskal-Wallis test showed that the students’ performance in Questions One, Three, Four, Five and Six were significantly affected by their study of Leaving Certificate Chemistry. The study of Leaving Certificate Chemistry made no significant difference in the students’ performance in Questions Two, Seven and Eight. The Kruskal–Wallis test statistics for these results are included in Table 7.9.

Table 7.9 Kruskal-Wallis Test statistics and Jonckheere trend of significance of study of Leaving Certificate Chemistry and performance in each test question.

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Kruskal-Wallis Test statistic H(2)</th>
<th>Level of significance</th>
<th>Jonckheere-Terpsta Test statistic</th>
<th>Level of significance</th>
<th>Significance of Leaving Certificate Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.432</td>
<td>P =0.002</td>
<td>-3.535</td>
<td>P &lt;0.001</td>
<td>✔ ✔</td>
</tr>
<tr>
<td>2</td>
<td>0.294</td>
<td>P =0.863</td>
<td>-0.475</td>
<td>P =0.635</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>6.534</td>
<td>P =0.038</td>
<td>-2.274</td>
<td>P =0.023</td>
<td>✔</td>
</tr>
<tr>
<td>4</td>
<td>9.31</td>
<td>P =0.010</td>
<td>-3.033</td>
<td>P =0.002</td>
<td>✔✔</td>
</tr>
<tr>
<td>5</td>
<td>21.17</td>
<td>P &lt;0.001</td>
<td>-4.395</td>
<td>P &lt;0.001</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>6</td>
<td>13.287</td>
<td>P =0.001</td>
<td>-3.028</td>
<td>P =0.002</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>7</td>
<td>2.942</td>
<td>P =0.230</td>
<td>-1.485</td>
<td>P =0.137</td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>0.679</td>
<td>P =0.712</td>
<td>-0.782</td>
<td>P =0.434</td>
<td>X</td>
</tr>
</tbody>
</table>

The cohort of students that had studied Higher Level Leaving Certificate Chemistry performed much better in Questions Five and Six (in particular) than the other two cohorts. Both of these questions involved the use of the grid of compounds (Figure 7.17). The advantage of using the grid was that numerous questions could be asked, and the students did not know in advance how many boxes were needed for an answer (Hassan *et al.* 2004). Question Five assessed the classification of organic compounds into 10 families of compounds. Question Six assessed the students’ ability to recognise isomers of four of the compounds. Using the 16-square grid may have added to the complexity of these questions. This required the students to register what compounds they had to find in the grid and then classify, name and recognise the molecular formula of the compound correctly to identify its functional group or its isomeric relationship with other compounds. This phase of restructuring and transforming the problem into a way that the student can understand is a critical determinant of the students’ ability to attempt and answer the question correctly (Bodner and Domin 2000). Answering the questions required the students to examine each compound in the grid carefully. These questions required more time and concentration than Question Four which also used the grid in Figure 7.17. For Question Four, the five
compounds to be examined were specified, whereas Questions Five and Six required a complete analysis of all compounds in the grid. This may have been a factor that contributed to the higher performance of the Higher Level Chemistry pupils in these questions, as it has a higher cognitive demand. The Jonckheere-Terpsta Test showed a significantly negative trend in performance between students who studied Higher Level, Ordinary Level and no Leaving Certificate Chemistry, where those that had studied Higher Level performed better than those that had studied Ordinary Level Chemistry, who in-turn performed better than those students with no Leaving Certificate Chemistry.

The study of Mathematics is effectively compulsory throughout Second-Level education in Ireland, so it is assumed that all of the participants in this study would have studied Mathematics at some level for their Leaving Certificate. However, 10 of the students did not answer this question in part A of the Third-Level Student Questionnaire. For this reason, the values given (Figure 7.35) are mean scores of those students (n=111) who clearly indicated whether they studied Higher Level or Ordinary Level Leaving Certificate Mathematics.

![Graph showing performance in the Diagnostic Test and level of Leaving Certificate Mathematics](image)

**Figure 7.35 Mean percentage score (%) of students in the Diagnostic Test in comparison with the level of Mathematics studied for their Leaving Certificate (n=111).**

51 (45.9%) of the students studied Higher Level Mathematics, and a greater number of students (60, 54.1%) studied Ordinary Level Mathematics. The mean difference in score between both cohorts was 10.9%. The Independent samples T-test found that this difference in performance was significant \( t(109) = 3.31, p = 0.001 \). While there were no questions directly assessing mathematical ability, calculations or use of formulae in the Diagnostic
Test, these results suggest that the students that had studied Higher Level Mathematics may have been operating at a higher stage of cognitive development. Much of the questions in the Diagnostic Test required the pupils to be operating at a formal stage of cognitive development e.g. predicting the first step in a reaction mechanism.

The box plot in Figure 7.36 shows the students’ performance in the Diagnostic Test with reference to their performance at each level of Mathematics in the Leaving Certificate.

![Box plot of students’ performance in the Diagnostic Test in comparison with their performance in Leaving Certificate Mathematics (n=90).](image)

The number of students that achieved each grade at Higher and Ordinary Level Mathematics is included in Table 7.10 along with the standard deviation and mean percentage scores. Similarly to the Leaving Certificate performance in Chemistry, the students that achieved higher grades at Higher Level also had a significantly higher mean score in the Diagnostic Test (p=0.003) than students who had studied Ordinary Level. The one-way ANOVA was used to test this hypothesis.
Table 7.10 Statistical data of students’ performance in the Diagnostic Test in comparison to their Leaving Certificate Mathematics grade (n=90).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mean score (%)</th>
<th>Standard Deviation</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>65.00</td>
<td>25.52</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>42.90</td>
<td>21.50</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>33.68</td>
<td>14.30</td>
<td>17</td>
</tr>
<tr>
<td>D</td>
<td>22.50</td>
<td>16.26</td>
<td>2</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>31.00</td>
<td>12.86</td>
<td>26</td>
</tr>
<tr>
<td>B</td>
<td>25.23</td>
<td>15.76</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>25.90</td>
<td>15.61</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>28.00</td>
<td>9.90</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 7.37 compares the average scores of each question achieved by the students that studied Higher Level Mathematics (51, 42.1%) and Ordinary Level Mathematics (60, 49.6%) for their Leaving Certificate.

Figure 7.37 Performance in each question with reference to level of Leaving Certificate Mathematics studied (n=111).

Note: The median percentage scores of zero for all students in Question Eight and Ordinary Level students in Questions Four and Six is because a score of zero was given when no attempt was made to answer the question.

It can be seen (Figure 7.37) that the students that had studied Higher Level Mathematics performed better in seven of the eight questions. The median score for students who had studied Higher Level and Ordinary Level Mathematics was the same for Question Two. The Mann-Whitney U Test showed that this difference in performance was significant for Questions One, Four, Five, Six and Seven. The level of Mathematics studied for the Leaving
CERTIFICATE had no significant effect on the students’ performance in Question Two, Three and Eight. The Mann-Whitney U test statistics for these results are included in Table 7.11 below.

**Table 7.11** Mann-Whitney U Test statistics for significance of study of Leaving Certificate Mathematics and performance in each test question.

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Mann-Whitney U Test statistic</th>
<th>Level of significance</th>
<th>Significance of the level of Leaving Certificate Mathematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1078.500</td>
<td>P =0.007</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>2</td>
<td>1431.000</td>
<td>P =0.552</td>
<td>✗</td>
</tr>
<tr>
<td>3</td>
<td>1369.000</td>
<td>P =0.334</td>
<td>✗</td>
</tr>
<tr>
<td>4</td>
<td>985.500</td>
<td>P &lt;0.001</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>5</td>
<td>982.000</td>
<td>P =0.001</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>6</td>
<td>1045.000</td>
<td>P =0.002</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>7</td>
<td>997.500</td>
<td>P =0.002</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>8</td>
<td>1459.000</td>
<td>P =0.598</td>
<td>✗</td>
</tr>
</tbody>
</table>

It should be noted that 35 (69.0%) of the 51 students who studied Higher Level Mathematics also studied Higher Level Chemistry for their Leaving Certificate. The remaining Higher Level Mathematics students did not study Leaving Certificate Chemistry. This may have been a contributing factor to the high performance of the Higher Level Mathematics students.

It was found that the study of Leaving Certificate Mathematics and Chemistry did not have a significant effect on the students’ performance in Questions Two and Eight of the Diagnostic Test. Question Two was the one of the best answered questions in the test (with Question Five), while Question Eight was one of the worst answered questions (along with Question Four). While parts of both questions Two and Eight (radical, carbocation, ionic addition, curly arrows) would have been studied as part of the Leaving Certificate Chemistry, the recognition of nucleophiles, electrophiles, the Markovnikov products are all topics that the students would have learned in introductory Third-Level Organic Chemistry. This finding reinforces the conclusion that the recognition of organic species is an easy topic to learn and understand and reaction mechanism is a difficult topic, at both Second-Level and Third-Level.

Table 7.12 provides a comparison of the Organic Chemistry content studied by the students in each of the participating five class groups.
Table 7.12 Comparison of course content studied by the students in the five difference participating class groups.

<table>
<thead>
<tr>
<th>University Class 1</th>
<th>University Class 2</th>
<th>University Class 3</th>
<th>Institute of Technology 1</th>
<th>Institute of Technology 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aliphatic Hydrocarbons:</strong> Alkanes, alkenes and alkynes, cycloalkanes, alkyl groups.</td>
<td><strong>Aromatic compounds:</strong> Functional group interconversion, activating / deactivating effects of orientation, aromatic heterocyclic compounds. <strong>Stereochemistry:</strong> Chirality and achirality, optical activity, R/S configuration, perspective and fisher projections, enantiomers, diastereomers and racemates. <strong>Kinetics:</strong> Stereochemistry and kinetic measurements. <strong>Carbonyl Groups:</strong> Aldehydes. Ketones. Carboxylic acids. Acidity of carboxyl group. Carboxylic acid derivatives: acid anhydrides, esters.</td>
<td><strong>Aromatic compounds:</strong> Aromatic structure, stabilization, reactivity, Huckel’s rules, <strong>Stereocchemistry:</strong> Chirality and achirality, enantiomers, diastereomers and meso forms,isher projections, stereochemical course of S_N1 and S_N2 reactions, <strong>Kinetics:</strong> Stereochemistry and kinetic measurements. <strong>Carbonyl Groups:</strong> Aldehydes. Ketones. Carboxylic acids. Carboxylic acid derivatives: acid anhydrides, esters, amides. <strong>Reactions:</strong> Wittig reaction and enolate.</td>
<td><strong>Aliphatic Hydrocarbons:</strong> Alkanes (including cyclic and polycyclic), alkenes, alkynes. <strong>Nomenclature</strong></td>
<td><strong>Spectroscopy:</strong> UV, IR and NMR. Basic principles of each technique, sample preparation, problem solving. Application of UV, IR and NMR.</td>
</tr>
<tr>
<td>Topic</td>
<td>Details</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>benzene derivatives.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Isomerism:</strong> Structural, conformational, geometric.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reactions:</strong> Electrophilic addition reactions, carbocations, Markovnikov addition, Polymeristaion, Substitution reaction mechanism ($S_1$, $S_2$) Aromatic Substitution reactions. Nucleophilic addition reactions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Occurrences and Uses.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Organic Polymers:</strong> Polyesters, polyamides, polyethylene, biological polymers, applications.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compounds with Carbon only:</strong> Diamond, graphite, fullerenes, carbon nanotubes.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>amines, heterocyclic amines, basicity.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Amination:</strong> Aldol and Claisen condensation reactions. Nucleophilic displacement reactions. Substitution Reactions; Electrophilic Aromatic Substitution, ($S_1$, $S_2$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Combustion and halogenation of alkanes.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preparation of alkenes - Elimination of alcohols and haloalkanes.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preparation of alkynes – dehydrohalogenation.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reactions of haloalkanes.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preparation and reactions of alcohols.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preparation of aldehydes and ketones–oxidation of alcohols and alkenes, hydration of alkynes.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reactions of aldehydes and ketones.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reactions of acids, esters, amides and amines.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Uses and occurrences</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reaction Mechanisms and Curved Arrows:</strong> nucleophilic substitution of haloalkanes by $S_1$ and $S_2$. E1 and E2 mechanisms. Electrophilic aromatic substitution (nitrilation, sulfonation, halogenation, Friedel-Crafts alkanylation and alkylation).**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aromaticity:</strong> Aromatic stabilisation and resonance, theories of aromaticity. Hückel’s Rule applied to benzenoid and heterocyclic aromatic compounds, polycyclic aromatic hydrocarbons. Benzene chemistry: electrophilic substitution reactions, effect of substituents.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Student Questionnaire was distributed to each of the class groups at the end or towards the end of the students’ completion of these modules. This was the final module of Organic Chemistry at undergraduate level for all students in university classes 1 and 2. The students in university class 3 had studied another previous module of Organic Chemistry and some (n= 51, in the Pharmaceutical and Industrial Chemistry course) would continue to study more Organic Chemistry in their undergraduate courses.

The students’ examination results for three of the Organic Chemistry modules studied by the students were made available to the researcher. It was optional for the students when completing the questionnaires whether to include their student ID number or not. The gatekeeper did not record the student ID numbers for all participating students. The Diagnostic Test results were only compared with the end of semester examination results of the students who had given their student ID numbers (n=81). The students’ performance in the end of semester examinations displayed a normal distribution. The Kolmogorov-Smirnov significance was at the level p= 0.200. When the examination results were compared with the Diagnostic Test results, it was found that there was a low correlation between the students’ performance in both assessments. A Pearson product-moment correlation coefficient was computed to assess the relationship between the students’ performance in their Diagnostic Test and their end of semester Organic Chemistry examination. There was a moderate correlation between these two variables but it was significant (r= .464, p < 0.001, n= 81). Of these pupils, 10 (12.0%) failed the Diagnostic Test and 9 (11.0%) failed their end of semester examination. The end of semester examinations is an assessment of what is taught in the Organic Chemistry modules. However, this only moderate correlation suggests that the examinations and Diagnostic Test are testing different types of understanding. “A lot of Organic Chemistry (as with other subjects) can be acquired by rote learning (this often being reflected by efficient recall in examination questions), real understanding demands the bringing together of conceptual understandings in a meaningful way” (Sirhan, 2007, p. 3). Students who performed well in the end of semester examination did not necessarily perform well in the Diagnostic Test. There are many reasons for this. Students have access to past examination papers to prepare for the end of semester examination, and students may also be more focused and motivated when answering questions in an end of semester examination. The Diagnostic Test was not given to the students in a formal examination setting, and the design and lay-out of the questions were unlike those in a typical examination paper, and the topics assessed were presented differently than what the pupils may have been accustomed to.
Students had no preparatory time for the Diagnostic test. The fact that the Diagnostic Test was anonymous and didn’t contribute to their final grade, may have meant that the students made less effort to concentrate on and complete the test. The poor performance in the Diagnostic Test does raise the question ‘Is normal teaching- teaching for understanding or teaching for recall in an examination?’ This merits further investigation.

A number of factors have been investigated in this analysis of the students’ performance in the Diagnostic Test. Table 7.13 provides a summary of the factors investigated and discussed in this section. It can be seen that the study of Leaving Certificate Chemistry and the level of Leaving Certificate Mathematics as well as the students’ course of study and performance in their end of semester examinations, were the most influential factors on their performance in the Diagnostic Test.
### Table 7.13 Summary of factors affecting the students’ performance in the Diagnostic Test.

<table>
<thead>
<tr>
<th>Variable Factor</th>
<th>Hypothesis Test used</th>
<th>Level of Significance</th>
<th>Concluding trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course of Study</td>
<td>One-way ANOVA</td>
<td>✓ ✓</td>
<td>Only a significant difference between university class 3 and Institute of Technology 1.</td>
</tr>
<tr>
<td>Age</td>
<td>Independent samples T-test</td>
<td>✓</td>
<td>No significant difference between performance of standard (18-21 years) students and non-standard students (&gt;22 years)</td>
</tr>
<tr>
<td>Gender</td>
<td>Independent samples T-test</td>
<td>✓</td>
<td>No significant difference between genders.</td>
</tr>
<tr>
<td>Leaving Certificate Chemistry Level</td>
<td>One-way ANOVA</td>
<td>✓ ✓</td>
<td>HL students performed significantly better than those with no LC Chemistry. The performance in the Diagnostic Test decreased from HL students to OL students to students who had no LC Chemistry. Study and level LC Chemistry had significant difference in performance in test questions 1,3,4,5 and 6.</td>
</tr>
<tr>
<td>Grade</td>
<td>One-way ANOVA</td>
<td>✓ ✓</td>
<td>Students who achieved higher grades in the LC Chemistry examination scored higher in the Diagnostic Test.</td>
</tr>
<tr>
<td>Leaving Certificate Mathematics Level</td>
<td>Independent Samples T-test</td>
<td>✓ ✓</td>
<td>HL students performed significantly better than those with OL Mathematics Level LC Mathematics had significant difference in performance in test questions 1,4,5,6 and 7.</td>
</tr>
<tr>
<td>Grade</td>
<td>One-way ANOVA</td>
<td>✓ ✓</td>
<td>Students who achieved higher grades in the LC Mathematics examination scored higher in the Diagnostic Test.</td>
</tr>
<tr>
<td>End of semester examination</td>
<td>Pearson’s correlation</td>
<td>✓ ✓ ✓</td>
<td>Moderate relationship between examination performance and performance in the Diagnostic Test.</td>
</tr>
</tbody>
</table>
Figure 7.38 summarises the students’ response to the five-point Likert rating scale given in part A of the student questionnaire. The ordinal data from the Likert scales was analysed using non-parametric methods. One the Likert scale, 1 = Really easy, 2 = Easy, 3 = Neutral, 4 = Difficult and 5 = Really difficult. The topics are listed in order from the topics that were rated as most difficult (highest median value) to the topics that were rated as easy (lower median values) by the students. Five of these topics were specifically assessed in the Diagnostic Test in part B of the Third-Level Student Questionnaire. These topics (Mechanism, Isomerism, Classification, Naming and Drawing) are highlighted with dashed bars in Figure 7.38.

Each of the eight questions in the Diagnostic Test assessed a different topic of Organic Chemistry. Figure 7.39 shows the students’ performance in each of the topics as the median percentage score for each test question. The topics (Isomerism, Drawing and Classification) highlighted with dashed bars in the bar chart as well as Mechanism and Naming (which have a median score of zero) were rated by the students in the Likert scale as easy or difficult (Figure 7.38).
The findings illustrated in Figures 7.38 and 7.39 are investigated further in Table 7.14. In Table 7.14, the Likert responses ‘really easy’ and ‘easy’ are grouped as Easy. The responses ‘difficult’ and really difficult’ are grouped as Difficult. The median percentage score for each question that assessed each of the topics listed is given. The Kruskal-Wallis Test was used to test significance between the students’ attitudes to the topics (as given in the Likert ratings) and their understanding of the topics (as assessed in the given test questions). It can be seen (Table 7.14) that the students’ attitudes to the topics had a significant relation to their performance on the test questions for Drawing, Naming, Classification and Isomerism. The negative Jonckheere-Terpsta statistics for each of these tests shows that there is a negative relationship between Likert rating and question score. The students who identified a topic as easy performed better in the question assessing that topic. The students who identified a topic as difficult tended to score lower in the question assessing that topic. This observation is as expected and illustrates that these students have an accurate appraisal of their own ability and understanding. However, as shown in the Table 7.14, the students’ rating of Organic Mechanism on the Likert scale had no significant effect on their performance in the test question. Given the poor performance in this test question (median score = 0%), this suggests that even students who listed the topic as easy still performed poorly in or didn’t attempt the test question assessing Mechanism.
### Table 7.14 Comparison of students’ attitudes to Organic topics and test performance (n=121)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Easy</th>
<th>Neutral</th>
<th>Difficult</th>
<th>Median percentage Score (%)</th>
<th>Kruskal-Wallis Test Statistic $H (2)$</th>
<th>Level of significance</th>
<th>Jonckheere-Terpsta Trend Test Statistic</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td>66 (54.1%)</td>
<td>40 (32.8%)</td>
<td>13 (10.7%)</td>
<td>30</td>
<td>7.153</td>
<td>$P = 0.028$</td>
<td>-2.092</td>
<td>$P = 0.036$</td>
</tr>
<tr>
<td>Naming</td>
<td>51 (42.1%)</td>
<td>39 (32.0%)</td>
<td>30 (24.6%)</td>
<td>0</td>
<td>15.196</td>
<td>$P = 0.001$</td>
<td>-3.866</td>
<td>$P &lt; 0.001$</td>
</tr>
<tr>
<td>Classification</td>
<td>46 (37.7%)</td>
<td>47 (38.5%)</td>
<td>21 (17.2%)</td>
<td>60</td>
<td>27.790</td>
<td>$P &lt; 0.001$</td>
<td>-5.143</td>
<td>$P &lt; 0.001$</td>
</tr>
<tr>
<td>Isomerism</td>
<td>21 (17.2%)</td>
<td>55 (45.1%)</td>
<td>40 (32.8%)</td>
<td>20</td>
<td>12.217</td>
<td>$P = 0.002$</td>
<td>-3.420</td>
<td>$P = 0.001$</td>
</tr>
<tr>
<td>Mechanism</td>
<td>16 (13.1%)</td>
<td>33 (27.0%)</td>
<td>68 (56.2%)</td>
<td>0</td>
<td>1.548</td>
<td>$P = 0.461$</td>
<td>-0.494</td>
<td>$P = 0.621$</td>
</tr>
</tbody>
</table>
Even though the attitudes to some of the Organic Chemistry topics recorded in part A of the questionnaire, were reflected in the students’ performance in the Diagnostic Test in part B, there is still some evidence to suggest that many students have a false perception of their own ability in some topics. For some students, topics that were perceived as easy (Naming and Drawing of organic compounds) were still answered poorly in the Diagnostic Test.

The students’ performance in each of the questions in the Diagnostic Test was presented individually in section 7.2.3. Many of the incorrect responses were also highlighted. These incorrect responses and incomplete attempts by the students provide valuable information about the misconceptions and difficulties held by these students. The findings of this Third-Level Student Questionnaire will be discussed with the findings of the Second-Level Pupil Questionnaire (I) in Chapter Nine.

7.3- Organic Chemistry Lecturer Questionnaire

7.3.1. Teaching of Organic Chemistry at Third-Level

20 Third-Level lecturers participated in this study and completed the Organic Chemistry Lecturer Questionnaire. 12 of these were lecturing in universities and eight were lecturing in Institutes of Technology. In total six universities and six Institutes of Technology were involved in this part of the Third-Level Study.

The lecturers involved in the study had a range of teaching experience from 4 years of teaching to 31 years. All of the participating lecturers were teaching introductory level Organic Chemistry. Some were also teaching more advanced Organic Chemistry (Figure 7.40). The majority of the lecturers were teaching Organic Chemistry to all years at Third-Level with just 7 (35.0%) teaching at post-graduate level. 14 (70%) of the lecturers, were teaching first year Organic Chemistry as integrated into a General Chemistry module. Only 6 (30%) of the lecturers were teaching Introductory Organic Chemistry as a separate module. 14 (70%) of the lecturers were teaching Organic Chemistry during the second semester of first year. The typical class size of a first year cohort learning Organic Chemistry was greater than 100 for 12 (60%) of the lecturers, greater than 50 for 6 (30%) of the lecturers and between 30-50 for 2 (10%) of the lecturers.
The lecturers involved in the study used many different types of assessment. All of those involved used an end of semester examination. The other types of assessment used are shown in Figure 7.41.

![Figure 7.40 Percentage of lecturers teaching Organic Chemistry at different years in third level (n=20).](image1)

![Figure 7.41 Different types of assessment used by the Organic Chemistry lecturers (n=20).](image2)

It can be seen that the many of the traditional types of assessment (end of semester examination, laboratory reports and mid-term assessments) are still the most
commonly used and practised forms of assessment. As shown and discussed in Section 7.2.4, the end of semester examinations may not be the most accurate method of assessing the students’ understanding of Organic Chemistry. Alternatives such as laboratory practical examinations and presentations on different aspects of Organic Chemistry may encourage the students to become more responsible for their own learning. In preparing for such assessments, students are often encouraged to look beyond the scope of the theoretical examination questions to develop a clearer understanding of a topic. In a practical examination or presentation, students should be able to explain the given reaction, isomeric relationship or how a compound is named etc. in their own words. This can demonstrate effective understanding rather than recalling a learned reaction equation, mechanism, or compound name in a written examination.

7.3.2. Areas of difficulty in Organic Chemistry

The lecturers were asked to indicate how difficult they find specific Organic Chemistry topics to teach. The lecturers rated each topic on a five-point Likert rating scale. On the scale 1 = very easy to teach, 2 = easy to teach, 3 = neutral, 4 = difficult to teach and 5 = very difficult to teach. The lecturers’ responses are summarised in Table 7.15. The data from the Likert scale used was ordinal and non-parametric. For this reason, the median and percentiles are used to describe the lecturers’ responses.

Table 7.15 provides a summary of the lecturers’ attitudes to the different Organic Chemistry topics. The topics with the lower median numbers were identified as easier to teach than those with the higher median numbers. The column on the right of Table 7.15 indicates the general trend of attitudes of the participating lecturers. The topics that lecturers find most difficult to teach were organic Reaction Mechanisms, Synthesis, and Organic Natural Products. The topics that lecturers find easiest to teach were Drawing, Naming and Classifying organic compounds as well as Laboratory work. The mean values are also included in Table 7.15 for interest.

It is important to note that the findings presented in Table 7.15 do not simply imply that topics that are easiest to teach are the best taught topics or conversely that topics rated as difficult to teach are the most poorly taught topics. Table 7.15 is only representative of the lecturers’ attitudes to teaching different topics.
Table 7.15 Summary of the lecturer’s attitudes to teaching different topics in Organic Chemistry (n=20)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Mean</th>
<th>25&lt;sup&gt;th&lt;/sup&gt; percentile</th>
<th>Median (50&lt;sup&gt;th&lt;/sup&gt; percentile)</th>
<th>75&lt;sup&gt;th&lt;/sup&gt; percentile</th>
<th>General Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing organic compounds</td>
<td>2.5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Easy</td>
</tr>
<tr>
<td>Naming organic compounds</td>
<td>2.7</td>
<td>2</td>
<td>2</td>
<td>3.75</td>
<td>Easy</td>
</tr>
<tr>
<td>Classification of organic compounds</td>
<td>2.45</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Easy</td>
</tr>
<tr>
<td>Physical characteristics of organic compounds</td>
<td>2.65</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
<td>Neutral</td>
</tr>
<tr>
<td>Isomerisation</td>
<td>2.85</td>
<td>2</td>
<td>2.5</td>
<td>4</td>
<td>Neutral</td>
</tr>
<tr>
<td>Organic reactions</td>
<td>3.30</td>
<td>2.25</td>
<td>3</td>
<td>4</td>
<td>Neutral</td>
</tr>
<tr>
<td>Organic reaction mechanisms</td>
<td>4.25</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>Difficult</td>
</tr>
<tr>
<td>Organic synthesis</td>
<td>3.45</td>
<td>2</td>
<td>3.5</td>
<td>4</td>
<td>Difficult</td>
</tr>
<tr>
<td>Organic natural products</td>
<td>4.15</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>Difficult</td>
</tr>
<tr>
<td>Oil refining and products</td>
<td>3.35</td>
<td>2</td>
<td>2.5</td>
<td>-</td>
<td>Neutral</td>
</tr>
<tr>
<td>Chromatography</td>
<td>3.75</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>Neutral</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>3.55</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>Neutral</td>
</tr>
<tr>
<td>Laboratory Work</td>
<td>2.15</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Easy</td>
</tr>
</tbody>
</table>

7.3.3. Teaching Methods and Resources in Organic Chemistry

A number of different textbooks were used by the lecturers. The most popular textbooks that the lecturers recommended their students to use was ‘Organic Chemistry’ by John E. McMurray used by 6 (30.0%) of the lecturers. The 8<sup>th</sup> edition of this book was published in 2011. ‘Organic Chemistry’ by Hart, Crane and Hart was also recommended by 5 (25.0%) of the lecturers for their students to use.

Figure 7.42 shows the teaching resources used by the lecturers involved in the study. The most popular resources used were lecture notes, molecular models and textbooks. The use of lecture notes and textbooks are very traditional teaching methods. 18 (90.0%) of the lecturers said that they used molecular models in their teaching of Organic Chemistry. However, due to the restrictive style of the question, it is not clear form the lecturers’ response whether these molecular models were used for demonstration purposes by the lecturers themselves or if they were used by the students.
When asked about their students’ use of model kits, 9 (45.0%) of the lecturers said that they did encourage their students to buy molecular model kits in their first year of studying Organic Chemistry. However, 9 (45.0%) of the lecturers didn’t encourage their students to buy molecular modelling kits. One lecture encouraged the students to make their own models using sweets or plasticine, while another recommended Organic Chemistry students in later years to buy the molecular model kits but not in first year. These responses suggest that the use of molecular models by 18 (90.0%) of the lecturers may refer to the lecturers’ own use of the models for demonstration purposes in the lectures.

The ‘other’ resources that were listed by 9 (45.0%) of the lecturers included student group PowerPoint presentations, online platforms, animations and classroom response clickers. Student presentations require the students to become more independent and responsible for their own learning. In the preparation for a class presentation, students are usually encouraged to pursue a particular topic or reaction and develop confidence in their understanding of the topic. Other resources, such as animations, can be very useful in Organic Chemistry to facilitate the three-dimensional visualisation of something that may otherwise be falsely perceived as flat or two-dimensional.
The lecturers involved in the study used a variety of approaches to teaching Organic Chemistry. These are shown in Figure 7.43.

![Figure 7.43 Teaching methods used by the Organic Chemistry lecturers (n=20).](image)

The most popular methods of teaching were PowerPoint presentations in lectures as well as separate tutorial classes. 14 (70.0%) of the lecturers used a ‘chalk and talk’ method of teaching. This approach can be useful when teaching Organic Chemistry e.g. to allow the students to see how a structure is drawn or named or to show a reaction mechanism etc. When the lecturer writes while talking, the students can see the steps involved e.g. in naming; identifying the longest chain, numbering the substituent etc. or in a mechanism; identifying the areas of high and low electron density, showing the transfer of electrons, drawing the intermediate formed etc. Other approaches used by the lecturers included having a guest lecturer speak to the students about a particular interesting aspect of Organic Chemistry. Some lecturers mentioned the use of gapped (skeleton) hand-outs to allow the students to complete the lecture notes themselves as they learn in the lecture.

The majority of the lecturers (17, 85.0%) found that practical work in the laboratory facilitates the students’ understanding of organic reactions. Pre-practical classes were mentioned as a useful teaching approach for practical work. These classes are useful to facilitate the students for the practical activity and to ensure that the students will understand the purpose and function of the laboratory session.
Most 14 (70.0%) of the lecturers explained that they tried to link the laboratory sessions to the lectures to facilitate the students’ understanding in the laboratory. The lecturers did this in the introductory talks at the laboratory sessions and through relating the theory in the lectures to reactions that the students carry out in the laboratory. 3 (15.0%) of the lecturers said that they specifically expect the students to include content from the lectures in their written laboratory reports.

7.3.4. Lecturers’ Perceptions of their Students’ Experience

In the final part of the Organic Chemistry Lecturer Questionnaire, the lecturers were asked about how they think their students perceive Organic Chemistry.

On a second five-point Likert scale, the lecturers were asked to indicate their perception of their students’ attitudes to Organic Chemistry. Three statements were listed for the lecturers to respond to. The statements were as included in Table 7.16.

On the Likert scale, 1= strongly agree, 2 = agree, 3 = neutral, 4 = disagree and 5 = strongly disagree. To summarise the data, the responses of ‘strongly agree’ and ‘agree’ were grouped as agree and the responses of ‘disagree’ and ‘strongly disagree’ were grouped as disagree. Table 7.16 shows the number and percentage of lecturers that agreed and disagreed with each statement. The most dominant responses are highlighted. The percentages indicate that the lecturers’ perceive that their students find Organic Chemistry interesting and enjoyable to learn, but not easy to understand.

Table 7.16 Summary of the lecturers’ perceptions of their students’ attitudes to Organic Chemistry (n=20).

<table>
<thead>
<tr>
<th>Organic Chemistry is...</th>
<th>Agree n (%)</th>
<th>Neutral n (%)</th>
<th>Disagree n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interesting.</td>
<td>14 (70.0%)</td>
<td>2 (10.0%)</td>
<td>4 (20.0%)</td>
</tr>
<tr>
<td>Enjoyable to learn.</td>
<td>11 (55.0%)</td>
<td>2 (10.0%)</td>
<td>7 (35.0%)</td>
</tr>
<tr>
<td>Easy to understand and learn.</td>
<td>1 (5.00%)</td>
<td>9 (45.0%)</td>
<td>10 (50.0%)</td>
</tr>
</tbody>
</table>

This Likert rating question was followed by an open-ended question in the Organic Chemistry Lecturer Questionnaire. The responses from this question provided more insight into the reasons why students find Organic Chemistry easy or difficult to understand. 6 (30.0%) of the lecturers thought that their students find Organic Chemistry easy to understand. Reasons given by these lecturers included the logical...
nature of the topics and the systematic rules e.g. naming. Some lecturers felt that their students found parts of Organic Chemistry easy and other parts difficult.

However, a greater number of lecturers (17, 85.0%) thought that their students found Organic Chemistry difficult to understand. Reasons given by these lecturers included the multi-dimensional nature of the subject, the different types of structures and representations, and the need for conceptual understanding. These reasons are characteristic of the difficult nature of the subject and imply that many of the lecturers are aware of the difficulties that have been identified in CER.

Other reasons, not related to the conceptual difficulty of the subject that given by these lecturers included poor attendance at lectures and different lecturers teaching different parts of the course. It is important to specify that such factors are not directly related to the difficulty of the subject itself but do contribute to the students’ difficulty in understanding the subject. It is evident that such ‘household’ problems are the responsibility of the students (to attend the lecture) and the lecturers (to be aware of what is taught in other parts of the course).

The lecturers were also asked to list the top five topics that they think their students find most difficult in Organic Chemistry. Figure 7.44 shows the topics that the lecturers thought their students found difficult. The values included above each of the bars in the graph are the cumulative percentage of lecturers that listed each of the topics as difficult. The legend on the right of the bar chart shows where each of the topics were ranked by the lecturers. Organic Mechanism was the number one topic that lecturers (14, 70%) perceived their students to have most difficulty with. It was also perceived as the overall most difficult topic for students to understand (18, 90%). The structure of organic compounds, organic reactions and stereochemistry were also listed as topics that the lecturers’ perceived their students to have most difficulty with. From the lecturers’ responses, it was understood that ‘structure’ referred to the shape of the organic molecules. Difficulties with representation of organic structure were categorised in the ‘drawing’ bar of the chart. Topics included in the ‘other’ category were aromaticity, instrumentation and natural organic products.
11 (55.0%) of all the lecturers thought that students who had studied Chemistry at Second-Level had an advantage when studying Introductory Organic Chemistry at Third-Level. This was because they are more familiar with the language used, the IUPAC nomenclature and the functional groups. However, 9 (45.0%) of the lecturers did not feel that having studied Chemistry at Second-Level was an advantage for the students at Third-Level. Reasons these lecturers gave were that many students who have studied Leaving Certificate Chemistry think they know and understand Organic Chemistry. The benefit of having studied Leaving Certificate Chemistry is dependent on the level and grade the students’ achieved. The lecturers felt that prior knowledge gained from study of Second-Level Chemistry is only an advantage at the beginning of the students’ study of introductory Organic Chemistry.

Figure 7.45 shows that the majority of lecturers (9, 45.0%), estimated that only half of the students in their class had studied Chemistry at Second-Level. 4 (20.0%) of the
lecturers estimated that less than half of the students in their class had studied Chemistry for their Leaving Certificate.

![Figure 7.45 The lecturers’ estimation of the percentage of students who have studied Chemistry at second level (n=18).](image)

### 7.3.5. Analysis of Results from the Lecturer Questionnaire

14 (70.0%) of the lecturers were teaching introductory level Organic Chemistry as part of a General Chemistry module for the first year students. This may mean that the time allocated to teaching introductory Organic Chemistry may be much less than when it is taught as an individual subject. The exact number of contact hours and content taught in each of the in the introductory courses is not known from the Lecturer Questionnaires. The European Credit Transfer and Accumulation System (ECTS) is a system for comparing the study attainment and performance in Third Level institutions. Some modules may be 10 ECTS or even 15 ECTS, dependent on the number of contact hours. It is assumed that those studying a separate Organic Chemistry module would study a broader syllabus and more content. Studying Organic Chemistry as a separate module also allows the lecturer to spend more time on particularly difficult topics to ensure the students’ true understanding. It is important also that sufficient time is spent at the beginning of the study of Organic Chemistry to ensure that the students clearly understand the fundamentals i.e. naming,
drawing, functional groups, electron density etc. as these are the prerequisites for true understanding of the topics that are persistently identified as difficult by students (organic Reactions, Mechanisms and Synthesis).

The findings from this Lecturer Questionnaire suggest that the typical first year Chemistry class at Third-level may have over 100 students. The lecturers estimated that about 50% of these may have studied Leaving Certificate Chemistry. The findings from the Third-Level Student Questionnaire (Figure 7.1) show that this estimation is accurate. Half of the lecturers did not think that having studied Leaving Certificate Chemistry was an advantage for this studying Organic Chemistry for the first time at Third-Level.

Traditional teaching methods and types of assessment were used by most of the participating lecturers. Lecture notes and textbooks were the most dominant resources used along with molecular models. While molecular models are useful to provide a three-dimensional illustration of molecular shape, orbitals and bonding, these would be more effective if they were handled, manipulated, built and investigated by the students themselves. Cost is one of the biggest factors inhibiting the students’ use of the molecular models. The model kits are expensive to buy and may not be seen as a worthwhile investment for students who are only studying one module of Organic Chemistry. This was evident as only one third of the participating lecturers encouraged their students to purchase these model kits. Even though ‘chalk and talk’ may be seen as an older method of teaching, it is still found to be particularly useful for the teaching Organic Chemistry to illustrate the step-by-step drawing of compounds, mapping of electron movement etc. The traditional methods of assessment listed and used most frequently by the lecturers, may offer a more convenient method of assessment for introductory Organic Chemistry. Alternative assessment methods such as laboratory practicals, student presentations, group projects etc. may not be applicable in an introductory level class due the restricted knowledge base of the students and large class sizes. More innovative forms of assessment may lend themselves better to more advanced courses where the students have developed broader subject knowledge.

However, it is the author’s opinion that such alternative methods of assessment would still be useful at an introductory level to increase interest and motivation in the
subject. It would also encourage the students to take greater responsibility for their own learning and investigation of the topics that are persistently identified as difficult.

7.4. Summary of Findings from the Third-Level Study

The findings from the Third-Level Student Questionnaire and Organic Chemistry Lecturer Questionnaire have been presented in detail in sections 7.2 and 7.3. Here, the main findings from both questionnaires will be summarised. These findings will be discussed with relevance to the findings from the Second-Level study in Chapter Nine.

7.4.1. Main findings from the Third-Level Student Questionnaire

This questionnaire was divided into two parts. Part A sought information about the students Science and Mathematics background and their attitudes to Organic Chemistry. The main findings from part A of the Third-Level Student Questionnaire are listed here:

- Chemistry was not a compulsory entry requirement for any of the courses of study involved. Just over 50% of the students had studied Leaving Certificate Chemistry, and their performance in the Leaving Certificate examination was in-line with the national trend.
- Students from the different course groups had different amounts of Chemistry studied at Third-Level. Only one class group had studied a previous module of Organic Chemistry.
- Over 40% of the students had studied Higher Level Leaving Certificate Mathematics. This was much higher than the national average.
- Almost 70% of the students who had studied Higher Level Mathematics for their Leaving Certificate had also studied Higher Level Leaving Certificate Chemistry.
- Drawing organic compounds was the only topic that was particularly identified as easy by the students.
- Topics that were identified as difficult to learn by the students included Reaction types, Mechanisms and Synthesis.

Part B of the questionnaire was composed of a Diagnostic Test. These are the main findings from analysis of the students’ results in this test:
• The median percentage score in the Diagnostic Test was 34.2%.
• The best answered questions in the Diagnostic Test were the questions assessing the Identification of organic species and also the Classification of organic compounds.
• The questions that the students performed the worst in were questions assessing Nomenclature and Mechanism.
• The following factors had a significant effect on the students’ performance in the Diagnostic Test; course of study, performance in the end of semester examination, level of Leaving Certificate Mathematics studied and the study of Leaving Certificate Chemistry.
• The students’ age and gender had no significant effect on the students’ performance in the test.
• The students displayed an accurate perception of topics described as easy; the students performed relatively well on these topics in the Diagnostic Test. However, the students performed poorly in other topics e.g. mechanism in the Diagnostic Test whether it had been rated as easy or difficult in part A.
• The students had a false perception of their understanding of Nomenclature. The students did not identify this topic as difficult in part A of the questionnaire, but it was still one of the most poorly answered topics in the Diagnostic Test. However, the style of the question given may have affected the students’ performance also.

7.4.2. Main Findings from the Organic Chemistry Lecturer Questionnaire

The findings from the Organic Chemistry Lecturer Questionnaire have been presented in Section 7.3. The main findings are summarised here:

• Introductory Organic Chemistry is mostly integrated into a General Chemistry module rather than being taught as a separate subject. Most of these General Chemistry classes are large groups (>100 students).
• Almost all of the lecturers teaching Introductory Organic Chemistry are teaching it to all years at Third-Level.
• Topics that the lecturers identified as easy to teach included: Drawing, Nomenclature, Classification of organic compounds and Laboratory work.
• Topics that the lecturers identified as difficult to teach included: Mechanisms, Synthesis and Organic natural products.
• Topics that the lecturers perceived their students found difficult to understand included Mechanisms, Structure, Reactions and Stereochemistry.
• End of semester examinations and laboratory reports are the most popular methods of assessment for Organic Chemistry used by the lecturers involved in the study.
• Teaching resources most commonly used by the lecturers included lecture notes, textbooks and molecular models. Feedback from the lecturers suggests that the use of the molecular models were for demonstration purposes.
• The most common teaching methods used included PowerPoint presentations, tutorial classes as well as ‘chalk and talk’.
• The lecturers perceived that their students held a positive attitude towards Organic Chemistry; finding it interesting and enjoyable. However, the majority of lecturers did think that their students found Organic Chemistry difficult to learn and understand.
• The lecturers were divided about whether experience of Leaving Certificate Chemistry facilitated students’ understanding and performance in Organic Chemistry at Third-Level.
Chapter 8

Cycle Two

Results (III)-

Organic Chemistry in Action!
8.1 – Introduction

The *Organic Chemistry in Action!* programme was trialled and evaluated in six Second-Level schools. The profile of these schools and details of this implementation phase have been outlined in Chapter Five (Section 5.3). The research methods and tools used in the evaluation of the programme have been outlined in Chapter Four (Section 4.7.1). As explained in Chapter Four (Figure 4.12) a mixed methods approach was used in the evaluation of the *Organic Chemistry in Action!* teaching materials. The findings from the evaluation of this implementation phase will be presented in this chapter. The findings will be presented in three sections, using the three lenses that were used for evaluation: participating teachers, participating pupils and comparison with a Control Group of pupils. The findings from each lens of evaluation will be presented individually in this Chapter. These findings will then be discussed together in answering the research questions that guided Cycle Two in Chapter Nine.

8.2 – Feedback from Participating Teachers

As already mentioned feedback from the participating teachers was gathered using four methods. These methods are outlined in Figure 8.1 below.

![Figure 8.1 Mixed method evaluation from participating teachers.](image)

The Venn diagram in Figure 8.1 illustrates how the four methods of data collection from the teachers were interlinked and related to each other. The Classroom Observations were carried out mid-way through the implementation phase. These gave the researcher an insight into the *Organic Chemistry in Action!* classroom and an opportunity to see first-hand how the
programme was being implemented by the teachers and received by the pupils. The findings of these observational visits will be outlined in Section 8.2.1 which follows.

The Teacher Diaries were distributed to the teachers at the initial Teacher Training Workshop. These allowed the teachers to record their immediate feedback and reflections on each of the lessons as they proceeded through the programme delivery. The main findings from these Teacher Diaries will be outlined in Section 8.2.2. As indicated in the same colour (blue) in Figure 8.1, the Classroom Observations and Teacher Diaries provided feedback from the teachers during their implementation of the intervention programme.

The Classroom Observations were also very useful in guiding and informing the researcher when planning the questions for the Chemistry Teacher Review Questionnaire. This questionnaire was distributed to, and completed by the participating teachers when they had finished teaching the programme. The main findings from the Chemistry Teacher Review Questionnaire will be outlined in Section 8.2.3. The Likert rating scales on the questionnaire provided the researcher with some quantitative feedback about the effectiveness of the programme and the teaching materials. There were also some short open-ended questions in the Chemistry Teacher Review Questionnaire.

The completed Chemistry Teacher Review Questionnaires and Teacher Diaries were returned to the researcher before each of the individual Teacher Interviews. It was important that the researcher read the Teacher Diaries and Chemistry Teacher Review Questionnaires in preparation for the Teacher Interviews. The Teacher Interviews allowed each teacher to provide their own feedback on the teaching materials and also allowed the researcher to ask the teacher to justify and explain the feedback given in their completed questionnaire and diary. The Teacher Interviews were useful in allowing the teacher to give an overall and personal evaluation of the *Organic Chemistry in Action!* materials without being restricted to the structure of the diary or questionnaire. The main findings and emerging themes from the Teacher Interviews will be outlined in Section 8.2.4. As themed together in the same colour (green) in Figure 8.1, the Chemistry Teacher Review Questionnaire and Teacher Interviews were used to provide the researcher with summative feedback from the teachers after their completion of their implementation of the intervention programme.
The findings are presented here with respect to each of the evaluation methods used. The recurring themes and responses from the teachers from each of the evaluation methods helped to confirm the reliability of the overall evaluation.

8.2.1. Classroom Observations

The purpose and guidelines of the Classroom Observations were outlined in Chapter Five (Section 5.3.3.2). The researcher carried out observational visits in the Chemistry classes of the three of the six participating schools: schools C, E and G were visited. All of these classes were held in a laboratory. The researcher used the same rubric to guide the observation of the pupils and teachers in each of the schools. This rubric is included in Appendix H. A summary of the teacher observations are included in Table 8.1. The stage of the programme that each of the classes were at is included in Table 8.1. Observations were made of teachers teaching different lessons in Units 3, 4 and 5. These observations were made and recorded during each of the lessons.

Through informal conversation with the teachers during these school visits, some further information was also gathered about the teaching materials. Much of the teachers’ feedback was related to the Pupil Workbooks. These teachers found that the Pupil Workbooks were time-consuming to complete during the lesson and that it was not always possible for the teachers to allow time for the pupils to complete their Pupil Workbooks during class time. In such cases, completion of the Pupil Workbook was assigned as part of the pupils’ homework. The teachers also expressed concern about the size of the Pupil Workbooks. Suggestions were made by the teachers to include a brief two-page summary at the end of each unit to facilitate the pupils’ revision for the examination. The inclusion of the PowerPoint slides in this summary was recommended by two of the teachers. These teachers explained that the PowerPoint slides were very useful, contain the necessary information, but in many cases, this same information is not included for the pupils in the Pupil Workbooks. This provided an indication to the researcher that these teachers did not understand the philosophy of the intervention programme. The necessary information and answers were deliberately not included in the Pupil Workbooks to encourage pupil investigations and inquiry-based learning. As an alternative to the Pupil Workbooks, one teacher suggested separate Pupil Worksheets and activity resources for the teacher. This would allow the teacher to integrate some of the activities of the programme into their own teaching methods rather than being confined to the defined lessons in each unit of the Organic Chemistry in Action! programme.
One of the biggest issues arising from these Classroom Observations, and from conversation with the participating teachers afterwards, was the timing of the lessons. The teachers explained how they did not have time to complete all of the Teacher Demonstrations or to allow their pupils carry out all of the non-mandatory activities that were planned for the lessons. It was apparent from this feedback that insufficient time was allotted for set-up and tidying away resources for the planned activities within the 35-40 minute class timeframe. The teachers explained that even to bring out, set-up, and put away resources takes time, and this was not factored into the allocated time for many of the lessons. This problem also reflects the lack of technical assistance for Science teachers in Irish classrooms.

Table 8.1 provides a brief insight into how each of the lessons in the *Organic Chemistry in Action!* programme were delivered by the participating teachers. While the pupils had access to and read their Pupil Workbooks throughout the lesson, it was clear that in the case of Teacher G, and sometimes with the other teachers also, the teacher told the pupils the correct answer to write into their Pupil Workbooks. It is clear that while the teachers did allow time for some of the inquiry-based activities (understanding the distillation process and modelling different possible isomers); they also wanted to ensure that the pupils had a correct and accurate record of the observation in their Pupil Workbooks. Each of the teachers used a variety of teaching resources and methods throughout each of the lessons: demonstrations, PowerPoint illustrations, writing on the white-board and group discussions. The spiral nature of the *Organic Chemistry in Action!* programme was evident in each of the lessons, as the teachers reminded the pupils of what they had learned in previous lessons and probed this knowledge to develop the pupils’ understanding in these lessons. Each of the teachers seemed to be aware of and addressed the possible misconceptions that the pupils may have had in the lessons.

During the three classroom observations, it was noted that each of the teachers did not complete the lesson as planned. Given that each of the teachers were teaching different lessons from different units, this suggests that the inadequate timing was a common problem throughout the programme. The teachers had to finish the lessons with omissions of some of the pupil activities (non-mandatory practical investigations).
Table 8.1 Summary of the Classroom Observations – Participating Teachers C, E and G.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Teacher input</strong></td>
<td>Very busy and rushed during the lesson.</td>
<td>Probes pupils’ inquiry at the introduction of the lesson.</td>
<td>Active, movement throughout the lab during the lesson.</td>
</tr>
<tr>
<td></td>
<td>Under pressure for time.</td>
<td>Asks pupils to make decision on set-up and solvents used in the teacher demonstration of Clove oil distillation.</td>
<td>Reads the Pupil Workbook with the pupils.</td>
</tr>
<tr>
<td></td>
<td>Reads the Pupil Workbook with the pupils.</td>
<td></td>
<td>Probes and sometimes tells pupils the answers for Pupil Workbook to ensure correct answer is recorded.</td>
</tr>
<tr>
<td><strong>Demonstrations</strong></td>
<td>N/A</td>
<td>Explain each step in the set-up of the Clove oil distillation.</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This demonstration is set up at the front of the class with help from the pupils through discussion.</td>
<td></td>
</tr>
<tr>
<td><strong>PowerPoint</strong></td>
<td>Used throughout the lesson.</td>
<td>Not used in this lesson, but is usually used.</td>
<td>Used throughout the lesson.</td>
</tr>
<tr>
<td></td>
<td>Integrated with use of whiteboard for drawing the 2-D structures.</td>
<td></td>
<td>Integrated with use of whiteboard for drawing the 2-D structures.</td>
</tr>
<tr>
<td><strong>Instruction</strong></td>
<td>Guidance to begin the activities and model building.</td>
<td>Emphasis on the small details of the distillation set-up.</td>
<td>Guidance to begin the activities.</td>
</tr>
<tr>
<td></td>
<td>Which pages of the Pupil Workbook to omit / complete.</td>
<td>Invite pupils up to the set-up to piece apparatus together and to ask questions.</td>
<td>Which pages of the Pupil Workbook to omit / complete.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tell the pupils which pages of the Pupil Workbook to complete at different stages of the lesson.</td>
<td></td>
</tr>
<tr>
<td><strong>Inquiry learning</strong></td>
<td>Different groups of pupils build different isomers of propanol.</td>
<td>Question pupils: How and Why?</td>
<td>Allow pupils to ‘explore’ with the molecular models giving hints e.g. ‘don’t allow free bonds’.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highlights the limonene structure to increase pupil interest.</td>
<td></td>
</tr>
<tr>
<td><strong>Links to previous lessons (spiral links)</strong></td>
<td>Intermolecular forces.</td>
<td>Links to extraction of chlorophyll (acetone as solvent).</td>
<td>Catalytic converters (link to rest of syllabus)</td>
</tr>
<tr>
<td></td>
<td>IUPAC Nomenclature.</td>
<td>Recall of chromatography technique.</td>
<td>Intermolecular forces.</td>
</tr>
<tr>
<td></td>
<td>Fractional Distillation.</td>
<td>Recall of boiling points and polarity.</td>
<td>IUPAC Nomenclature.</td>
</tr>
<tr>
<td></td>
<td>Aromatic and aliphatic.</td>
<td></td>
<td>Fractional Distillation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aromatic and aliphatic.</td>
</tr>
<tr>
<td><strong>Use of assessment</strong></td>
<td>Assigned homework given in the Pupil Workbook.</td>
<td>Asking pupil questions and questioning pupil answers ensured a continued group discussion throughout the lesson.</td>
<td>Questions asked by teacher.</td>
</tr>
<tr>
<td><strong>Feedback given to</strong></td>
<td>Positive feedback to correct responses and attempted answers.</td>
<td>Positive Feedback for correct pupil responses and recall.</td>
<td>Positive feedback.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Answering pupil questions.</td>
</tr>
<tr>
<td>pupils</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Answering pupil questions.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Answering pupil questions and suggestions for a suitable solvent.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Using models made by the pupils to show the whole class.</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Awareness of possible misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Polarity and electronegativity.</td>
</tr>
<tr>
<td>– Explains to pupils why ethanol would not be a suitable solvent for extraction of the eugenol (soluble in water also)</td>
</tr>
<tr>
<td>– Explain how water and eugenol are immiscible even though their vapours travel together through condenser.</td>
</tr>
<tr>
<td>– Which hydrogen atoms to remove from hexane to make cyclohexane.</td>
</tr>
<tr>
<td>– Allow pupils to show and name the different models that they have made.</td>
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</tbody>
</table>

<table>
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<tr>
<th>Variable teaching approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Group discussion.</td>
</tr>
<tr>
<td>– Provide instruction and guidance.</td>
</tr>
<tr>
<td>– Use of the Whiteboard.</td>
</tr>
<tr>
<td>– Use of PowerPoint.</td>
</tr>
<tr>
<td>– Demo of models built by pupils.</td>
</tr>
<tr>
<td>– Set up of the steam distillation demonstration.</td>
</tr>
<tr>
<td>– Drawing the eugenol structure on the board.</td>
</tr>
<tr>
<td>– Movement throughout the classroom.</td>
</tr>
<tr>
<td>– Group discussion.</td>
</tr>
<tr>
<td>– Drawing 2-D structures on the board.</td>
</tr>
<tr>
<td>– Movement throughout the classroom.</td>
</tr>
<tr>
<td>– Group discussion.</td>
</tr>
<tr>
<td>– Use of the Whiteboard.</td>
</tr>
<tr>
<td>– Use of PowerPoint.</td>
</tr>
<tr>
<td>– Demo of models built by pupils.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Homework assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Homework from previous lesson corrected at beginning.</td>
</tr>
<tr>
<td>– Some questions in Pupil Workbook lesson assigned as homework.</td>
</tr>
<tr>
<td>– Assigned homework for the current lesson also.</td>
</tr>
<tr>
<td>– Write up the lab report in hard back copies for homework (as assigned in the Pupil Workbook)</td>
</tr>
<tr>
<td>– Homework from previous lesson corrected at beginning.</td>
</tr>
<tr>
<td>– Some questions in Pupil Workbook assigned as homework.</td>
</tr>
<tr>
<td>– Assigned homework for the current lesson also.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use of additional resources in teacher Kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>– Classroom response cubes</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Lesson completion and conclusion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Lesson not completed even with omission of the practical (sodium and ethanol).</td>
</tr>
<tr>
<td>– Finished on pg. 238 of Pupil Workbook.</td>
</tr>
<tr>
<td>– Yes, with the omission of both pupil activities (solvent extraction and steam distillation)</td>
</tr>
<tr>
<td>– Teacher will set up solvent extraction as a demonstration in the next lesson.</td>
</tr>
<tr>
<td>– Lesson complete without the practical exp (catalytic cracking)</td>
</tr>
<tr>
<td>– Lesson concluded with pupils completing ‘What have I learned?’</td>
</tr>
</tbody>
</table>
The researcher had the opportunity to speak with the participating teachers after the observed lesson. From the lesson observations (Table 8.1) and from conversation with the teachers, two main criticisms of the programme were identified: the teachers found the programme time-consuming and they were also concerned about the variety of the content in the programme, fearing that the core syllabus content that ‘pupils need to know’ for the examination was not clear.

The main concerns raised in relation to the timing of the programme were:

- The *Organic Chemistry in Action!* programme was new to the teachers, and so required a lot of planning and reading (of the materials) at the beginning in preparation for the lessons.
- Not enough time for pupils to complete the Pupil Workbook questions within the class.
- Timing for the lessons was unrealistic.
- Teachers had limited time to read and check the pupils’ completion of the Pupil Workbooks to ensure that the correct responses and answers were recorded, for use for revision and study later.

The main concerns raised in relation to preparation for the Leaving Certificate examination were:

- Teachers still felt the need to give revision and summary notes to the pupils for examination preparation (in particular to the Higher Level pupils).
- Teacher C felt that there needed to be a clearer focus on the syllabus, examination questions, marking scheme and chief examiner’s reports, and that there was too much content that is not on the syllabus. They explained that pupils want to know ‘what parts do they need to know’.
- Teacher G explained that they may not carry out the oxidations of ethanol using the alternative oxidising agent (potassium permanganate), as learning two sets of colour changes (including that for sodium dichromate also) in the oxidation reactions may be confusing for the pupils.
- The steps of the reaction mechanisms are presented in the Pupil Workbook in a step-by-step inquiry-based manner over a number of pages. Teacher C felt that these need
to be condensed and summarised in a manner that the pupils will be able to write them for the examination.

- Teachers felt that the repetitive (spiral) nature of the course was sometimes frustrating for the Higher Level pupils in particular, as these pupils were focused on the examination and covering the necessary content.

Given these two main negative points of feedback given by the teachers, all three teachers did have a positive opinion, overall, of the Organic Chemistry in Action! materials and resources at this stage of the implementation phase. The teachers acknowledged the importance and relevance of how the topics were sequenced in the programme. They found the spiral nature of the course useful for integration and revision of topics. The teachers found that this repetition was particularly useful for the Ordinary Level pupils. They felt that pupils, who may not have understood a concept correctly the first time, have a better chance of understanding when they meet it again in a later lesson. It was evident from these classroom visits that the teachers were using the resources provided in the Teacher Resource Kits. The contents of the Teacher Resource Kit have been outlined in Chapter Five (Section 5.2.4.3, Table 5.5). The teachers commended the effectiveness of the classroom response cubes (for formative assessment), plastic building blocks (to introduce the concept of isomerism), polystyrene spheres (to illustrate the homologous series) and the molecular model kits (for shape, bonding, functional groups, building polymers etc.). The teachers appreciated the value of these concrete resources in facilitating the teaching of difficult abstract concepts. All three teachers (C, E and G) also valued the PowerPoint presentations for the lessons, and found the diagrams, animations and videos were effective tools for pupil learning. Teacher C explained that due to time constraints, they became more dependent on the lesson PowerPoint and looked only at this in preparation for the lesson, rather than using the Teacher Guide.

All three teachers specifically commented on the value of the ‘What have I learned?’ section at the end of each lesson. The teachers also valued the Homework Assignments provided for each lesson. Although the teachers suggested that improved summary sheets were necessary at the end of each unit, they valued the Homework Assignments, because as Teacher C explained, it is difficult to have written homework for pupils when teaching Organic Chemistry. The past examination questions are not suitable until the end of the pupils’ study of the topic, so the Homework Assignments and lesson summaries in the Organic Chemistry
in Action! programme were useful for formative assessment of the pupils on a daily basis. All three teachers observed, indicated their intention to use the PowerPoints, spiral structure approach and the resource kit in their future teaching of Organic Chemistry. All three teachers said that the programme and resources had helped to make Organic Chemistry a more enjoyable and easier topic to teach, and Teacher G in particular, acknowledged that the explanations and information in the Teacher Guide had helped to improve their own knowledge and understanding of Organic Chemistry.

8.2.2. Teacher Diaries

The Teacher Diaries were also useful in providing the researcher with direct feedback from the teachers after each of the lessons. The Teacher Diaries were given to the teachers at the Teacher Training Workshop. The template of the Teacher Diary is included in Appendix H. The teachers completed the diaries manually and returned them to the researcher (by post) when they had finished teaching the programme. The purpose of the Teacher Diaries was to provide the teachers with a medium to record their immediate feedback and brief reflection of thoughts after each lesson. Any of the emerging issues were then discussed with the researcher in the Teacher Interview at the end of the implementation phase. Some of the teachers were very brief in their comments given, while other provided more detailed feedback about specific activities that worked well or didn’t work well with their own respective classes.

Each of the Teacher Diaries was transcribed and qualitatively analysed to identify common themes from the teachers, as well as identifying recommendations and criticisms for particular lessons or activities. The complete transcriptions of the six Teacher Diaries are included in Appendix K. The findings from the Teacher Diaries will be presented here as a summary of the teachers’ feedback. Many of the diary entries have been extracted and included in the presentation of the findings in this Section. The Unit number and Lesson number along with the Teacher code are given with each of the extracted comments that follow.

There was some disparity between the teachers’ opinions of activities and lessons that were effective and useful and those that were ineffective and time-consuming. Some of the criticisms made by the teachers were related to their focus on preparing pupils for the Leaving Certificate examination, the time constraints and the specific use of some of the
resources that they found to be ineffective in their classrooms. These teachers outlined some recommendations from their own teaching of Organic Chemistry to improve the Organic Chemistry in Action! programme.

8.2.2.1. Pressure for Examination Preparation

It was clear from much of the teachers’ responses and feedback in the Teacher Diaries that the summative assessment of the Leaving Certificate Chemistry examination was a determining factor in their evaluation of the Organic Chemistry in Action! materials. While the programme was designed to include specifically the Organic Chemistry sections of the current Leaving Certificate Chemistry syllabus (Table 5.4 in Chapter Five), in many cases, the teachers felt that the necessary syllabus content to be learned was not outlined clearly enough for the pupils. In some cases the teachers felt that certain ‘important examination topics’ were not given enough emphasis:

“Should be a slide at end summarising all of mechanism together or somewhere in workbook for them [pupils] to write it [ionic addition mechanism] all out in one go. Arrows are not needed in L.C., so I told them to leave them out” (Teacher C, Unit 4, Lesson 4).

Printing the Pupil Workbooks in greyscale rather than in colour (due to the cost) did not facilitate their use for the pupils or the teachers. If the workbooks were printed in colour, the necessary and highlighted ‘Important Note boxes’ may have been useful for the pupils.

In many cases, teachers wanted more emphasis to be placed on ‘practising the answers’ for examination questions rather than developing understanding of the concepts.

“Again, they only need a few lines summarised after learning [ionic addition mechanism] would be more beneficial to them” (Teacher B Unit 6, Lesson 4).

“In my opinion perhaps too much detail here- exam Q’s very straight forward on this section [improving Octane Number]” (Teacher D, Unit 3, Lesson 4).

Many of the non-mandatory activities were omitted due to limited time available in class.

Many of the teachers explained that they did not spend time on such activities that would not be directly assessed in the Leaving Certificate examination.

“I really dwelled on the $H_2$ in this, and skipped thru most of the other slides-no relevance to course. Biodiesel- didn’t do this, or talk about it much – not on course”

(Teacher C, Unit 3, Lesson 5).
“Making biodiesel, nice activity, but is it necessary for course?”

(Teacher D, Unit 3, Lesson 5)

While these extracts provide an insight into the teachers’ focus on examination preparation, their diary entries also reflected their pupils’ focus on the examination:

“Uneasy feeling in the class- some students very exam orientated”

(Teacher A, Unit 1, Lesson 2)

“Kids getting frustrated with lack of definite notes”

(Teacher B, Unit 1, Lesson 4)

“I found that the students had trouble understanding what they needed to know at the end of the lesson”

(Teacher E, Unit 4, Lesson 1).

These entries related to the pupils’ experience of the programme suggests that the format in which the content was presented (in the two Pupil Workbooks) may not have been useful for the pupils in their preparation for the Leaving Certificate examination.

As explained already in Chapter Two (Section 2.3), the use of dichromate as an oxidising agent has been banned in Second-Level schools in Ireland since early 2011 (DES 2011a). However for the Leaving Certificate examination, pupils are expected to know the colour changes and oxidation states for dichromate in the preparations of ethanal and ethanoic acid by the oxidation of ethanol. The author provided details in the Organic Chemistry in Action! Programme for using potassium permanganate as an alternative oxidising agent for these preparations so that the pupils could still set up the equipment and carry out the mandatory experiments in class. However, from many of the teachers’ diaries, it is clear that although this alternative oxidising agent was used in some cases, the teachers still had to teach the pupils the oxidation reactions using different reagents, as required in the examination:

“Too much repetition of KMnO₄ for unsaturation- no marks in exam, must be bromine!”

(Teacher C, Unit 2, Lesson 5)

“Used animation from exp CD rom Understanding Chemistry to show rxn using Na₂Cr₂O₇”

(Teacher E, Unit 7, Lesson 4)

“Went through KMnO₄ as oxidising agent as will be coming across it in titrations but am not going to mention it again in organic as don’t want to get them confused”

(Teacher G, Unit 7, Lesson 2).
8.2.2.2. Time Constraints

There was much evidence in the Teacher Diaries of material, activities and demonstrations that were omitted from many of the lessons due to limited time. The following extracts from different teachers provide an insight into the consistent challenge that all of the teachers faced with regard to completing the lessons as planned within each class period:

“Too much activity and work in this lesson for single class, nearly need an assistant”
(Teacher B, Unit 1, Lesson 4)

“For all of these lessons [Unit 4], I just followed PowerPoints and students’ workbooks, I did none of the activities or demos – No Time”
(Teacher C, Unit 4)

“Busy lesson- did not have time to complete the optional Teacher Demonstration”
(Teacher D, Unit 3, Lesson 2)

“This lesson was done during a double class (single recommended- not feasible)”
(Teacher E, Unit 2, Lesson 5)

This consistent feedback from all of the teachers suggests that the author was inaccurate in planning the number of activities and amount of content for many of the lessons. As well as over-planning by the researcher, the time constraints may also be as a result of the lack of familiarity and proficiency by teachers in the use of the materials. While the teachers explained that they had to omit many of the activities, they did recognise the possible value of the activities and suggested that they may be more appropriate for Transition Year Science:

“Too much info here, would be good for TY?”
(Teacher A, Unit 5, Lesson 1)

“Nice, would be great to do with a TY group. Felt students getting a little stressed at this point and alarmed at the thought of a second booklet. Really only needs to be mentioned here, love to do it, only curriculum constraints”
(Teacher B, Unit 5, Lesson 1)

None of the teachers carried out Lesson 3 in Unit 5, which was Making Perfume. While the teachers did acknowledge the value of the application of extraction techniques, essential oils, understanding of diffusion and molecular size for making perfume, all of the teachers suggested this lesson would be more suitable for a Transition Year activity.

8.2.2.3. Constructive Feedback about the Design Criteria

The specific design criteria of the Organic Chemistry in Action! programme were outlined in detail in Chapter Five (Section 5.2.2). Some of these criteria and teaching strategies were
described as effective and useful by the teachers (these will be discussed below). However, not all of the elements of the programme were found to be effective by all of the teachers.

A key element of the Organic Chemistry in Action! was the spiral structure and introduction of topics (Figure 5.2), whereby parts of different topics were introduced to the pupils in a ‘need to know’ basis and then revisited and developed throughout the programme. However, some of the teachers found this structuring of the content too repetitive:

“The repetition is helpful but the workbook needs to be condensed”

(Teacher B, Unit 4, Lesson 4)

“A lot of the same stuff again, getting very repetitive. I like the spiral but there is no need for total repetition”

(Teacher C, Unit 4, Lesson 6)

The use of molecular modelling by the pupils and teachers was an integral part of the programme. While most of the comments in relation to the use of the models were positive, there were some cases where the teachers did not find the use of the models beneficial to pupil learning:

“Pupils got distracted during the model-making – drawing would have been more useful”

(introduction of chloroalkanes]"

(Teacher E, Unit 4, Lesson 2)

“Pupils found model demonstration and activity [of substitution mechanism] confusing”

(Teacher E, Unit 4, Lesson 3).

Another resource that was not found to be effective for some of the teachers was the jigsaw pieces designed for use to teach the parts and processes of the instrumentation techniques:

“Students found jigsaws too time consuming and too difficult to arrange in books, didn’t work well at all”

(Teacher C, Unit 5, Lesson 6).

8.2.2.4. Suggested Changes for Improvement

The teachers were encouraged to record any aspects of their own teaching approaches that they did or would integrate into their teaching of Organic Chemistry. While most of the teachers taught the material as directed in the Teacher Guide, some resorted to using their own methods:

“Mechanism; OK, maybe could be condensed and summarised better (went back to my own notes for this)”

(Teacher B, Unit 4, Lesson 3)

“I always mention (H) when discussing reduction and give a simple mechanism (allow students to predict mechanism)”

(Teacher E, Unit 7, Lesson 5).
Where teachers gave comments (as these above) in the Teacher Diaries, the Teacher
Interviews were useful in allowing the teacher to expand and explain their ‘own methods’ of
teaching the particular topics. Such examples will be discussed in Section 8.2.4 below.

In other cases, the teachers taught the Organic Chemistry in Action! programme as intended
by the author but recorded suggestion of how the particular approaches used could be
improved when revising the materials. Examples of some of the teachers’ suggestions are
shown here:

“Students need to be taught theory in one lesson, and do practical in the next. They need time
to process the material” (Teacher C, Unit 6, Lesson 2)

“More distinction need to be made between principles and processes [of instrumentation
techniques] as chief examiner states this is a common misunderstanding”

(Teacher E, Unit 5, Lesson 6)

“Not enough slides to explain how to do experiment [preparation of soap]. They need to do it
themselves as a mandatory exp. It would have been nice to teach it to them using
PowerPoint” (Teacher C, Unit 8, Lesson 7)

These suggestions and other will be taken into consideration in the revision of the teaching
materials. Another factor raised by the teachers was the effectiveness of the course for the
Higher Level and Ordinary Level pupils. While some teachers felt that the ‘slow pace’ and
repetition of the course facilitated the Ordinary Level pupils, there were other lessons where
the teachers felt the inquiry-approach and investigatory nature of the Pupil Workbook was
too complex for the Ordinary Level pupils:

“Again, for the weaker students, finding the additional families hard to remember… new
functional groups. Material presented and Workbook Q’s facilitating the stronger student in
this lesson. Flow chart making sense for them (stronger students) – more difficult concept for
the weaker student” (Teacher D, Unit 7, Lesson 5)

8.2.2.5. Effective Design Criteria

The specific elements of the course that were not found to be helpful by the teachers have
already been listed and discussed above. However, more of the resources were found to be
useful for the teachers and pupils involved in the implementation phase. These will be
outlined here. It is important to acknowledge that this mixed response and diverse experience
of the same materials from the six teachers suggests that the feedback may be more subjective than objective in nature.

### Molecular Model Kits

Although, there were some mixed responses from the teachers about different elements of the programme, all of the teachers did find the use of the Pupil Model Kits and the Teacher Model Kit effective in facilitating the pupils’ understanding in a number of ways. There was much evidence that this hands-on approach was beneficial for the learners (many of whom were at the concrete stage of cognitive development) for understanding the shape and structure of organic compounds; “keen student interest in lesson- hands-on approach suited them” (Teacher D, Unit 1, Lesson 3)

The use of models facilitated the pupils’ in a number of ways.

1. Understanding the concept of isomerism:
   
   “Using the molecular model activities was excellent to help students understand isomers”
   
   (Teacher E, Unit 2, Lesson 2)

   “Compared to previous years, students found this concept [isomerism] easier due to the hands-on approach”
   
   (Teacher D, Unit 2, Lesson 2)

2. Understanding the structure of benzene:
   
   “Deduction approach for students to deduce the shape of benzene excellent. I had found in previous years they were simply given the shape of benzene and never really had any concept of the resonance structure associated with it”
   
   (Teacher D, Unit 2, Lesson 5)

   “The Teacher Demo model was very good to explain the delocalised bonding”
   
   (Teacher G, Unit 2, Lesson 6)

3. The instability and reactivity of pi bonds:
   
   “I found the Teacher Demonstration of the C≡C effective… in previous years, difficult topic to grasp. Teacher Model Kit excellent”
   
   (Teacher D, Unit 4, Lesson 6)

   “Did activity with the models [understanding reactivity of alkenes], students were a bit confused (following the workbook), but seemed OK by the end of the lesson, answered the Pop Test well”
   
   (Teacher C, Unit 4, Lesson 4)

4. Understanding why and how organic reactions happen:
   
   “Getting pupils to build models of dehydrogenation and hydrogenation was very good”
   
   (Teacher G, Unit 2, Lesson 3)
“Good link for students of ester link between an alcohol and carboxylic acid. Deduction from modelling very good exercise”.
(Teacher D, Unit 8, Lesson 6)

“Models and dehydrogenation of primary alcohols to aldehydes – very good”
(Teacher A, Unit 7, Lesson 2).

“Modelling condensation reaction works very well here because of the removal of water during reaction”
(Teacher E, Unit 8, Lesson 4)

“Making polymer chains worked well. Using the models to build polymers worked well for students to understand how the bond opened up”
(Teacher G, Unit 2, Lesson 4)

“Activities (models and workbooks) relating to polymerisation were very well received by students. Listening to students during modelling activity I felt learning was taking place”
(Teacher E, Unit 2, Lesson 4)

5. Understanding reaction mechanisms:

“Modelling the mechanism really did help the students to get a grasp of the concept [substitution mechanism]… very good”
(Teacher D, Unit 4, Lesson 3)

“Good lesson, especially with models for them to build it through to explain mechanism and getting them to figure out termination, they liked the card game to go with it”
(Teacher G, Unit 4, Lesson 3)

“I felt students understood well addition rxn’s which were enhanced by addition rxn card game….In the past I found students had no understanding of the mechanism …. The modelling activity is fantastic to help in their understanding of the steps of the reaction”
(Teacher D, Unit 4, Lessons 3 and 4)

As well as the Pupil Model Kits and the Teacher Model Kit, the teachers also gave some very positive feedback about the effective use of many of the other resources included in the Teacher Resource Kit. The quotes below provide an insight into the success of some of the other resources. It is important to note that these diary extracts are not representative of all of the resources used by the teachers, but are useful examples:

“As VSEPR Theory was covered before some students were okay the ones who had trouble before found the demonstration with balloon useful”
(Teacher E, Unit 1, Lesson 4)

“Polymer-Monomer card game was good. Students took them home to use them”
(Teacher G, Unit 2, Lesson 4)

“Polymers well represented with the paperclips”
(Teacher D, Unit 2, Lesson 4)
“Very good lesson – they enjoyed cutting out jigsaw pieces of instruments, made it more interesting than just looking. Sent them home to solve CSI”

(Teacher G, Unit 5, Lesson 6)

“Excellent visual aids here [instrumentation]… students can visualise: GC, HPLC, MS. Reference to CSI very very interesting for the students. Starting a lot of conversation, interest and Q’s. Cut-out instrumentation very useful as student activity”

(Teacher D, Unit 5, Lesson 6)

“Pop Questions are good for making them think about what they just finished”

(Teacher G, Unit 7, Lesson 4)

“Ester formation well illustrated with card game”

(Teacher D, Unit 8, lesson 4)

Facilitating Pupil Understanding

One of the key criteria in the design of the Organic Chemistry in Action! intervention programme was to facilitate the understanding of difficult concepts for learners, many of whom are at the concrete stage of cognitive ability. The cognitive ability of Second-Level pupils and the cognitive demand of Organic Chemistry have been discussed in detail in Chapter Three (Sections 3.3.1 and 3.4.2). Organic mechanisms in the Leaving Certificate Chemistry course require formal cognitive understanding. Organic Mechanisms have also been identified as a specific area of difficulty for those learning Organic Chemistry at Second-Level. There is much evidence from the responses from these teachers that the approach used to introduce and teach mechanisms in the Organic Chemistry in Action! programme was effective in facilitating the pupils’ understanding of this topic:

“I like that focus is put on why alkenes react, rather than ‘learning the mechanism’ as it allowed the students to apply knowledge to additional reaction not on the syllabus”

(Teacher E, Unit 6, Lesson 4)

While the focus was on learning and understanding, some teachers also acknowledged that “evidence of mechanism well presented in format needed for the exam” (Teacher D, Unit 6, Lesson 4).

Two of the teachers commented in particular on the order of the introduction of the compounds for the addition mechanism. Teacher A recognised this psychological sequence as it facilitated the pupils’ understanding and development of the ionic addition mechanism as a whole: “V. good, would do, H-Cl, Cl-Cl, Br-Br in that order NB” (Teacher A, Unit 6, Lesson
4). By having the pupils deduce the steps of the mechanism using different compounds to add on, they developed confidence in their understanding rather than resorting to rote learning.

“Good lesson. Going through the mechanism initially allowing the pupils to discover / deduce the steps and then reinforcing it 3 more times with addition of H₂, Cl₂ and Br₂ was good. The evidence of the mechanism then was easy to deduce as they had worked through it 4 times”

(Teacher G, Unit 6, Lesson 4)

Other strategies used to improve and facilitate the pupils’ understanding of the complex concepts included the use of analogies. The teachers were very positive in the feedback given about these analogies and their effectiveness:

“Like the wine → vinegar analogy as it helped to explain the new ‘oxidation’”

(Teacher E, Unit 7, Lesson 2)

“Analogy with lego and sandwiches was very good in explaining limiting reagent”

(Teacher G, Unit 7, Lesson 4)

“Really like limiting reagent analogy-sandwich (have used it myself in the past)”

(Teacher E, Unit 7, Lesson 4).

**Context-based Approach**

As discussed above, many of the teachers omitted some of the non-mandatory practicals and investigatory pupil activities due to timing constraints. Many of these additional activities were included as an effort to make the topics more relevant and applicable to the pupils’ lives e.g. making perfume etc. Although there is much evidence that not all of these activities and discussions were carried out, some evidence in the Teacher Diaries does suggest that the inclusion of applications and contextual links within the lessons were effective in increasing pupil engagement in Organic Chemistry:

“Fantastic applications included from everyday Science in material presented. Students engaged well”

(Teacher D, Unit 2, Lesson 4)

“Very modern, very relevant, even picked up some information myself”

(Teacher B, Unit 1, Lesson 2)

“Good class, lead to a lot of discussion at times”

(Teacher G, Unit 3, Lesson 2).

“Students interested in this lesson- practical applications”

(Teacher D, Unit 8, Lesson 5).
Effective Teacher Demonstrations

Some of the Teacher Demonstrations were simply used to illustrate and explain concepts to the pupils: “understanding of reflux demonstration good practice” (Teacher D, Unit 8, Lesson 3) and the use of the polystyrene spheres “… was good for understanding concept of a homologous series” (Teacher E, Unit 2, Lesson 1). From these comments, it is clear that these demonstrations were effective. However, for the most part the Teacher Demonstrations were effective in increasing pupils’ interest and enjoyment in the lessons, while also stimulating their thinking:

“Loved the teacher demo [storm in tea-cup] suggested …. Students very impressed”
(Teacher D, Unit 7, Lesson 3)

“Storm in a test-tube- lovely demo. They enjoyed and were able to explain what occurred”
(Teacher G, Unit 7, Lesson 3)

“Carbon tower excellent. Good introduction. Nice demonstrations”
(Teacher B, Unit 1, Lesson 1)

“Demonstration very effective [Pringles rocket]”
(Teacher D, Unit 1, Lesson 4)

“Teacher demo of the ‘Disappearing Polystyrene cup’- they found fascinating”
(Teacher G, Unit 2, Lesson 4).

“They loved the teacher demo- ‘Ice on Fire’”
(Teacher G, Unit 2, Lesson 5)

The extracts from the diaries listed above provide an insight into the value of the Teacher Demonstrations in increasing pupil interest in the lessons and stimulating their thinking.

Effectiveness of the Spiral Structure

There was much more positive than negative feedback about the spiral structure. This is evident from the diary entries below:

“They realised by the end of the lesson that things / questions get asked a lot and they are learning it due to the repetition”
(Teacher G, Unit 3, Lesson 2)

“Very good lesson as a lot of re-capping on previous material and good at reinforcing and grounding the material”
(Teacher G, Unit 4, Lesson 6)

“Quick lesson as it was going back over polarity etc. that they have seen before and can now quickly work out the questions”
(Teacher G, Unit 7, Lesson 3)

As well as valuing the revision of topics through the spiral structure, the teachers also appreciated the structure of the programme and sequence in which the topics were
introduced. The ‘drip-feed’ introduction of topics facilitated the pupils’ ability to build and develop the new concepts and frameworks clearly:

“Students found this [reactivity of double bond in alkenes] straight-forward. I think their bank of knowledge from the previous modules on the course is really beginning to stand to them. Becoming confident in the subject matter”  (Teacher D, Unit 4, Lesson 4)

“By the time this lesson arrived the students appeared to be quite familiar with the process of adding across a double bond, and were able to discuss bond breaking and forming well”  (Teacher E, Unit 6, Lesson 3)

Figure 8.2 summarises the main feedback from in the Teacher Diaries. Each of these have been discussed and supported with relevant extracts from the diaries.

![Figure 8.2 Summary of the main comments emerging from the Teacher Diaries (n=6)](image)

The Teacher Diaries and Teacher Questionnaires were returned to the researcher before the individual Teacher Interviews were carried out. This allowed the researcher to follow-up on any comments made by the teachers in the diaries and also gave the teachers an opportunity to justify and develop the opinions expressed in their diaries.
8.2.3. Chemistry Teacher Review Questionnaires

In comparison to the findings from the Classroom Observations and the Teacher Diaries, which have been presented in Sections 8.2.1 and 8.2.2 respectively, the Chemistry Teacher Review Questionnaires were completed by the teachers after they had completed their implementation of the intervention programme. These Chemistry Teacher Review Questionnaires therefore provide a summative evaluation of the teachers’ attitudes to the intervention programme in comparison to the observational visits and diaries that provide specific feedback from the teachers as each lesson and unit was taught.

The Chemistry Teacher Review Questionnaire used for the evaluation of the *Organic Chemistry in Action!* programme is included in Appendix H. On the first page of the questionnaire the teachers were asked to indicate on a Likert scale their attitudes to the resources, Pupil Workbook, Teacher Guide, practical work, and relevance of the *Organic Chemistry in Action!* programme. Due to the small number of teachers (n=6) involved as participants in this study, it was decided that representing the percentages of teachers that selected each point on the scale for each criterion would not be worthwhile. Instead of presenting the median scores on the Likert rating for each of the criteria listed in the Chemistry Teacher Review Questionnaire, the responses are illustrated in Table 8.2 using green ticks and red crosses. Each symbol (cross, tick or question mark) in Table 8.2 represents the opinion of one of the teachers. The use of colour in Table 8.2 facilitates the analysis of the overall responses from the teachers. The resources listed and elements of the Pupil Workbook and Teacher Guide listed in Table 8.2 have already been explained in Chapter Five (Section 5.2.4).

All of the teachers rated Molecular models, Lesson PowerPoints, Homework Assignments, ‘What have I learned?’ (Lesson summary), Important Note boxes and the Interesting Insight boxes as really helpful or helpful in their teaching of Organic Chemistry. Individual teachers listed the Playing cards, Non-mandatory investigations, Teacher demonstrations and Mandatory experiments as not helpful or really not helpful in their teaching of Organic Chemistry. Half or more of the teachers rated all of the remaining topics as really helpful or helpful in their teaching of Organic Chemistry. *Organic Chemistry in Action!* materials that were never used by individual teachers included the Playing cards, Classroom response cube, Outline of the lesson outcomes, Word Spy (for new vocabulary), the Summary classification charts, Group discussions and the Listing of examination questions per unit.
### Table 8.2 Summary of the Chemistry teachers’ attitudes to the key elements of the Organic Chemistry in Action! programme (n=6)

<table>
<thead>
<tr>
<th>Element</th>
<th>Really helpful ⬠</th>
<th>Helpful ⬠</th>
<th>Indifferent ⬠</th>
<th>Not Helpful ⬠</th>
<th>Really not helpful ⬠</th>
<th>Never used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resources</strong></td>
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<td>Molecular models</td>
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<td>🔳</td>
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<td>Playing cards</td>
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<td>Classroom response cube</td>
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<td>Lesson Power Points</td>
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<td>🔒</td>
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<tr>
<td>Videos</td>
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<tr>
<td>Animations</td>
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<tr>
<td><strong>Pupil Workbook</strong></td>
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<tr>
<td>Order of lessons and topics</td>
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<tr>
<td>Outline of lesson outcomes at the beginning</td>
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<tr>
<td>Completing the workbook</td>
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<tr>
<td>Homework Assignments</td>
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<tr>
<td>‘What have I learned?’</td>
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<tr>
<td>Important Note boxes (for definitions)</td>
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<tr>
<td>Word Spy (highlight new vocabulary)</td>
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<tr>
<td>Summary classification charts</td>
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<tr>
<td><strong>Practical Work</strong></td>
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<tr>
<td>Experiments and investigations (Non-mandatory)</td>
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<tr>
<td>Teacher demonstrations</td>
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<td>Mandatory experiments</td>
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<tr>
<td><strong>Relevance and Interest</strong></td>
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<td>Links to everyday life</td>
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<td>Links to Industry</td>
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<tr>
<td>Chemistry Chronicles</td>
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<td>Group discussions</td>
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<tr>
<td>‘Interesting Insight’ boxes</td>
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<tr>
<td><strong>Teacher Workbook</strong></td>
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<tr>
<td>Highlighting possible Learning difficulties</td>
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<td>Lesson plan Flowchart</td>
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<tr>
<td>Listing of Exam Questions per unit</td>
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<tr>
<td>Solutions and answers to problems in Pupil Workbook.</td>
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<td>🔔</td>
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</tbody>
</table>
As well as being asked about the physical resources provided in the Teacher Resource Kit, the teachers were also asked to rate on a five-point Likert scale their attitudes to the teaching approaches and strategies used in the *Organic Chemistry in Action!* programme. The teachers’ (n=6) responses to this Likert scale (Table 8.3) are presented in the same manner as in Table 8.2 before with the ticks and crosses. The first column in Table 8.3 also shows the teachers’ intention to use the teaching approaches in their teaching of Organic Chemistry in the future.

Table 8.3 Summary of the teachers’ attitudes to the teaching approaches incorporated into the *Organic Chemistry in Action!* programme (n=6)

<table>
<thead>
<tr>
<th>Teaching Approach</th>
<th>Use in Future Teaching</th>
<th>Really helpful</th>
<th>Helpful</th>
<th>Indifferent</th>
<th>Not Helpful</th>
<th>Really not helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral introduction of topics</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Linking assessment with learning outcomes in Teacher Guide</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
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<tr>
<td>Homework assignments – for Formative Assessment</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Partial notes to be completed in class</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Inquiry based approach</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Visual Aids for difficult concepts: E.g. animations, diagrams.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Molecular models: To understand shape and structure</td>
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<tr>
<td>Context-based approach</td>
<td>✔️</td>
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<tr>
<td>Micro-scale and alternative practical experiments.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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</tbody>
</table>

All of the teachers listed the Spiral Introduction of topics, Visual aids and Molecular models as really helpful or helpful in their teaching of Organic Chemistry. Therefore, it is not surprising that all of the teachers intend to use each of these teaching approaches in their teaching of Organic Chemistry in the future. Four or more of the six teachers intend to use all of teaching approaches listed in Table 8.3 in the future. This observation is a good indication of the success and usefulness of these specific criteria that were incorporated into the *Organic Chemistry in Action!* programme. The only aspects of the course that were not found to be helpful by two of the teachers were the use of the partial notes for the pupils and the inquiry-based approach.
The remainder of the Chemistry Teacher Review Questionnaire was made up of nine open-ended questions. These questions gave the teachers an opportunity to express their opinion and comment on aspects of the course that were most helpful, least helpful and to recommend improvements that could be made. The teachers were also asked about how the programme benefited their pupils and also their own approach to teaching Organic Chemistry. Free space was available at the end of the questionnaire for the teachers to provide any further comments or feedback about the course.

Most of the responses in the open-ended questions were consistent with the responses given by teachers in both of the Likert scales (Tables 8.2 and 8.3). All of the teachers again listed the molecular modelling kits as one of the most effective and useful resources in the Teacher Resource Kit. Other resources listed by individual teachers included the polystyrene spheres, classroom response cubes, lesson PowerPoints, the additional practical activities and the spiral structure of the programme. All of the teachers agreed that the molecular models and other resources were very helpful for the visual learners and provided the pupils with a hands-on approach to learning. They also added enjoyment and fun to the lessons. The molecular models facilitated pupils’ inquiry. The spiral nature of the programme was listed as effective as it helped to reinforce the difficult concepts. Four of the teachers listed the playing cards as the least effective and useful resource. These teachers explained that the pupils lose their focus when playing the games and that some of the games were too complex for the pupils. However, the game cards were listed as effective and enjoyable by the two other teachers. The jigsaw-piece sheets given for teaching Instrumentation were listed as the least effective tool by one of the teachers. This teacher explained that they were too time-consuming to complete in class. All of the teachers mentioned the poor timing of the lessons as their biggest criticism of the *Organic Chemistry in Action!* programme. Implementation of this programme required more class time that the teachers would have given to teaching Organic Chemistry using their own methods. Half of the teachers explained that the Pupil Workbook was too long and that the pupils were frustrated by the time required to complete the Workbook and course. One of the teachers suggested that the programme may be better suited for a fifth year class where there is not as much pressure for examination preparation. The time limitation was the main reason given by many of the teachers for omitting some of the Teacher Demonstrations and optional pupil activities. While two of the teachers felt that the programme was well structured, the other teachers made some recommendations to improve the *Organic Chemistry in Action!* programme. Two of the teachers felt that the
Thermochemistry (section 5.4 of the Leaving Certificate Chemistry syllabus) should have been included in the programme as it is closely linked to the study of Fuels. The teachers recognised the need for the content of the programme to be reduced slightly. One teacher recommended a clearer focus on the content of the Leaving Certificate syllabus and a limitation on the inclusion of ‘irrelevant information’. While the Organic Chemistry in Action! programme was specifically structured to cover the content of the Leaving Certificate syllabus (Table 5.4), it was apparent from this feedback that this teacher may not have appreciated the value of the contextual and inquiry-based elements of the programme. Two teachers recommended a shorter ‘notebook’ for the pupils containing the content of the PowerPoint slides and brief notes for easy study and revision. One of these teachers explained that activity sheets should be given separately to the teacher for use in the introduction and learning of the topics.

There were mixed responses in the teachers’ responses to whether the programme benefited Higher Level and Ordinary Level pupils equally. Four of the teachers felt that the spiral introduction of topics, repetition and visual aids were beneficial for the Ordinary Level pupils. While two of the teachers felt that the Higher Level pupils found the repetitive nature boring, these teachers did recognise the benefit of the revision of topics (in particular the non-organic topics e.g. bonding, electronegativity, oxidation-reduction etc.). One teacher felt that the programme was better suited to Higher Level pupils only as some of the content and inquiry-based activities were too difficult for the Ordinary Level pupils to understand. One teacher felt that both cohorts of pupils benefited from the spiral nature of the programme.

Four of the teachers felt more aware of the possible misconceptions in learning Organic Chemistry after their participation in the programme. By understanding these possible difficulties and alternative frameworks that the pupils may develop, these teachers felt better prepared to help the pupils to work through the difficult topics and thus facilitate a clearer understanding of Organic Chemistry.

All of the teachers agreed that the teaching approaches used in this programme could be implemented in other areas of Chemistry: in particular with relation to the mole concept, chemical equilibrium and rates of reaction. One of the teachers felt that Organic Chemistry lends itself well to a spiral introduction of topics as it is a long part of the course.
Overall, all of the teachers said that they enjoyed teaching the course and found it interesting, although it was time-consuming. All of the teachers said that they will incorporate elements of the programme to enhance their teaching of Organic Chemistry in the future. One teacher explained the difficulty in presenting someone else’s work as intended by the author. This was a factor to be considered with all of the participating teachers; they were confined to teaching the Organic Chemistry using the *Organic Chemistry in Action!* materials, which in many cases deviated from their own methods of teaching Organic Chemistry in previous years. The implementation of this new and unfamiliar approach may have added to the teachers’ demands in preparation and implementation of the *Organic Chemistry in Action!* programme.

The quotes below provide an insight into the closing remarks given by the teachers in the Teacher Questionnaires:

“Very good programme. Presenting someone else’s work was greatest difficulty for me (after 26 years of my own approach). Some of the PowerPoints and activities will certainly be incorporated in the future”

(Teacher A)

“All in all, delighted to have taken part in the module. I was enthusiastic which flowed over to students. I loved the newness of it. However, it has left me strapped for time. The workbooks do need to be condensed”

(Teacher B)

“Pupil Workbooks are not great, too much going on in them. They should be either a textbook for reading and students take notes in class or a workbook with Q’s only, but the combination of both made them very hard to use both as a teaching resource for me and a learning resource for students- they repeatedly complained about them”

(Teacher C)

“I enjoyed using the resources and found the approach interesting. I would have liked to trial the course with 5th years instead as there would have been less pressure”

(Teacher E)

“I am glad I participated in it as I do feel it has changed the way I will teach Organic for future years”

(Teacher G)
8.2.4. Teacher Interviews

The process used in the analysis of the Teacher Interviews has been outlined in Chapter Four (Section 4.3.2). The stages involved in the analysis of this qualitative data have been summarised (Table 4.3 and Figure 4.6). The Teacher Interviews were semi-structured. There were some common questions asked to all of the teachers, planned by the researcher from specific themes emerging in the returned Teacher Diaries and Teacher Questionnaires.

These themes addressed in these semi-structured interviews were:

- Teachers’ attitudes to the *Organic Chemistry in Action!* programme
- Structure of the *Organic Chemistry in Action!* programme
- Content of the *Organic Chemistry in Action!* programme
- Resources included in the *Organic Chemistry in Action!* programme
- Prediction of the pupils’ perspectives of the programme
- Approaches taken to teach difficult topics
- Focus on the Leaving Certificate Chemistry syllabus and examination
- Teaching for understanding

Some specific questions were also asked to certain teachers as a result of feedback given in their Teacher Diaries and Teacher Questionnaires. The general questions used to guide the structure of the interviews are included in Appendix H. Interviews were carried out with all six teachers who implemented the *Organic Chemistry in Action!* programme. The six Teacher Interviews were transcribed. These complete transcriptions are included in Appendix L.

Each of the interviews lasted approximately 30 minutes, except for the interview with Teacher C, which took 60 minutes. After careful analysis, organising, coding, theming and describing of the interview transcripts, some common issues arose from each of the themes that the researcher had investigated.

Figure 8.3 provides a summary of the issues arising from each of the themes that were discussed in the Teacher Interviews. Overall, there were some mixed responses from the teachers in relation to a lot of the themes. In some cases all teachers agreed about the effectiveness of the programme, while in relation to other issues there was some disparity in the teachers’ responses.
Figure 8.3 Summary of the emerging themes and issues from the Teacher Interviews (n=6)
Note: OCIA is an abbreviation for Organic Chemistry in Action!
The findings from the Teacher Interviews will be presented here using the themes listed above. The main issues arising from each theme discussed, as well as the positive and negative feedback from the teacher will be presented and illustrated by inclusion of extracts from the interview transcripts and individual teacher quotes.

The letter “I” is used to represent the interviewer (the researcher) in any extracts taken from the Teacher Interviews. As before, each teacher is referred to using the code letter for their school i.e. Teacher A is the Chemistry teacher in School A.

In this discussion, the focus is more on the programme as a whole as opposed to specific resources and approaches that were effective or ineffective for the teachers. Detail about the teachers’ attitudes to particular aspects of the course and resources have already been outlined in the findings from the Teacher Diaries and Teacher Questionnaires. As explained already, the Teacher Interviews sought to gather information from the teachers about their attitudes to the specific design criteria, the teaching approaches used in the programme and the feasibility of such a programme within the context of the Irish Leaving Certificate programme.

8.2.4.1. Teachers’ Attitudes to the Organic Chemistry in Action! programme

The teachers involved in the implementation of the intervention programme had varying amounts of previous teaching experience. Teacher A had been teaching in Second-Level for over 20 years, and was positive and willing to try new teaching approaches: “Like if you’re 25 years doing the same thing, it’s nice to change it around you know?” Two other teachers had been teaching Leaving Certificate Chemistry for over five years. Teachers C and D had both completed postgraduate studies in Chemistry. One of these teachers had experience as a laboratory demonstrator and Chemistry tutor in Third-Level education; “as regards teaching experience, I spent my entire PhD, and right up to last year back doing tutorials…. It’s particularly focusing on teaching kids, who are having trouble with First Year Chemistry at University”. Teacher B had been teaching Leaving Certificate Chemistry for 5-10 years, but had worked previously in industry and outlined the benefits of this experience: “… your laboratory skills would be a lot more up to scratch. Like we would have been doing trace analysis, so it was fierce… am accurate and … basically if you didn’t start the day off right, and do everything accurately precise…”
As explained already in Chapter Five (Section 5.3.1) the teachers involved in implementing the intervention programme were all self-selected from the original group of 100 teachers randomly selected to participate in Cycle One of the project. Given that the participating teachers volunteered for participation in the programme it is not surprising that they were all enthusiastic and positive about teaching Organic Chemistry, even though anecdotal evidence suggests this section of the course is avoided by many teachers.

“Personally... I love Organic Chemistry. I know a lot of teachers don’t like it... and they don’t like teaching it. I don’t think that these days... they don’t do it [avoid teaching Organic Chemistry]. I know when I was in school, there was a lot of ... we don’t do it. I know like when I went into college, there was a lot of people who had never done Organic Chemistry. [pause] I would hope that that’s gone now, I don’t know..... But I like it, I like teaching it, I find it interesting as a subject...”

(Teacher C)

The teachers outlined how the Organic Chemistry in Action! programme increased their pupils’ interest and their own interest in Organic Chemistry:

“Yes, absolutely, the visual effects just added so much more interest in the class than I would have had in previous years. Yeah, definitely. It added a lot of interest, and in fairness that’s what it is about, trying to get them to sit down and think about the Chemistry that they are doing ...”

(Teacher D)

“I know while we want them to be ... We want them to be interested in it too. I know now before this Organic wouldn’t have been my favourite and now I like better now myself, and that’s a good thing”

(Teacher B)

8.2.4.2. Structure of the Organic Chemistry in Action! programme.

As with most of the design criteria and resources used in the intervention programme, while the teachers complimented the advantages of these, they also highlighted the difficulties that arose during the implementation and suggestions for improvement. The two main issues relating to the structure of the programme that emerged in the Teacher Interviews was the spiralling introduction of the topics as well as the timing of the lessons and units. The teachers’ feedback on both of these issues will be outlined here.
Spiral Introduction of Topics

For the most part, the teachers’ attitudes to the spiral structure of the programme were positive, as can be seen from the interview extracts below:

“Well it seemed to be very well put together programme... now and that’s not boosting your ego or anything...”

“Basically, but from my point of view it was well thought out and an awful lot of revision in it, which is obviously very useful”.

“No, ‘tis marvellous. Like you really put a lot of work into it like, it’s obvious, and it is well thought through. What I like about it is, there is no flaw in it, do you know what I mean?”

(Teacher A)

“Overall, I thought it was a really really good modern approach. I found it relevant. I found it kind of exciting. I found… I learned things that I didn’t know, which was a real joy, and which meant I was very enthusiastic about every chapter. Uhm... and I found... I thought the spiral learning was really beneficial to them. And I know sometimes in my own head... while I might have been giving out and cursing it in my own head; I think the constant... let’s say... using the models, and the drawing out and that, it is good for them [pupils]. D ’you know?”

“Yeah, the spiral learning definitely... It was like, we have done, we have done this, and now we’re moving onto this..... building their knowledge the whole time” (Teacher B)

“They were constantly linking back to something they had done in previous unit or you know just to re-cap on what they had done. Oh God yeah, that was very good.”

“If I’m honest with you, you gave us a lesson plan for each lesson, in a book, OK. And for me, I just found that fantastic.”

“I have to be honest, I think in terms of ... just your links from one family to another, remembering back from unit 2... what we looked at, the structure or whatever it was... I did. I found that it did help them.” (Teacher D)

“Overall, I thought it was a great idea, it’s a great concept. I like the way it goes into the understanding of it, rather than the learning off, because I think that’s the way it should be going. I don’t like the way people...I would rather a student know how to do a mechanism for any compound, rather than just learning mechansims for specific compounds. I think that addressed this issue really really well.”

“So, overall, I thought it was good, and you know the girls did enjoy it.” (Teacher E)

“But you were revising stuff the whole time, like looking back into different sections and they were all linking back into each other. And it was great that way”. (Teacher G)
However, while the teachers did find the spiral introduction of topics beneficial for pupil understanding, there was also some indication from the teachers that this approach was repetitive:

**Teacher A:** *This idea of reviewing what you have done the last day, that is a good thing.*

I: Yeah

**Teacher A:** *But a lot of them slept because... they kind of felt “was there going to be any little bit new today?” You know that kind of a way?*

I: Yeah

**Teacher A:** *So, yeah a little bit repetitive, yeah.*

This feedback from Teacher A was echoed by other teachers also:

**Teacher C:** *There was a bit too much repetition. Like I think they did alkenes three times, they did alcohols twice. Well, I mean that’s no harm.*

I: Hmm.

**Teacher C:** *Especially with alcohols.... But it would be better if some of it was in September, and... the rest of it was in December, like do you know what I mean?*

Suggestions from Teacher C, later in their interview reinforced their idea of using the spiral introduction of topics, but integrating other areas of the syllabus into the programme also- to make it less monotonous and repetitive for the pupils.

Teacher E expressed the pupils’ aspiration to fully complete each topic at any one time rather than having it presented to them in fragments:

**Teacher E:** *Like the spiral learning is great. But if you start one part, and they want to find out more about it, then it’s like “Oh we have to wait and come back it”. You know the way?*

I: Oh right, yeah.

**Teacher E:** *You know what I mean? Whereas they would be like “can we not just continue on and find out more about this bit?”. So that was one thing that they kind of.... They had to wait to get to the next bit, which at times they just found a little bit frustrating.*

Teacher A felt that the repetitive nature of the spiralling curriculum would be appropriate “if you had an Ordinary Level class on their own, that would be grand. But that never exists in any school” (Teacher A). Due to the fragmented presentation of the content in the spiral drip-feed introduction, Teacher B suggested that “What they need at the end of it is- so what’s
important from that, what do we need to know. So just summarise it a bit better from each chapter” (Teacher B).

**Time Constraints**

The poor timing of the activities, lessons and units within the programme was one of the biggest criticisms given by all of the teachers. As a result of spending longer time than usual teaching the Organic Chemistry section of the course, many teachers expressed concern about completing the Chemistry syllabus in time for sufficient revision before the Leaving Certificate examinations.

“It took forever, but the Organic is very long and it is important, but it just took forever.”

“Usually finish about the first week in May, which is quite late, but that’s just the way it is. And it will be second or third week in May now… which is tough going for those who are looking for good results, you know?” (Teacher A)

“Like, I like to be finished the course before the mocks, but this year I’m not… [pause] and like then, I have got to go back over and revise everything. Like there is just not time to…. Do all of the fun stuff you wanted to do.”

“Like as a teacher that I mean I would have had to really sit down and go through everything like word for word in the Workbook and go through the PowerPoint in preparation for the class- and I didn’t do that. I know I should have, but you just don’t get time.” (Teacher C)

Teacher C went on to explain that towards the end of the programme they “stopped looking at the Teacher manual because I was just seeing things that I knew I wasn’t going to do, because I didn’t have enough time” and taught the lessons mainly from what was on the PowerPoint slides, with the omission of the Teacher Demonstrations and non-mandatory pupil activities.

Teacher B acknowledged that the limited time available was not only a reflection on the intervention materials but a criticism of the Leaving Certificate course itself: “Yeah, the only concern, the only thing… would be the time. That is the only clause. And it’s a pity, but it’s just the constraints of the actual Leaving Cert course”. They explained how they “would have loved to have been able to spend the time and do the other parts… It was kind of more interesting…” but it just wasn’t feasible within the restrictions of the Leaving Certificate course “…it’s not a criticism, it’s just the constraints of the actual course itself. And you just
don’t have the time”. Teacher B also explained how the limited time available affected the pupils’ completion of their Pupil Workbooks:

“It was brilliant at first, but when we got towards the end and the mocks were coming I found I had to just bomb through it, and I had to get through. So we tended to concentrate on the overheads and then they would fill in their books at night. But definitely the latter end of their books are not filled in near as good as the start of it. Simply because at that stage, I had run out of time”.

(Teacher B)

The activities and demonstrations outlined for the lessons in the programme were not practical for teachers who were moving between classrooms and laboratories for their lessons as this restricted the preparation time available for them. None of the teachers mentioned having a laboratory technician in their schools. This would have helped to facilitate their preparation of the practical activities.

The teachers’ attitudes to the contextual links and practical work included in the Organic Chemistry in Action! programme will be discussed in more detail under the theme of issues arising relating to the content of the programme. However, one aspect of the programme that the teachers did recommend reducing to accommodate for the limited time available was the additional context-based activities and investigations.

Teacher C: There is too much for them to learn as it is. So, it’s kind of, what they have to learn- make that fun, rather than adding something new in.

I: Hmmm.

Teacher C: If there was a couple of ... like I mean they don’t have to be two separate books, but if there was a couple of pages saying- here’s the learning, nearly a reflection of what’s on the PowerPoint. Obviously without the animations and video clips, but the pictures there, the key learning points are there...the definitions ... the mechanisms... the stuff.

I: Hmmm.

Teacher C: And then, the extra little fun bits could be in the PowerPoint and not in the Workbook, you know, the like “Did you know?” or like.... And then have a page of questions... rather than having the questions in the middle of what they had to learn. That was what they were finding hard.

As illustrated above, Teacher C suggested restricting the activities and investigations more closely to the content of the syllabus. This would make them more worthwhile for the teachers and pupils.
Other recommendations were to teach this programme to fifth years, when there is more time available and without the stress of preparing pupils for mock examinations in February:

“Am, just kind of going through it, and the rush and the time. I… I honestly would think about teaching it in fifth year to them instead of sixth year.” (Teacher E).

Teacher D suggested shortening some of the questions in the Pupil Workbook.

While most of the teachers were concerned about the time required to complete the Organic Chemistry in Action! programme, two of the teachers acknowledged the value in spending more time teaching for understanding:

“Yes, definitely, definitely. I can most definitely see the advantage of that [spending more time teaching Organic Chemistry].”

“So, in terms of do I think it is worthwhile? Absolutely, definitely. It is worth spending the extra…”

“And I do think it is worth the effort, in terms of the length of time it takes to get through it, for making it easier for them, yeah, definitely.” (Teacher D)

Teacher E echoed the importance of teaching for understanding and also acknowledged the significance of the Organic Chemistry in the Leaving Certificate examination as further justification for spending sufficient time teaching it:

**Teacher E:** But I think that in general, it’s the pressure of the system that means you know… that I have until May to teach the Chemistry course, but my mocks were on the 2nd of February, and I don’t have the course finished. You know that way?

Like, I know teachers who manage to teach Organic Chemistry in three weeks. I think that’s amazing, but I just can’t... [laughs].

I: Wow, yeah.

**Teacher E:** And I spend from September to December, you know that way? It’s just…. But my girls know it! And so, I don’t care.

And I said that to them, like for something that is nearly a third of the paper, and something that even the examiner himself, has admitted, because he is an organometallic chemist. And he has admitted that it is an important part of the course, that they should actually put the understanding in.

And they [examiners] are not looking, they are not looking for learning off anymore, they are looking for understanding.
In contrast to the other teachers, Teacher G did not seem to be under as much pressure for time, and was happy to spend longer on the Organic Chemistry section, knowing that their pupils understood the content:

“And the other two teachers [in the school] were asking me and they were … they were saying, because the other teacher with sixth year Chemistry, she knew that I was behind with it and I was like I am still finishing the book [OCIA] the way it is…I’m not [rushing or stopping it] because as I said, I found it so good. They picked up from me that I had a good response to it [OCIA]. But I am, it has changed my attitude to teaching it.”

(Teacher G)

### 8.2.4.3. Content of the *Organic Chemistry in Action!* programme

Much of the content of the intervention programme was based on practical applications to the pupils’ lives and contextual examples and illustrations of Organic Chemistry in everyday life and in industry. While some teacher welcomed these interesting insights into Organic Chemistry to create interest in the subject, other teachers remained more focused on the examination and felt restricted by the limited time available to teach the course. These mixed responses to the programme will be discussed here using quotes from the interviews to provide an accurate insight of the teachers’ opinions.

**Context-based approach**

“I think that for the first time, they got everyday Organic Chemistry, they got examples, like making it applicable to everyday life. Alright, like previously teaching the course, I wouldn’t have went into as much detail, in terms of the practical examples and that sort of thing. So for them, I thought that was fantastic.”

(Teacher D)

Teacher G also shared some insight into how the contextual links raised interest and discussion among pupils in their class:

**Teacher G:** Yeah, they kind of… There were a few very interesting things in them.

**I:** It got them interested in it.

**Teacher G:** Like I would never have thought of the stuff…. Like there was one there… Erin Brockovich, which was very nice.

**I:** Oh yeah, the chromium…

**Teacher G:** The stuff in the water, like I mean I would never have made that connection. Like it was just that bit extra, the pieces of information there… Like it doesn’t take too long, and I
know there was one section, one that we were reading... Oh about the renewable sources of energy.

Yeah, and we had a right discussion on that because there is one the lads [pupils] and his father is involved with growing elephant grass, miscanthus grass...

I: Oh right.

Teacher G: So that was a great discussion that evening. He was able to add stuff to it.

Due to the time restrictions however, some of the teachers felt that too much time and effort was spent on including contextual applications of the Chemistry for the pupils while in reality “they find... you see a lot of the Organic is interesting anyway. The petrol... they all want to drive the cars, so you have that” and “once you mention alcohol and metabolism, they are into that...” Teacher A went on to explain that “there is enough in there to maintain a decent level of interest”.

While Teacher C appreciated that the pupils “did get that message that like everything is related to Organic. They really did. You know the beginning lessons.... Like I think they were really interesting”. However, Teacher C did express some concern “But a lot of that... is not relevant, not on the syllabus” and explained such material could be removed in an effort to reduce the content of the programme:

“Yeah, our role is to do a bit of both- to make it interesting, and to teach them so that at the end of the day, they get their grade, which is what we try to do, well what I have always tried to do anyway. And it was nice to kind of have some of that there, but there was just a bit too much of it” (Teacher C).

It was clear that Teacher C did admit that while the context-based approach was interesting, the core content for the exam was equally important:

“You know, I do kind of give them a bit of additional information and kind of fluff it up so that they can understand it. But then, I will always focus in on- for the exam, this is what you need in the end of the day, but you have to make it fun too.” (Teacher C).

Alternatively, Teacher B suggested leaving the context-based information in the materials and leave it to the pupils’ and teachers’ discretion if it is read or not: “You can have what’s interesting in there also. The good kid will read it, the bad kid won’t” (Teacher B).

In all, despite the restrictions due to the time available all of the teachers find the context-based approach interesting and appealing to both them and their pupils:
“So like some days I would come across, you know in your ‘Did you knows?’ and I would find myself like saying “Did you read that last night? And wasn’t that interesting?” I loved the one at the beginning of plastics, where it showed the history of all the different polymers being made…” (Teacher C)

“I liked the fact that it added in the extra bits, you know? That you wouldn’t get out of a book or that you wouldn’t usually see. I liked that” (Teacher E)

Teacher E also suggested an idea for integrating news and current affairs items into the Chemistry class; “to start photocopy articles in newspapers and have the pupils to make up a sort of a journal of all the latest news in Science as it goes through the year would be great for them”.

**Practical Work**

As illustrated in the findings from the Teacher Questionnaire (Table 8.2 and 8.3), the teachers did find the practical work helpful in their teaching of Organic Chemistry. The teachers explained how the structure of the Pupil Workbook was helpful at times in facilitating the pupils’ understanding and preparation for the practical work. For example labelling diagrams of the set-ups; labelling the apparatus and also the reactants and products collected:

“Yeah, I liked that [labelling the diagram set-ups for the experiments], that was good. I thought that like those little boxes that they fill in, that was good” (Teacher B).

In preparing the practical work for the intervention programme, emphasis was placed on providing the teachers with procedures using alternative oxidising agents following the ban on use of dichromate in Irish Second-Level schools. For this reason, each of the teachers were specifically asked about how they taught and carried out the two mandatory experiments involving the oxidation of ethanol (preparation of ethanal and preparation of ethanoic acid). Two of the teachers (Teachers B and D) had taken their classes to a nearby university to carry out the mandatory Organic Chemistry experiments. Some of these experiments were also carried out in the school laboratory before or following that visit. Both teachers explained that the pupils were allowed to use sodium dichromate as an oxidising agent in the Third-Level laboratory. Other teachers who had to teach this mandatory experiment in their school laboratory explained the difficulty and complication involved in using the suggested alternative oxidising agent (potassium permanganate):
"I didn’t [carry out the oxidation using potassium permanganate], and I just said, we’re just going to learn the colour changes using dichromate. I explained to them why you had done it, explained to them, that it [dichromate] has been banned, and if we do it with this [potassium permanganate] we will get an experiment, but... just to avoid confusion, I just stuck with it [colour change of the dichromate]."

(Teacher C)

This extract from the interview with Teacher E provides an insight into the complication of teaching the oxidation of alcohols without the use of dichromates in the school laboratory:

Teacher E: It’s like actually, the one other thing that they found very difficult—was the ethanal and the ethanoic acid. They are finding it tremendously difficult because they have never done it. An even, if you substitute in potassium permanganate... in the end, they don’t want those colour changes in the exams.

I: Yes, I know...

Teacher E: They are just not accepted...you know? Not yet. But, it’s just, they found... when they are not doing stuff themselves, they just don’t get it.

I: Yeah.

Teacher E: Even then, they would say that the hardest question they would get would be the one on ethanal or ethanoic acid. And then one came up on the mocks.

I: Oh right.

Teacher E: And just, you know, that was hard because they just can’t relate anything to it. They find that difficult.

I: And, yes, I was just going to ask you, because you mentioned [in your Teacher Diary] that you used the animations for the dichromate when you were teaching it. Did you do the actual permanganate oxidation set-up?

Teacher E: Yeah. They had a look at the permanganate and they had a look at the set up. But as I said, then, what they find difficult is when it comes to actually doing the experiment...

I: The colour changes...

Teacher E: I know it’s just the colour changes that are different. But you would be surprised; they think that it is just a completely different experiment.

I: Yeah, they don’t realise it’s the same oxidation of ethanol.

Teacher E: But it is the one thing that I will repeat with them again before the Leaving Certificate. Yeah, I plan to repeat them before the Leaving Certificate, because they just...

Most of the discussion in the Teacher Interviews relating to the practical work in the intervention programme was focused on the difficulties and challenges that the teachers faced in implementing the practical work as intended. Some of the teacher did appreciate the
alternative procedures that were included because “…it’s [alternative procedures for mandatory experiments] great because you can actually do stuff quick” (Teacher G).

However, while the micro-scale alternatives were useful for demonstration purposes, many of the teachers explained that they still preferred to use the macro-scale set-ups because as explained by Teacher A; “they are going to be examined in the Section A, and the experiments are very dictated to you…” . Teacher A continued in explaining that: “Yes, all of those [micro-scale and optional demonstrations] are very good, but you still have to do… they are extra. You still have to do the full proper ones”. In discussing the difficulties of implementing the planned practical work in this programme, the teachers shared their own experiences and approaches to teaching practical work that they have found to be useful in previous years.

These ideas included incorporating peer-teaching to revise the practical work;

Teacher B: So I’m trying to finish the course now, but then one day, I’m going to get each of them to go to each desk and set up a different experiment.

I: Oh right...

Teacher B: And then, I’m going to get them to go around and kind of as a revision.

I: Oh good.

Teacher B: But like I said, I will do that, where they all set up their own experiments and…

I: Yeah, that is a good idea.

Teacher B: And what I’ll do, is I’ll get them all to explain to each other, so will almost be like peer-teaching, do you know what I’m saying?

Use of the PowerPoints to facilitate pupil understanding and prepare for practical work;

Teacher C: But, like that, it’s up here [pointing at the wall]. Like when I was doing soap with them last week, there was some photos of the reflux, and that was good…And I was using that to teach it…

I: Hmmm.

Teacher C: But there was loads of…. I can’t remember, there was one of them, and it wasn’t great. The pictures were in the book, but not on the PowerPoint.. I can’t remember which one… But I would have liked it all to be up here [pointing at wall], so like I’m teaching them how to do it, and the next day they come in and do it.
Introducing practical work each week to develop laboratory skills and techniques;

“Like usually I would have been doing an experiment a week, whether they have done the theory or not, and that way, they get to see the apparatus and put it together a bit more”.

(Teacher A)

Some of the teachers’ suggestions such as that from Teacher A above have not considered the pupils’ understanding of the practical work.

Like the non-mandatory pupil activities and alternatives for the mandatory set-ups, many of the Teacher Demonstrations were not carried out due to limited time available to the teachers:

“For most of the others [Teacher Demonstrations], I just used the animations.”

(Teacher A)

“I actually… to be totally honest, I stopped even reading them [Teacher Demonstrations]...So there could be some there, that are worth doing… but … I used to just look at the PowerPoint slides and say – OK this is what I am teaching in this class, and I would go in and do that”

(Teacher C)

“I have to honest there, no, I didn’t [complete all of the Teacher Demonstrations]. I didn’t have time, yeah I’m sorry. For any of them that required maybe a demonstration that they would have been doing, I wouldn’t have. I have to be honest, just time-scale wise I wouldn’t have time to do them”.

(Teacher D)

These quotes above are representative of all teachers involved in the intervention programme. In some instances, the teachers explain that lack of equipment or resources was another reason for omitting the demonstrations. Despite this, there is some evidence that the demonstrations that were carried out were effective:

“But the ones that they did do, they did enjoy, you know that way? Like I thought, even using the Pringles tin, they loved that. They just thought it was great … and they got it, they just got it. They got the whole air and fuel mixture….Yeah, it’s just, it’s that kind of stuff that they will remember”

(Teacher E)

“Oh they did, like there were some days, the students were gone, some of them were gone… like they may have had to go to orals or something, but they were raging if they were missing it [Teacher Demonstrations]”.

(Teacher G)
“Like I mean the Storm in a Test-tube I did, and they loved that. Now any of the ones..... Like I did that, and then they [the pupils] actually explained to me... What went on.... Now I didn’t think they would, but they were able to go through exactly and explain to me ‘word for word’ what had happened from the lead up to it.” (Teacher G)

Teacher D suggested providing the teachers with more flexibility about which demonstrations to carry out and which to omit: “For teachers, you could actually present the same material, but leave it for us to decide “OK, I simply do not have time for that demonstration” or for you to take the time to put them [Teacher Demonstrations] in groups, to put them together” (Teacher D). While not all of the Teacher Demonstrations were carried out in the implementation phase, feedback suggests that they are effective and beneficial for pupil understanding and generating interest if time allows.

8.2.4.4. Resources included for the Organic Chemistry in Action! programme

Tables 8.2 and 8.3 provide quantitative evaluation of the teachers’ attitudes and use of the resources included in the Teacher Resource Kit for the Organic Chemistry in Action! programme. As can be seen from these tables, the teachers were very positive about their use and the effectiveness of most of the resources. For this reason, the general positive comments about the resources are not included here. The following quotes provide a greater insight into why the teachers found the resources and molecular models in particular so helpful. These quotes are useful to illustrate the positive feedback represented in Tables 8.2 and 8.3:

“I never thought of that [sandwich and Lego analogies for teaching the limiting reagent], you know? That actually made so much sense to them, rather than the way I would go about it normally” (Teacher A)

“I had never done anything beyond that [making isomers with the models]. But this year... we used them so much more. And I saw the value of using them, like every time you learned a new family, like building the alcohol, building the ketone, building the ester... Am, You know, like modelling the mechanisms even. You know that kind of thing? I had never thought to use them... Yeah, it just never occurred to me to use them in those situations, so that was great. It’s something, it really helped them to visualise the different functional groups by building them, you know?” (Teacher C)
“The videos and the animations, some of them very applicable as well, making practical examples for them which is great, and any visual aid is so useful in any subject I think. It does break up the theory. Organic can be a lot of theory thrown at them. If you’re doing like, for us, from the course, there is a lot of theory, and for them, they can find it very very boring. The animations and the videos and some of your suggested experiments that we wouldn’t have completed before really really really took them, and got them really interested.”

(Teacher D)

“Just from watching the girls, the girls loved being able to do the mechanisms with the molecular models. They had a ball them….Because, they are just really visual like that. It [use of molecular models] kind of helped them an awful lot. It was kind of something I kind of used before, but now, I’m incorporating the molecular models from first to sixth year, whereas before, I wouldn’t have. But now I do, because it just worked so well with the sixth years. They [the pupils] actually, actually focused when they were doing the models and they would make stuff up. And if anything, I know this sounds weird, but they actually used to kind of compete to see who could make the models first and who could get the answers quicker and stuff like that”.

(Teacher E)

“Oh, they did enjoy them… they did. And actually for one of them near the start they did ask to take home the cards [Game cards] themselves”.

(Teacher G)

Teacher C explained the value of the Homework Assignments in the Pupil Workbooks:

Teacher C: Now, I have to say, I absolutely loved the “What have I learned?” section.
I: Oh right, at the end?
Teacher C: Yes, we did that in every single one of them. We never missed one.
Teacher: Because the big problem with Organic for me, up to now, is that in the textbooks, there are not a lot of questions, whereas there is an awful lot of learning.
I: Hmm.
Teacher C: Like you spend about two just months learning, learning, learning, learning… and you don’t have written homework for them to do. And… very quickly, they stop doing homework.
I: Yeah.
Teacher C: Because to students, if they are not writing something down, they don’t have homework. And even at 18…they know… OK, look I’m meant to be learning this, but they still stop doing it. But if you can give them a little bit of writing every day to focus in on what they have learned, it’s brilliant!
These extracts and quotes provide a flavour of the general feedback from the teachers about the resources that were provided with *Organic Chemistry in Action!* programme. However, during the interviews, the researcher also asked the teachers to comment on aspects of the resources that were least effective and provide ideas on how these could be improved.

The majority of the teachers did not like the skeletal and fragmented nature of the Pupil Workbooks. For the most part, the problems faced by the pupils and teachers with the style and format of the workbook seemed to stem from their lack of experience and familiarity with this type of investigatory learning. The pupils and teachers were both more comfortable with using a textbook as a reference and having a separate Workbook for questions and exercises. Teacher A explained that having completed the Pupil Workbook “*really at the end of the day, they [the pupils] didn’t know what they were to learn and what they weren’t to learn*”. Teacher C also explained that this approach is “just not what they are used to. It’s not what I’m used to. It wasn’t…. like a reference book for them, because there was too much information in it”.

**Teacher E:** Yeah, it’s just at times, the girls were like looking down and saying “That’s not in the book, do we take that down?”. You know that way? So usually, they would see something [on the PowerPoint] and know this is important, but the relating it back to the book was hard for them. You know that way?

**I:** Yeah.

**Teacher E:** So they were kind of looking up and seeing one thing and looking down and seeing another. And then that kind of then tends to… that just, just distracts them a little. But...

**I:** Hmmm.

**Teacher E:** But it’s just, that’s just probably because of the way that they have been brought up.

This fragmented provision of information between the PowerPoint presentations, Teacher Guidebook and Pupil Workbooks was a criticism made by two of the other teachers also. Teacher B expressed concern about the size of the two Pupil Workbooks and the effect this had on the pupils’ perception of the programme. However, they did appreciate the value of the content within the Pupil Workbooks if sufficient time allowed:

“*Right, am... Well I think I did say this… Like I went through [picks up the Pupil Workbook I]… Like I do think the introduction is nice. One thing too is that I found… and the kids found it a little bit daunting when they saw the two booklets. Like you know... I probably... Like while a huge amount of work has gone into this... If the course would allow you, and going forward, if the NCCA would allow you to spend that length of time, the amount of time that is
required, you would have a fantastic.... You would be coming out with kids doing brilliant in Organic Chemistry, and them understanding it like they never…” (Teacher B)

Despite this positive feedback about the Pupil Workbooks, Teacher B still suggested that they need to be condensed:

“I suppose what I would make it… is what’s going to be examinable, say like I would take it from that, and then add in the some of the other little bits… But then maybe that is the wrong approach, I don’t know.” (Teacher B)

There was some positive feedback about the content and layout of the Pupil Workbooks also;

“I actually think that it is [Pupil Workbook] quite user-friendly. Like I mean the blanks are left there for them. You have kind of you know… spider diagrams, you have less… You have a way of connecting one thing to another, and I think that’s really nice” (Teacher D).

When discussing resources that were not as effective as intended, three of the teachers explained that the card games were not effective in their classrooms. They explained that the pupils found them distracting, and they were not as appealing to the pupils as they were for the teachers.

The teachers did have useful ideas of additional resources that could be included to facilitate the teaching of Organic Chemistry. Teacher A suggested the use of “Show-me boards- You know where they have a little thing A-4 size…” . These would be useful to provide the teacher with immediate feedback in the classroom and also particularly useful for teaching mechanisms. Teacher E suggested that the pupils develop their own Photo Journal of the practical experiments that they carry out in the classroom: “Photos of their set-ups, of everything that they do. Because I’ve found now that this year I let them pull out the mobile-phones and take pictures of all their experiments.”

As well as these suggestions for possible resources, Teacher A also suggested the need to highlight the actual names of the functional groups as well as the names of the families of compounds as “that seems to be an issue with some of the examiners at the moment. They want them to know the names of the functional groups”.

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8.2.4.5. Perception of Pupils’ Perspectives of the programme

Since no interviews were carried out with the participating pupils, the teachers were asked to discuss and explain their perspective of their pupils’ experience of the Organic Chemistry in Action! programme.

The teachers explained that “before this, generally, as I said, I think that they [the pupils] just see Organic as one big lump of theory” (Teacher D). Teachers A and B explained that their pupils have a positive view Organic Chemistry despite its difficult reputation: “they find it [Organic Chemistry] tough, but it’s not something they hate, you know?” (Teacher A) and “I have to say the group will say it themselves now that they love Organic Chemistry” (Teacher B). General feedback from the teachers suggested that programme increased the pupils’ interest and understanding of Organic Chemistry:

“So, from their [the pupils’] experience, in terms of the visual aids, in terms of the PowerPoints and in terms of what they are actually doing in class with the models and the experimental work, absolutely 100% enhanced their learning. 100%, definitely….I don’t think there is anything else that I would have added to make it any more student friendly for them”

(Teacher D)

As already mentioned, there was some conflicting feedback from the teachers when asked if they felt the programme benefitted the Higher and Ordinary Level pupils equally.

Some teachers felt it was more suited for the Ordinary Level pupils:

“The better ones didn’t like it and the weaker ones did is the truth….Because things were nice and slow, and because they got to handle stuff.”

(Teacher A)

“I think the weaker ones, the lower grades, I think it would have been beneficial to them, the weaker ones… The repetition, going back over stuff, whether they know it or not… will have helped them, Yeah.”

(Teacher B)

These teachers also explained that the Higher Level pupils were not interested in some of the ‘extra information’ and optional activities “anything that was outside the course, they had no interest in it” (Teacher A). They were concerned about the amount of time taken to complete the course. It is clear from these teacher quotes, that many of the pupils were very exam-driven:
“There are 2 or 3 [pupils] there…. Are they are looking for their A1 or A2, and they were there ‘are we ever going to get this course finished?’…Do you know? You could feel that vibe coming back all of the time”

(Teacher A)

“And the one thing that the girls did say was that they found the pace a bit slow at times. Whereas they used to kind of maybe just get things [new concepts] a little bit quicker. Maybe there were things that they got, but then when we repeated it and repeated it then the second time, they became just a little above bored with it like. You know that way?” (Teacher E)

Teacher B also made the point that some high-achieving pupils are prepared to just study and learn the material irrespective of how it is taught or presented to them:

“I think if you asked them “Do they feel like this course has helped them?”, I think the better ones will say no, because the better ones were frustrated by it… But that does not mean that it didn’t go in. They just feel like it hasn’t gone in. But I think it has…. These kids are so good, that they would pick it up anyway… if you just have a robot there reading from a book… or me singing and dancing, they are going to do well anyway”

(Teacher B)

However, Teacher D felt that although all of their class gained a better conceptual understanding of Organic Chemistry, some of the content was too difficult for the Ordinary Level pupils:

“...I suppose as I said, I have a class of mixed ability, and the Higher Level students probably benefitted more and the lower-ability pupils will find it that… just that slight bit more difficult. But 100%, for a conceptual understanding of Organic Chemistry, there is no comparison between teaching it in this way [using the OCIA materials] and teaching it as from the old Leaving Certificate course. No comparison, definitely no comparison”.

(Teacher D)

Teacher G also indicated that they felt all of their pupils (Higher and Ordinary Level) had a better understanding of Organic Chemistry from the programme:

Teacher G: The Ordinary Level … to the extent that going back repeating stuff helped them.
I: Yeah

Teacher G: Am... the Higher Level, I’d say it did as well... but I’m not as regards.... See some of them are quite quick, so the brighter ones would pick it up themselves anyway.
I: Yeah

Teacher G: Like they are actually a good class, as classes go... No I ... I just find myself that the whole lot [Higher Level and Ordinary Level] that they did benefit. Like I said to you, I
don’t know how well they did as regards the test [Pupil Questionnaire], but I do find myself, as after teaching it…. That I know their knowledge is better than it would have been normally [teaching in the traditional manner].

8.2.4.6. Approach to Teaching Difficult Topics

The teachers felt that the presentation of topics (identified as difficult in previous studies and in Cycle One of this project) in the Organic Chemistry in Action! materials was effective in facilitating pupil understanding. There was also much evidence throughout the interviews that these teachers are finding the same topics challenging to teach. (The list of topics identified as difficult to teach and learn in Leaving Certificate Organic Chemistry are shown in Figures 6.4 and 6.36 of Chapter Six).

Feedback from the teachers suggested that many pupils are still rote-learning reaction mechanisms:

“Like for the B, C and D students... like you know... they find the mechanisms hard. And constantly, you will find that... what they are asked for, they will give the wrong one.... Like if they are asked for the mechanism for C₂H₄ plus chlorine, they will give you the wrong one. They will give you the one for substitution instead of the addition one, because they don’t read the questions properly, because they are not fully comfortable with which one... what is C₂H₄ and what is C₂H₆”.

(Teacher C)

Other topics listed in Figure 6.4 (Chapter Six) were also highlighted by the teachers in Cycle Two; “For some... for the not really Higher Level students, they will find the am... the just the functional groups very confusing” (Teacher D).

Although the use of curly arrows (to map electron movement) are not a requirement in writing mechanisms in the Leaving Certificate examination, these were included in the teaching of both mechanisms (free radical substitution and ionic addition) in this intervention programme in order to facilitate the pupils’ understanding of the mechanisms.

All of the teachers except for Teacher C used the arrows in their teaching of reaction mechanisms. Teacher C admitted that they haven’t looked at arrows since they were in college:

“But God... If I had to start thinking about where the electrons are going... you know, it’s something I haven’t done in years...You’re talking what about 12-13 years since I have written a red arrow, so I... if I had to teach it, I would have to sit down and seriously.... Just try drag it out of somewhere at the back of my head”

(Teacher C)
Through further questioning, Teacher C explained how they approach and teach mechanisms:

**Teacher C:** So what I do is I get them to... I teach it with diagrams, so they can see what’s going on. So I would draw the four diagrams on the board, and we teach it through the diagram. And then I give... they have a hand-out in front of them, where they take the four diagrams down. There are four boxes. And then beside each diagram we go back and we write our phrases. And then the last one and we finish it off. And then, I give them another hand-out where there is four boxes coming down: for adding on a $\text{H}_2$, for adding on $\text{H}_2\text{O}$, for adding on Bromine ... and for adding on- and they know that Bromine has an extra step.

**I:** Yeah.

**Teacher C:** And then they practice drawing it out, drawing it out, drawing it out.

**I:** Hmmm.

**Teacher C:** So then, they have got in their notes, they have one setting to learn and then the rest, there is worksheet, and it’s like to practice writing it out, writing it out, writing it out with the diagram and with the phrase – again and again, and again. So that through repetition, it’s going to end up in there [their heads].

This approach used by Teacher C for teaching mechanisms explains why many of the pupils in their class may give the incorrect mechanism when answering a question. It is clear that these pupils are learning by memorisation rather than understanding.

The remaining teachers felt that the way reaction mechanisms were approached and taught in the intervention programme was beneficial for pupil understanding. These quotes provide an example of the teachers’ feedback:

“... In your work you could see when it was planar, it was easy to attack the thing... there was a reason for... you know the nucleophilic attack, or whatever, do you know?”

(Teacher A)

“Say for the mechanisms, you are breaking it down, you know, you are looking at the intermediate compounds, you know like.... Even myself, I have to be honest, I learned a lot...So definitely, for them, I think, like they have found a major difference. But for me as well, I have to be honest, there are so many different ideas of how to present it [reaction mechanisms] to them in... in... just in a manner that they are actually able to think. As opposed to here are the notes on the mechanism and let’s write it out now for the exam question.”

(Teacher D)

Teacher G emphasised how the use of the molecular models increased pupils’ understanding and ability to even predict the reactions and mechanisms due to the shape and bonding in the
Teacher E explained their own method of teaching the reaction mechanisms. They justified why they preferred to use the whiteboard rather than the PowerPoint:

**Teacher E:** Because I find if you put it on PowerPoint, there's not as much interaction with it. And if you put like a whole mechanism up at once, and they just don’t get it. Whereas, I just go in on the board, and I’ll start with like...let’s say if you’re doing addition. And, I’ll start with the alkene, and I go “right, where are the electrons? Where is the negative charge? Where is the positive charge?..OK, what do we do here?”. And they are writing down along with you.

**I:** And, do you use the arrows to show the movement of the electrons?

**Teacher E:** Oh yeah. You would have to use curly arrows. Oh God, yeah. No, no, they have to. And the arrows have to go to the right places. Like they are told exactly. Because it is kind of fuzzy sometimes, not in your book, but in am, in their textbook, the direction of the arrows is a bit fuzzy. So they are told exactly where it has to go. It has to be very accurate.

Teacher G, like Teacher E emphasised the importance of the use of arrows when teaching the mechanism to facilitate understanding and prepare the pupils for future study of Chemistry; “Like when they go to college, they will be using the arrows...And the way I look at it then is that it is the grounding for them”.

Instrumentation was another topic that was found to be difficult to teach and learn in previous studies and in Cycle One of this project. Two of the teachers (B and D) explained that their pupils had an opportunity to see and use the instruments during their visits to a Third-Level institution. These teachers agreed that no classroom resources can be more effective that actually giving the pupils the opportunity to see and use the instruments for themselves. All of the teachers agreed that the prepared PowerPoint for Instrumentation was very effective; the use of the animations and pictures of the instruments facilitated the pupils’ understanding of the principles and processes involved in each technique. Teachers B and D explained that in previous years they had just given the pupils a single sheet with a summary of what the pupils needed to know about instrumentation for the examination. “It was like there is a hand-out. And on one page, I was given this at a training course years ago ... Am, it had all the different instruments, and it had principles, processes, uses ... and all of them were on one page” (Teacher B). All teachers agreed that the visual impact of the PowerPoint was useful in
their teaching of instrumentation. However, Teacher A was concerned that covering all of the techniques in one lesson may have overloaded the pupils:

“Six or seven different things…. It’s very hard for them to… and like there is very little difference between some of them. Like from what we are at, the Gas Chromatography and the HPLC are pretty much the same thing”.

(Teacher A)

8.2.4.7. Focus on the Leaving Certificate Chemistry Syllabus and Examination.

From the findings and extracts presented so far from the Teacher Interviews, there is much evidence that the Leaving Certificate examination is the focus of most of the teaching and learning, leaving teachers with little opportunity to deviate from the restrictions and guidelines of the current Leaving Certificate syllabus. As Teacher B simply explained that it’s “because we are in the game that we’re in” and the pupils want and need good grades to proceed to Third-Level education. All of the teachers explained how they always practice examination questions with their pupils after covering each topic and also at the end of the year.

Although this should not be the sole focus and purpose of education, this issue has to be addressed in the evaluation of the *Organic Chemistry in Action!* programme. The limited time available to teach Organic Chemistry and the description of contextual applications as ‘irrelevant’ have already been mentioned above. Given this feedback from the teachers, the researcher felt the need to ask if the teacher felt that their pupils were sufficiently prepared to answer the Organic Chemistry questions in the Leaving Certificate Chemistry examination having participated in this programme.

While Teacher B did feel that their pupils had learned and understood the Organic Chemistry well, they were concerned about the alternative teaching approaches used in the programme and the effect these may have on the pupils’ performance in the traditional examination setting:

“Whereas maybe… that is one criticism of the book, they have gotten out of the hang of maybe writing down and answering… but we’ll be practising that now in the next couple of weeks”

(Teacher B).
For some teachers the spiral introduction of topics facilitated their pupils’ ability to learn:

“I’m telling you right now- if they were asked the test for unsaturation, there is NO WAY any of them are not going to get it right. And even phrases like am... you know – why is the boiling points higher for one thing than the other, you know, it was the intermolecular bonds, the intermolecular bonds, the intermolecular bonds....because it was reinforced so many times”

(Teacher C)

However, such good understanding was almost seen as a ‘waste’ if it is not examined; “So, yeah I do think there were certain aspects that like.... They are much better at than other years... but like... they mightn’t come up [in the examination], like you know?” (Teacher C).

Many of the teachers appreciated the importance of learning for understanding rather than rote learning, in the eventuality of an un-predicted question in the examination. These teachers felt that the *Organic Chemistry in Action!* programme was effective in facilitating pupils’ understanding and encouraging them to think about problems.

“It’s OK rote learning if a question comes up as predicted. But conceptual understanding, and as things are going, I think the exams are going to change, so absolutely, this should stand to a good standard of student dramatically like in answering the exam questions... like a mechanism. So most definitely, I think this [OCIA] will aid their ability to examine an exam question with a little bit of thought behind it.”

(Teacher D)

The teachers were asked if they felt the Pupil Workbooks would be useful for the pupils when revising for their examination. Three of the teachers did not think that large Pupil Workbooks were suitable for revision, and if anything, would be more off-putting for the pupils. Two of the teachers (B and D) however, did think that if used appropriately, they could be a useful revision aid.

“I think for them, they will be a little bit put off about going back and flicking through Workbook 1 and Workbook 2, however, what they have learned in there as they were going through does help in terms of their revision when they are putting it all together.... So, they may not go back and revise every single section, but for me I would have given them... well they may have taken some of the notes down, and they will have copies of the PowerPoints alright”

(Teacher D)

Four of the other teachers had also given copies of the PowerPoints to their pupils to facilitate their study for the examination. The teachers also valued the ‘What have I learned?’ summaries at the end of each lesson. In their interviews some of the teachers commented on
the usefulness of the prepared table in the Teacher Guide with the examination questions categorised per topic and Unit; “So having done Unit 2, you should be able to do the following bits out of the exam papers... yeah. Yeah, that was good because it saved me searching, searching and searching” (Teacher A).

When discussing the effectiveness of the Organic Chemistry in Action! programme in terms of preparation for the examination, the teachers reiterated the need to omit topics that were not on the syllabus due to time constraints.

Teacher C: Some of the sixth years were a little bit anxious like “what are we learning?”...
I: Yeah, like they didn’t have time for this [OCIA]....
Teacher C: And I know that’s sad, because they are young and they are supposed to be enjoying school, but they are so obsessed with Leaving Cert, Leaving Cert, Leaving Cert.
I: Yeah.
Teacher C: It’s the way things are going... and it’s the way they have been conditioned.

Each of the teachers were asked to explain what changes they would like to make to the current Leaving Certificate Chemistry syllabus and examination (with a particular focus on the Organic Chemistry). The quotes listed below provide an insight into the ideals of the participating teachers on how to improve the current system:

“Am, they have stopped asking really difficult calculations as well. Like there was a time... when you know this limiting yield thing went into the Organic as well. But now, it is separate, which is fair enough. Once they can take it separately, it’s grand, it will suit the mathematical crowd”.

(Teacher A)

“Like even if maybe... if they were allowed to... If they were doing their own experiment and they were allowed to ... If maybe they had to go through maybe five Organic experiments of something, and they were told that they were going to be doing... like an oral exam. Say the experiment would be set up in front of them, and they would have to talk through and explain what would or wouldn’t happen. That might be better? You know? I don’t know.... Writing all this stuff down [Laboratory reports], there is no learning in that really. It’s just a paper-pushing exercise after all.”

(Teacher B)
“There is a whole load of stuff and it always comes up on one question... And that is what makes it difficult... If you could go “this stuff... is going to be in this question, and then.... This stuff is going to be in that question”. So if there was a question on families, then a question on... something else...”

(Teacher C)

“To the Leaving Certificate Organic syllabus? [pause] Yeah, make it essentially less predictable. Like I know I’m not... but even if you look at question two, the questions on the experimental work doesn’t really reflect on if they really have done the experiment or if they haven’t.

Like they could just have learned the colour change, learn the oxidation number change or learn whatever it is. It’s, it’s ... I mean, it definitely has to become, I would imagine less predictable and more about conceptual understanding. That’s what’s needed at college like to be honest”.

(Teacher D)

“You know, give them a chemical compound, like if you give them aspirin, they should be able to spot the carboxylic acid, they should be able to spot the aromatic group, they should be able to tell you that the carbon is positive, you know?

They should be able to tell you the type of reactions that it will undergo”. 

(Teacher E)

From these responses and suggestions, it is clear that, Teachers A and C would prefer the examination to be more specifically structured and hence more predictable and easier to answer for pupils. However, the responses from Teachers B, D and E above suggest that these teachers value the importance of assessing the pupils’ true understanding and ability to solve and explain unseen problems.

8.2.4.8. Teaching for Understanding

The teachers’ comments and feedback about the effectiveness of the intervention programme in changing their approach to teaching Organic Chemistry will be summarised in the final theme (Section 8.2.4.9). First, it is important to highlight the mixed responses that emerged in the Teacher Interviews relating to the teachers’ comments on how pupils learn and what they understand as effective teaching.

In all, there is evidence to suggest that the teachers appreciated the importance of presenting new material in a manner that was appropriate to the psychological capabilities of the pupils: “it was well thought out and an awful lot of revision in it, which is obviously very useful” (Teacher A).
Teacher D explained that the approaches used in the intervention programme:

“…really got them [the pupils] up in terms of thinking about the mechanism and it questioned. I have to be honest, previous to this, we might have went through the mechanisms, went through the different steps and everything, but then a lot of them would still have just went into rote-learning; where they were literally learning off initiation, propagation, termination… I think the... just the way the workbooks were laid out for them and the assignments that were given for the Higher Level students was fantastic. They just got it”

Teacher B placed value on the efforts made to increase pupils’ interest in Organic Chemistry as well as their understanding:

“And that’s a lot of it too... I know while we want them to be ... We want them to be interested it in it too. I know now before this Organic wouldn’t have been my favourite and now I like better now myself, and that’s a good thing...And Christ, we should be gearing them [pupils] up, and getting them ready and getting them more interested in it”. (Teacher B)

Teacher D also valued the importance of a true understanding in preparing young people for future careers in Science and Chemistry; “to go and work in labs or to do Science, they need that understanding. So, that for me would be what would need to change in terms of teaching the Leaving Cert syllabus and sitting the exam”.

While there was some criticism about the spiral structure of the programme, which was already presented above, it was evident that overall, the teachers did appreciate the purpose of the particular sequencing and presentation of the content:

“So I would be very very slow to say.... To take a part of this out. Because I understand that each part that you put in, is really there to build them up, to get them ready for the next part”. (Teacher D)

“Overall, I thought it was a great idea, it’s a great concept. I like the way it goes into the understanding of it, rather than the learning off, because I think that’s the way it should be going” (Teacher E)

Teacher G expressed concern about shortening or reducing the content of the Organic Chemistry in Action! programme:

Teacher G: Yeah, I…I…. I don’t know that now. Because I was even thinking that for me now next year maybe using it, I would actually maybe go more by your book.

I: Oh right.
Teacher G: Because if you kind of go... like here is a list of activities that you can use, and here is a worksheet...

I: Yeah

Teacher G: I don’t think that you would give it as much justice as you have done it, with how you have done it in your book.

It is evident from such insights that for the most part the teachers had an understanding of the need to present information in a manner appropriate to the pupils’ level of cognitive ability, for example enabling pupils to learn from three-dimensional rather than the misleading two-dimensional representations and challenging pupils to think rather than just learn:

“This business of sometimes where you were naming the ready-made compounds that were labelled A,B,C,D,E,F,G. I thought that was very good where they had to handle them and look at them to identify them, do you know?” (Teacher A)

Through discussion with the teachers, it was evident also that many of them had recognised that some aspects of the Leaving Certificate Organic Chemistry syllabus were too difficult for the pupils, for example:

“Synthesis, I think is beyond them. Now they [examiners] don’t ask a whole lot of it...But now, I don’t mind the reaction schemes, but the business of “how can you get from here to here in less than three steps?”, I don’t think that sixth years... really honestly unless they are very good are going to be able to handle that.” (Teacher A).

Teacher C also recognised the need to allow pupils the time to “kind of digest” new information:

“You know, for it to settle in?.. I don’t know, like into the second part of the brain... I don’t know, this could be complete waffle...But to go from the input part of the brain to the useable part. I don’t know, I remember reading somewhere like, if you give them a piece of information, they have to have time to process it before they can use it” (Teacher C)

Insights such as these suggest that the teachers are aware of how their pupils learn and strategies that can facilitate their learning.

The teachers were also aware of how different pupils learn and study in different ways for the examination: writing their own notes, using the given notes, using the PowerPoint slides etc. Most of the teachers seemed happy to “just leave them free to do whatever they want really, as long as they are learning it [laughs]” (Teacher E).
Despite feedback from the teachers indicating their understanding of how pupils learn and the importance of tailoring teaching methods and approaches to the pupils’ needs, some comments from teachers indicated that while the teachers were aware of the pupils’ needs, the most appropriate teaching methods were sometimes not implemented. For instance some of the pupils had visited the Third-Level college to carry out the Organic Chemistry mandatory experiments before learning the related theory in the classroom. Teacher A also admitted that they usually “would have been doing an experiment a week, whether they have done the theory or not, and that way, they get to see the apparatus and put it together a bit more”. While such an approach may facilitate the pupils’ development of laboratory technique and skills, it is doubtful that the pupils would be able to comprehend at a molecular level what is happening during the experiments.

Insights from the teachers suggest that in the examination-driven culture, very often more emphasis is placed on preparing the pupils for the examination rather than taking the time to improve their conceptual understanding; “I suppose, it could be down to my own teaching style; where I introduce the topic, dodadodado…etc. etc. etc. work down through it, and then like “make sure you know, this, this, this and this” (Teacher C).

The following comments from Teacher C suggest that they may not have valued the true purpose of the *Organic Chemistry in Action!* programme, perhaps disregarding the value of the teaching approaches used; “I remember even being in Limerick, the day we met you and getting the feel that it was going to be…kind of a more hands-on approach…. You know this idea that… people are always saying to us teachers about learning through inquiry-based learning and all that”.

This extract from the interview with Teacher C also indicates that they did not understand the inquiry-based approach used, Teacher C sometimes suggested that the pupils should have been given the answers:

**Teacher C:** Yeah, because I remember we were introducing oxidising alcohol to an aldehyde or a ketone or a carboxylic acid and that kind of stuff before they knew what a carboxylic acid was, before they knew what an aldehyde was.

**I:** Oh yeah…

**Teacher C:** So what I would have traditionally always done – here are all the families, then in the next chapter, because this is just the way the book does it- here are all the reactions.
It is clear from this that Teacher C valued the activities in the programme, as resources to break up the theory-based content rather than as learning tools to facilitate cognitive development and understanding. Teacher C admitted that they did not focus on or read the possible misconceptions that were highlighted in the Teacher Guidebook; “Honestly, I tended to not read a lot of the Teacher Workbook”.

Teacher C: I know there is, like you do want them doing a bit of stuff. Like the Organic is long… So now I do have a couple of activities that I can throw in.

Teacher C: I do have this extra written work that I can give them that I can throw in.

8.2.4.9. Influence of the Organic Chemistry in Action! programme on Future Teaching

The Organic Chemistry in Action! programme aimed to improve the teaching and learning of Organic Chemistry in the Leaving Certificate course. It is clear from much of the teachers’ feedback that they appreciate the new and fresh approach to teaching Organic Chemistry; “Like if you’re 25 years doing the same thing, it’s nice to change it around you know?”

The extract from the interview with Teacher B below highlights the teachers’ appreciation of the thought process involved in the intervention programme materials:

Teacher B: Yeah, and I think I was more… My attitude was more positive and more upbeat and everything like that, and I think theirs’ was too… I found that where I might have ploughed on other years, and maybe like have just kept going… I didn’t think as much… I suppose, you get like that too when you have been teaching for while…

Teacher B: Whereas, the way you would have phrased questions, the way you would have asked questions at different times… I knew that that was making sure that there was not any problems with misconceptions. And I definitely… like a textbook does not take that into consideration…

Teacher B: So that is nice. It’s almost like it’s so personal.

The other teachers also explained how their experience of teaching the Organic Chemistry in Action! programme has had a positive influence on their teaching:

“There are great resources that I will use, and I did feel that it has improved aspects of my teaching of the Organic. So, I …overall, I’m glad to have participated in it…. And there will be things, aspects of it that I will incorporate into my teaching, I will. It has changed me, like
I will teach things differently, I am not going to go back to the way I was before.”  
(Teacher C)

“100%, for a conceptual understanding of Organic Chemistry, there is no comparison between teaching it in this way [using the OCIA materials] and teaching it as from the old Leaving Certificate course. No comparison, definitely no comparison... 100% improvement on teaching Organic.”  
(Teacher D)

Although the teachers indicated on the Teacher Questionnaire (Table 8.3) their intention to use and integrate aspects of the Organic Chemistry in Action! resources and materials in their future teaching, the interviews provided a greater insight into how the teachers intended to use the materials.

There were some complications and reasons why teachers were not intent on using some of the materials again in the same manner:

“I would have my own sequence normally where I would do the physical properties and I do my naming and then later on, I get onto the reactivity and that sort of thing....Do you know? Just, when it’s not your own, you don’t own it [pause] or maybe I should have had it all read beforehand... that would have helped.”  
(Teacher A)

“I prefer to make up my own stuff. But, what I do is I have, like I have a stack of stuff on my laptop from other people, and I incorporate bits of everything in. But I like the slides that I use to be my own. And I like making my own worksheets, unless I find a really good worksheet like, there is no point in re-inventing the wheel...Because then I feel that like, I know what’s coming next. Whereas if you don’t know what’s coming next...not that you don’t know what’s coming next, but you’re kind of...you know it’s more fluent when you have made them up yourself and you understand it a lot better.”  
(Teacher E)

From these quotes it is clear that the teachers feel more comfortable using their own approach and sequence of content as they are more familiar with it. However, all of the teachers did say that they intended to use parts of the programme and the resources in their future teaching. These quotes that follow are representative of general feedback from each of the teachers that were interviewed:

“Maybe if I was to do it [OCIA programme] a second time, I would know... this is where it is going....”  
(Teacher A)
“You want to be given materials, because then you use them, and then you might decide-OK, I’ll use this again, or like I love that, but for... Like for all the stuff you gave me, there are some bits that I am never going to use again, but there are some bits that I will. You know... that I will probably build into my own, that I will incorporate into my own. And then there are some that I will probably just use as they are which is great to have that.” (Teacher C)

“Well, as I said, it’s different and I definitely intend to use it again. And I have actually learned a lot from it. Even in terms of making references to everyday things, you know? ... The simple demos that you suggested that I would never in a million years have thought of.” (Teacher D)

“Well overall, I do think it [OCIA programme] was very good, a very good course. Like some of the pupils were even asking me would I use it again?... And yes, I would use it again next year definitely” (Teacher G)

The teachers also gave specific reference of their intention to use particular resources e.g. the molecular models, classroom response cubes, fun demonstrations etc. Some of the teachers had shared the resources with other teachers in their schools and intended to pass on the useful ideas of the Organic Chemistry in Action! programme beyond their classrooms:

“Yeah, it’s [classroom response cubes] something, I’m going to encourage my ah... the other Science teachers, something I’m going to tell the other Science teachers about, something we could bring in. It is brilliant, yeah! And they love it, my students love it. The sixth years used to love when I started taking the box out.” (Teacher D).

The teachers explained why they did not intend to use certain aspects of the programme in their future teaching. The teacher who had the most teaching experience of all teachers involved in the intervention programme felt that they were “aware of a lot of the misconceptions already. You know that sort of a way?” and that such a programme may be more suited and helpful for someone at the beginning of their teaching career; “If you were starting out, and you had never taught that [Organic Chemistry], you would have a template to start with”. This teacher also explained the difficulty in teaching someone else’s work; “Ah, you know yourself, unless you actually have written it down yourself, you don’t even know where it is leading, you know?”
Other comments from teachers helped to explain how the continued pressure to prepare pupils for the examination limits the teachers’ flexibility and opportunities to use alternative teaching methods:

“I just went back to my own notes because they were briefer. And I suppose, I have … when I’m going through, when they are going through… like I give them an exam question at night, I would be going through the marking scheme, and they are so in on it now. And I would, they would… even by the time May comes, I would hand them a marking scheme and let them mark themselves. Now, maybe that is…. It’s not the right way to teach, but at the end of the day, if they want the results…. Like I’ve done the teaching, they have done the homework, so now at the end of the day; let’s start practising to get this exam craic right.” (Teacher B)

The extract from the transcript of the interview with Teacher C summarises how precious class-time is for the teachers, in particular with examination classes:

Teacher C: Yes, it’s all about time. And every time a teacher takes part in any kind of course… or in-service or training day – where you have people from outside coming in saying “OK, why don’t you do this? Why don’t you try this?” Every single time, we are going to go “We don’t have time” [sighs].

I: Yeah.

Teacher C: Until they shorten the course, or give us…. Or lengthen our teaching day… which is more likely going to happen.

Teacher C also suggested breaking up the Organic Chemistry by teaching other areas of the Chemistry syllabus in between the Organic Chemistry topics, to prevent overloading the pupils with Organic Chemistry ‘all in one go’:

“I think that I like the idea of the spiral thing, liking coming back to it and doing it again. I might try do that again. You know like split those chapters up, because I think it’s the trying to learn the whole lot together, trying the whole lot in one go, is the hardest thing for students. They will all write down saying the hardest thing is this, the hardest thing is that, but, I think it’s there is too much learning to do all in one go”

(Teacher C)

The main issues and feedback arising from the Teacher Interviews have been presented in this section. The main issues arising from the themes listed in Figure 8.3 have been presented in detail here. These findings will be discussed in more detail when the research questions for Cycle Two are addressed and answered in Chapter Nine.
8.3 – Feedback from Participating Pupils

The Venn diagram in Figure 8.4 illustrates the three research methods that were used to gain feedback from the participating pupils. Using the same colours as in Figure 8.1, the Classroom Observations and Focus Group are highlighted here in blue. Feedback from the pupils using these qualitative methods was gained during the implementation phase of the intervention programme. In comparison, the Pupil Questionnaires (highlighted in green) were completed by the pupils at the end of their experience of the Organic Chemistry in Action! programme. The participating pupils completed the Organic Chemistry in Action: Second-Level Pupil Questionnaire (II). Part C of this questionnaire provided quantitative data for the evaluation of the Organic Chemistry in Action! programme.

![Figure 8.4 Mixed method evaluation of the participating pupils](image)

8.3.1. Classroom Observations

The classroom observation of the pupils took part in the same schools (C, E and G) and classes as the Teacher Classroom Observations that were reported in Section 8.2.1 above. The guiding rubric used by the researcher in observing the pupils is included in Appendix H. A summary of the main observations are included in Table 8.4 which follows. Overall, it was evident in all three classes that the pupils worked co-operatively when using the molecular models and were engaged in discussion in investigating and solving the given problems and in recalling content learned in previous lessons. It was evident that the spiral curriculum was effective in developing pupils’ knowledge base as they were able to recall and apply previous knowledge e.g. IUPAC naming, intermolecular forces, polarity, solubility etc. to facilitate their understanding of the subsequent topics that they were learning.
The summary in Table 8.4 provides an insight into the participation and involvement of the pupils in the three classrooms during the observed lessons. The most encouraging observation noted by the researcher was the pupils’ efficiency and ability in recalling and developing the content and information that they had learned in previous lessons. The pupils seemed to enjoy working by themselves and in small groups, with all three of the teachers operating more as facilitators of the lessons. The molecular models were used in all three of the observed lessons. The pupils were enthusiastic about getting and using the models, and many competed to see who could make the structures the fastest, and there was much debate and discussion about how to name different isomers and compounds that were made. The pupils engaged well in discussion of the contextual links that were included in the lessons. Topics such as the use of essential oils and fuel prices etc., as discussed by the pupils are listed in Table 8.4. It is clear that these real-life applications of the content learned in the classroom was effective in interesting the pupils and therefore should facilitate their ability to understand and remember the lesson.

In school C, the pupils had just received the results of their mid-term assessment given by the teachers assessing Fuels. Most of the pupils were very pleased with their results in this test, and expressed how they had expected Organic Chemistry to be more difficult before they started studying it. It is clear that the pupils were enjoying their study of Organic Chemistry and were encouraged by the evidence that they had gained a good understanding of the topic also. During the lessons, there were some references made to previous demonstrations carried out by the teachers. This again suggests that these were effective in facilitating pupil understanding and recall of concepts. The pupils recalled and described the Pringles rocket and Carbon Tower (dehydration of sugar with sulphuric acid) demonstrations as ‘cool’.
Table 8.4 Summary of the Classroom Observations – Participating pupils in schools C, E and G.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of molecular models</td>
<td>Pupils discussing while building and making models.</td>
<td>Not as part of lesson, but as an aside at the end of the lesson, pupils were able to name (pi-bond) models already built by the teacher.</td>
<td>Eager to get the model sets at beginning of class.</td>
</tr>
<tr>
<td>Interest in the lesson</td>
<td>Classroom discussion, pupils engaged with the lesson and the teacher.</td>
<td>Interest in uses of the essential oils e.g. clove oil for a tooth ache, lavender, eucalyptus, tea-tree oil.</td>
<td>Context of fuels and engines.</td>
</tr>
<tr>
<td>Involvement (participation)</td>
<td>Answering teacher questions</td>
<td>Only small amount of off-task discussion.</td>
<td>Discussion fuel prices.</td>
</tr>
<tr>
<td>Use and completion of workbooks</td>
<td>Correct previous homework in Pupil Workbooks.</td>
<td>Completion during the lesson – p. 269 during discussion, p.273 after the steam distillation set up.</td>
<td>Completion during class through group and teacher discussion.</td>
</tr>
<tr>
<td>Help from the teacher</td>
<td>Uses the PowerPoint to lead the lesson.</td>
<td>Probing questions for recall.</td>
<td>Probing questions to pupils.</td>
</tr>
</tbody>
</table>

School C (14/11/11) Unit 4: Lesson 5:
- Use of molecular models:
  - Pupils discussing while building and making models.
  - Not as part of lesson, but as an aside at the end of the lesson, pupils were able to name (pi-bond) models already built by the teacher.

School E (14/11/11) Unit 5: Lesson 2:
- Interest in the lesson:
  - Classroom discussion, pupils engaged with the lesson and the teacher.
  - Interest in uses of the essential oils e.g. clove oil for a tooth ache, lavender, eucalyptus, tea-tree oil.

School G (28/11/11) Unit 3: Lesson 4:
- Use of molecular models:
  - Eager to get the model sets at beginning of class.
  - Good inquiry approach evident.
  - Good co-operation; one pupil counts, one builds, one names the compounds.
  - Very quick to build models

- Interest in the lesson:
  - Eager to get the model sets at beginning of class.
  - Good inquiry approach evident.
  - Good co-operation; one pupil counts, one builds, one names the compounds.
  - Very quick to build models
<table>
<thead>
<tr>
<th>Questions asked by the pupils</th>
<th>− How can you name something with a methyl group?</th>
<th>− How much steam is necessary for steam distillation?</th>
<th>− Why O.N. differ between the isomers of pentane?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>− A lot of pupil questions to check for their own understanding.</td>
<td>− Why is a pear-shaped flask used?</td>
<td>− How would you know knocking is happening?</td>
</tr>
<tr>
<td></td>
<td>− Should general formula of alcohols be written as O-H or –OH?</td>
<td>− How does a solvent extract things?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>− Why is water the bottom layer in the separation funnel?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Practical work (integration, involvement, understanding)</th>
<th>− Model building.</th>
<th>− Helping teacher to set up parts of the Clove-oil distillation set-up.</th>
<th>− Model building.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>− Isomers of propanol.</td>
<td></td>
<td>− Satisfied to discover the structure of benzene in reforming.</td>
</tr>
</tbody>
</table>

| Group discussion | − Comparison and naming of isomers of propanol. | − Discussion about chlorophyll and chromatography. | − Fuel prices. |
|                 |                                                | − Long and detailed discussion to decide polarity and solubility of eugenol. | − ON of isomers of pentane. |
|                 |                                                | − Decision about an identification test for eugenol – looking at its structure to deduce use of bromine. | − Pairwork discussion- how to make cyclohexane from hexane. |

| Understanding lesson outcomes | − Not outlined or read by the teacher, researcher is unsure if pupils read these before the lesson? | − Outcomes were not highlighted or read by the teacher in the lesson. | − Read by the teacher at the beginning of the lesson, outlined and explained to the class. |
|                             |                                                | − Evident that the pupils had achieved the lesson outcomes by the end of the lesson. |                                                  |

| Use of homework assignments | − Corrected at the beginning of the class. | − Lab report will be written up for homework in hardback copies. | − Corrected at the beginning of the class. |
|                           | − Assigned by teacher for the next lesson. | − No correction of homework from the previous lesson. | − Assigned by teacher for the next lesson. |
|                           | − Pupils correct own answers and responses at beginning of the lesson. |                                                    | − Pupils correct own answers and responses at beginning of the lesson. |

<table>
<thead>
<tr>
<th>Use of additional resources from Resource box</th>
<th>− Not in this lesson</th>
<th>− Not in this lesson</th>
<th>− Not in this lesson</th>
</tr>
</thead>
</table>
From the Classroom Observations, it was evident that some of the pupils were concerned about how these enjoyable and interactive lessons were preparing them for the Leaving Certificate examination. The pupils were anxious for the teachers to highlight the important points in the Pupil Workbook so that ‘they would know what to learn’. A small number of pupils did ask why there were not any examination questions included in the Pupil Workbook. Some pupils felt that there were too many questions and investigations in the Pupil Workbook and that more ‘notes’ would be more helpful. The Higher-Level pupils in particular were concerned about the ‘slow progress’ and length of time that the programme would take to complete and the amount of content in the Pupil Workbooks. Such criticism and concern about the inquiry-based approach to learning is a reflection of how accustomed the pupils have become to learning ready-made notes in preparation for examinations. For many of these pupils, the sole purpose of learning seemed to be ‘for the examination’. This is understandable however, as their performance in the Leaving Certificate examination will determine their entry to Third-Level education, and it appears to be the prevailing ethos in Irish Second-Level schools.

8.3.2. Focus Group

A Focus Group was held with the participating teacher and pupils in School B in November 2011. At this stage this class had almost completed Unit 4 in the Organic Chemistry in Action! programme. This was decided as a suitable time to hold the Focus Group with the class as they were half-way through the programme and were able to share their experiences and feedback on the design criteria and key elements of the programme. The details of how the Focus Group was carried out have been outlined in Chapter Five (Section 5.3.3.3).

The Focus Group was held with the teacher and pupils together. The presence of the teacher helped to encourage the pupils to recall certain positive and negative experiences of the programme. The class were very co-operative, and most of the pupils present contributed to the discussion. Some were more forthcoming in the amount of feedback and insight that they gave than others. The Focus Group was directed by the pupils and teachers by flicking through the Teacher Guidebook and Pupil Workbooks of the lessons they had completed to date. This helped the recall of particular aspects of the programme.

Overall, the pupils were very positive about the programme even though it was new to them and different to the more traditional classroom practice that they would be accustomed to.
The pupils were very enthusiastic and motivated about the programme. The value of the practical work was mentioned a number of times. The teacher had completed all of the Teacher Demonstrations to that point and these were well-received by the pupils. The pupils had also completed all of the mandatory and non-mandatory experiments to that point. The pupils recalled and explained certain elements of this practical work: what they had seen and smelt, what happened or what didn’t work so well. The pupils were able to explain in detail their observations and findings from these. From this discussion, there was much evidence to suggest that the practical activities and demonstrations in the programme were effective in motivating the pupils and facilitating their understanding of topics.

The pupils made a lot of reference to the use of the models and the Lego blocks etc. They enjoyed the activity in each of the lessons. They appreciated that the programme was ‘not just listening and writing all the time’. The pupils explained how some of the activities helped them to think about things and understand Chemistry better. One such example outlined by the pupils in the Focus Group was their understanding of distillation. Through the discussion of intermolecular forces and boiling, it was clear that the pupils understood how and why the fractions of crude oil are separated. The pupils explained that inclusion of videos and animations in the PowerPoints were ‘fun’ and more interesting and helpful than having to read the same content from a textbook. The pupils were able to discuss and recall aspects of the Chemistry Chronicles, which suggested these had been read and discussed in previous lesson. The pupils explained that reading these articles raised their interest in the topic and how they would look forward to following lessons to develop their understanding. The pupils admitted that before starting Organic Chemistry, they had perceived it as a difficult area of Chemistry. However, they explained how surprised they were with how relevant and important it was to their own lives. Teacher B’s background of working in industry may also have helped increasing the contextual emphasis of the programme.

These sixth year pupils made special reference to the value of the revision of topics during the Organic Chemistry programme. They mentioned how the revision of topics such as electronegativity and bonding, was helpful as they had covered these topics in fifth year, but did like the recall and revision insertions in the Pupil Workbooks. Their teacher also highlighted and commended the effectiveness of the spiral curriculum used as it allowed the pupils to develop and progress their knowledge of Organic Chemistry without overloading.
The only criticism that the pupils gave about the Pupil Workbooks during the Focus Group was that in some cases, the amount of space provided for naming or drawing compounds was too small and hence, this made it difficult for the pupils to complete these exercises clearly. The pupils and teacher explained how in some lessons, there was not sufficient time for completion of the Pupil Workbook with the investigations and activities. In such cases, the pupils completed the Pupil Workbook as part of their homework. The Homework Assignments were corrected at the beginning of every lesson by discussion with the pupils sharing their answers. The pupils explained how their teacher had to highlight some of the important parts of the Pupil Workbook that need to be ‘learned off’ for the examination e.g. stems of the IUPAC names.

At this point of the programme, the teacher explained that they were just using the Homework Assignments for assessment of understanding at the end of each lesson and unit with the intent to do Leaving Certificate examination questions at the end of the study of Organic Chemistry. Overall, the feedback from the teacher and pupils was very positive. This teacher (Teacher B) was already inquiring and interested in ordering Pupil Workbooks for use to teach Organic Chemistry with their up-coming fifth year Chemistry class.

From the report of these findings from the Focus Group, it suggests that the teacher’s and pupils’ experiences of the Organic Chemistry in Action! programme was very positive and enjoyable. However, as reflected in some of the feedback from Teacher B (Section 8.2), concerns relating to time constraints and examination preparation transpired towards the end of the programme. It is important to bear in mind when reading these findings that this feedback from the Focus Group was gathered during the implementation phase, and may not necessarily an accurate summative evaluation of the pupils’ and teacher’s experience and attitude towards the programme.
8.3.3. Organic Chemistry in Action: Second-Level Pupil Questionnaire (II)

As explained in Chapter Four (Section 4.7), there were three parts in the Organic Chemistry in Action: Second-Level Pupil Questionnaire (II). This complete questionnaire is included in Appendix H. Parts A and B were used for comparison with the Control Group. The findings from these parts will be discussed in Section 8.4 which follows. In comparison to the feedback gained from the participating pupils during the implementation phase of the programme, Part C of the Pupil Questionnaire (II) was completed by the pupils after they had completed the Organic Chemistry in Action! programme.

Part C of the Organic Chemistry in Action: Second-Level Pupil Questionnaire (II) included a Likert rating scale for the pupils to express their feedback about the different elements of the programme. 83 (95.0%) of the 87 pupils that participated in the Organic Chemistry in Action! programme completed this part of their questionnaire. The pupils rated each of the listed resources and elements of the programme on a five-point Likert scale where 1= Really helpful, 2= helpful, 3= indifferent, 4= Not helpful and 5= Really not helpful. The pupils were also asked to indicate any cases where they had never used certain resources or aspects of the programme. The resources ‘never used’ by the highest number of pupils were the Classroom Response Cubes (22, 25.0%) and the Playing cards (18, 21.0%). 16 (18.0%) of the same pupils indicated that they didn’t use either of these resources. All of the pupils used the Lesson PowerPoints, Important note-boxes, Mandatory experiments, Links to everyday life and Links to industry. The remaining resources and elements of the course were never used by less than 6.0% of the participating pupils.

Table 8.5, summarises the pupils’ ratings of the resources and criteria of the Organic Chemistry in Action! programme. The ordinal data from the five-point Likert scale was non-parametric. For this reason, the median values are included in Table 8.5 and the corresponding trends are shown in the final column. The mean values are also included here for interest. These findings (Table 8.5) illustrate an overall very positive attitude towards the Organic Chemistry in Action! programme from the participating pupils. The molecular models were the most popular and helpful resources, as indicated by the median score of 1, indicating that the pupils found them ‘really helpful’ in their study of Organic Chemistry. The pupils were indifferent in their attitudes towards the Playing game cards, Completion of the Pupil Workbook, Homework Assignments and the Chemistry Chronicles. However, the pupils found all the remaining resources helpful in their understanding or Organic Chemistry.
While there were some individual responses indicating that particular resources were not helpful, this overall response suggests that all participating pupils found most aspects of the programme beneficial for their learning and understanding.

The five points on the ordinal scale were grouped into three groups for multivariable analysis. ‘Really helpful’ and ‘helpful’ were grouped together as ‘helpful’ while ‘not helpful’ and ‘really not helpful’ were grouped together as ‘not helpful’. The Pearson Chi-square Test was used to investigate if the following variables had a significant effect on the pupils’ ratings of the resources used in the programme: Level of Leaving Certificate Chemistry, Level of Leaving Certificate Mathematics, gender of the pupils, and the pupils’ prior performance and study of Junior Certificate Science. The results from this test are summarised in Table 8.6 (following Table 8.5).

Table 8.6 shows that almost all of the design criteria incorporated in the Organic Chemistry in Action! programme were effective helping the pupils to develop an understanding of Organic Chemistry despite differences in gender and prior background in Junior Certificate Science and Mathematics.
Table 8.5 Participating pupils’ Likert rating of Organic Chemistry in Action! resources (n=83)

<table>
<thead>
<tr>
<th>Resources</th>
<th>25th Percentile</th>
<th>Median (50th Percentile)</th>
<th>75th Percentile</th>
<th>Mean</th>
<th>General Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular models</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.64</td>
<td>Really Helpful</td>
</tr>
<tr>
<td>Playing cards</td>
<td>2</td>
<td>2.5</td>
<td>4</td>
<td>2.63</td>
<td>Indifferent</td>
</tr>
<tr>
<td>Classroom response cube</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.86</td>
<td>Helpful</td>
</tr>
<tr>
<td>Lesson Power Points</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.83</td>
<td>Helpful</td>
</tr>
<tr>
<td>Videos</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.85</td>
<td>Helpful</td>
</tr>
<tr>
<td>Animations</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.82</td>
<td>Helpful</td>
</tr>
<tr>
<td>Order of lessons and topics</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2.26</td>
<td>Helpful</td>
</tr>
<tr>
<td>Outline of lesson outcomes at the beginning</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2.39</td>
<td>Helpful</td>
</tr>
<tr>
<td>Completing the workbook</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2.68</td>
<td>Indifferent</td>
</tr>
<tr>
<td>Homework Assignments</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2.55</td>
<td>Indifferent</td>
</tr>
<tr>
<td>‘What have I learned’?</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2.25</td>
<td>Helpful</td>
</tr>
<tr>
<td>Important Note boxes</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.74</td>
<td>Helpful</td>
</tr>
<tr>
<td>Word Spy</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2.66</td>
<td>Helpful</td>
</tr>
<tr>
<td>Summary classification charts</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2.06</td>
<td>Helpful</td>
</tr>
<tr>
<td>Non-mandatory activities</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2.23</td>
<td>Helpful</td>
</tr>
<tr>
<td>Teacher demonstrations</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2.05</td>
<td>Helpful</td>
</tr>
<tr>
<td>Mandatory experiments</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.76</td>
<td>Helpful</td>
</tr>
<tr>
<td>Links to everyday life</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.94</td>
<td>Helpful</td>
</tr>
<tr>
<td>Links to Industry</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2.09</td>
<td>Helpful</td>
</tr>
<tr>
<td>Chemistry Chronicles</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2.58</td>
<td>Indifferent</td>
</tr>
<tr>
<td>Group discussions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2.32</td>
<td>Helpful</td>
</tr>
<tr>
<td>‘Interesting Insights’</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2.37</td>
<td>Helpful</td>
</tr>
</tbody>
</table>
### Table 8.6 Investigation of factors influencing effectiveness of the Organic Chemistry in Action! resources (n=83)

<table>
<thead>
<tr>
<th>Resources</th>
<th>Level of J.C. Science</th>
<th>Level of L.C. Mathematics</th>
<th>Level of L.C. Chemistry</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test Statistic ($\chi^2$)</td>
<td>Level of significance</td>
<td>Test Statistic ($\chi^2$)</td>
<td>Level of significance</td>
</tr>
<tr>
<td>Molecular models</td>
<td>0.801</td>
<td>P= 0.938</td>
<td>0.333</td>
<td>P= 0.988</td>
</tr>
<tr>
<td>Playing cards</td>
<td>3.689</td>
<td>P= 0.450</td>
<td>1.437</td>
<td>P= 0.838</td>
</tr>
<tr>
<td>Classroom response cube</td>
<td>.400</td>
<td>P= 0.982</td>
<td>1.523</td>
<td>P= 0.823</td>
</tr>
<tr>
<td>Lesson Power Points</td>
<td>.659</td>
<td>P= 0.995</td>
<td>0.453</td>
<td>P= 0.978</td>
</tr>
<tr>
<td>Videos</td>
<td>2.150</td>
<td>P= 0.708</td>
<td>0.519</td>
<td>P= 0.972</td>
</tr>
<tr>
<td>Animations</td>
<td>1.443</td>
<td>P= 0.837</td>
<td>1.622</td>
<td>P= 0.805</td>
</tr>
<tr>
<td>Pupil Workbook</td>
<td>2.387</td>
<td>P= 0.881</td>
<td>2.743</td>
<td>P= 0.602</td>
</tr>
<tr>
<td>Order of lessons and topics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outline of lesson outcomes at the beginning</td>
<td>3.020</td>
<td>P= 0.554</td>
<td>4.932</td>
<td>P= 0.294</td>
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<tr>
<td>Completing the workbook</td>
<td>8.986</td>
<td>P= 0.061</td>
<td>6.279</td>
<td>P= 0.179</td>
</tr>
<tr>
<td>Homework Assignments</td>
<td>4.670</td>
<td>P= 0.587</td>
<td>2.549</td>
<td>P= 0.636</td>
</tr>
<tr>
<td>‘What have I learned?’</td>
<td>6.244</td>
<td>P= 0.396</td>
<td>1.285</td>
<td>P= 0.864</td>
</tr>
<tr>
<td>Important Note boxes</td>
<td>0.387</td>
<td>P= 0.943</td>
<td>0.751</td>
<td>P= 0.687</td>
</tr>
<tr>
<td>Word Spy</td>
<td>1.849</td>
<td>P=0.933</td>
<td>2.059</td>
<td>P= 0.725</td>
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<tr>
<td>Summary Charts</td>
<td>2.898</td>
<td>P= 0.822</td>
<td>4.380</td>
<td>P= 0.357</td>
</tr>
<tr>
<td>Practical Work</td>
<td>7.338</td>
<td>P= 0.291</td>
<td>1.284</td>
<td>P= 3.864</td>
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<tr>
<td>Non-mandatory activities</td>
<td>1.054</td>
<td>P= 0.983</td>
<td>1.452</td>
<td>P= 0.835</td>
</tr>
<tr>
<td>Teacher demonstrations</td>
<td>4.550</td>
<td>P= 0.603</td>
<td>3.480</td>
<td>P= 0.481</td>
</tr>
<tr>
<td>Mandatory experiments</td>
<td>1.306</td>
<td>P= 0.971</td>
<td>5.382</td>
<td>P= 0.250</td>
</tr>
<tr>
<td>Links to everyday life</td>
<td>6.322</td>
<td>P= 0.388</td>
<td>4.196</td>
<td>P= 0.380</td>
</tr>
<tr>
<td>Chemistry Chronicles</td>
<td>2.961</td>
<td>P= 0.564</td>
<td>4.801</td>
<td>P= 0.308</td>
</tr>
<tr>
<td>Group discussions</td>
<td>3.289</td>
<td>P= 0.772</td>
<td>3.340</td>
<td>P= 0.503</td>
</tr>
<tr>
<td>‘Interesting Insights’</td>
<td>1.135</td>
<td>P= 0.889</td>
<td>2.533</td>
<td>P= 0.639</td>
</tr>
</tbody>
</table>

**Note:** L.C. = Leaving Certificate, J.C. = Junior Certificate
73 (84.0%) of the pupils that participated in the intervention programme were studying Higher Level Leaving Certificate Chemistry and 14 (16.0%) were studying Ordinary Level. 49 (56.0%) of the pupils were studying Higher Level Mathematics, 37 (53.0%) were studying Ordinary level and one pupil was studying Foundation Level Mathematics. The Pearson Chi-Square Test showed that the level of Chemistry or Mathematics that the pupils were studying for their Leaving Certificate had no significant difference on the pupils’ rating of the resources listed in Table 8.5.

35(40.0%) of the pupils were male and 50 (58.0%) were female. (Two of the pupils did not indicate their gender). The only significant difference in the responses between both genders was in their rating of the Non-mandatory experiments and investigations (p= 0.026). 24 (86.0%) of the males rated these as ‘really helpful’ or ‘helpful’, while only 26 (55.0%) of the females had such positive feedback about the non-mandatory activities. This finding suggests that all of the resources and design criteria were equally helpful for both males and females except for the non-mandatory activities which the males found to be more helpful in their study of Organic Chemistry than the females.

Following the Likert scale rating of the resources and criteria used in the programmes, the pupils were also given an open-ended question, where they were asked to indicate their favourite and least favourite aspects of the Organic Chemistry in Action! programme and to justify their choice. Only 63 (72.0%) of the pupils answered to indicate their favourite aspect of the course. The most common answers given by these pupils were the use of the molecular models (18, 29.0%) and the practical work (investigations and experiments) (21, 33.0%). The main reason given by the pupils who chose the molecular models as their favourite aspect of the course was that they were fun to use and enjoyable (5, 28.0%) and that they facilitated their understanding of molecular shapes (13, 72.0%). Various other topics were listed by different pupils, but all other topics were only listed by less than 5 (8.0%) of the pupils.

When asked to indicate their least favourite aspect of the programme, only 49 (56.0%) of the pupils answered this question. The most popular response was the Pupil Workbook. 18 (37.0%) of these pupils mentioned that this was their least favourite aspect of the programme. The main reasons given by these pupils was that the Pupil Workbooks were not helpful (7, 39.0%), too long (6, 33.0%) and that there was too much to learn (3, 17.0%). This finding supports the median values included in Table 8.5 where the median values from the Likert scale indicate how the pupils were ‘indifferent’ about completion of the Pupil Workbook and
the Homework assignments. This suggests that the presentation of the content in the Pupil Workbook may not have been beneficial or favourable in facilitating the pupils’ understanding of Organic Chemistry. It is the researcher’s opinion that if the Pupil Workbooks could have been printed in colour, perhaps, the pupils may have found them more attractive and user-friendly. Although some other responses were given, no other aspect of the course was listed as the least favourite by more than 4 (5.0%) of the pupils.

8.4- Comparison with a Control Group

The effectiveness of the Organic Chemistry in Action! programme was evaluated using three lenses as illustrated in Chapter Four (Figure 4.12): the participating teachers, participating pupils and through comparison with a Control Group. The questionnaire that was distributed to the Control Group had two parts; A and B. The content of this questionnaire was identical to parts A and B of the questionnaire distributed to the pupils that participated in the intervention programme. The details of both parts of the questionnaire have been outlined and explained in Chapter Four (Section 4.7.4). The Control Group: Second-level Pupil Questionnaire (II) and the Organic Chemistry in Action: Second-Level Pupil Questionnaire (II) are both included in Appendix H.

The response rate from the schools that participated in the intervention programme and as part of the Control Group have been outlined in Chapter Five (Tables 5.6 and 5.7 respectively). Part A provided the researcher with information about the pupils in both groups, including their previous Science and Mathematics experience as well as their attitudes to Organic Chemistry in the Leaving Certificate. Part B contained 10 questions in the Test for Understanding, which aimed to assess the pupils’ understanding of different topics in Organic Chemistry.

The findings from Part A of both questionnaires will be presented in Section 8.4.1 which follows. The pupils’ background in Science and Mathematics and their attitudes and interest in Organic Chemistry will be compared. In Section 8.4.2 the performance of both groups of pupils in the Test for Understanding will be compared.
8.4.1. Part A- Science and Mathematics Experiences

8.4.1.1. Science and Mathematics Background

In total six class groups from six different schools participated in the intervention programme and nine class groups from nine different schools participated as part of the Control Group by returning and completing their Pupil Questionnaires (II). To ensure that valid comparisons could be made between the Control Group and the Intervention Group, it was important to firstly investigate the profiles (age, gender and school type) and background (Science and Mathematics) of both these groups.

Table 8.7 provides a summary of the background information of both groups of pupils; Intervention Group and Control Group. The Pearson Chi-Square Test was used to investigate if there were any significant differences between both groups of pupils in relation to their school type, gender and study of Science and Mathematics. The age distribution for both cohorts of pupils was found to be not normal using the Kolmogorov-Smirnov Test (p <0.001). The median age for both groups was 17 years and the interquartile range for both was 1. A column showing the total number of participating pupils (n=204) is included in Table 8.7 also. This column is useful to show how the percentages of the Intervention and Control Groups are fairly representative of the total group of pupils.

As can be seen from the p values included in Table 8.7, the only factor that was significantly different between both groups of pupils was the type of school that they were attending. None of the Intervention Group attended a single-sex boys school, while 15 (12.8%) of the Control Group did. 66 (76.0%) of the Intervention Group were attending co-educational Second-Level schools, while only 56 (47.9%) of the Control Group were. For this reason, it will not be possible to compare both groups of pupils according to their school types.

Although the difference was not found to be significant, it should be noted from the percentages included in Table 8.7 that a greater percentage of the Control Group had studied Higher Level Science and Higher Level Mathematics for their Junior Certificate. A greater percentage of the Control Group were also studying Higher Level Chemistry and Higher Level Mathematics for their Leaving Certificate. In addition, a greater percentage of the pupils in the Control Group were also studying other Science subjects for their Leaving Certificate. All of these factors suggest that pupils in the Control Group have a better Science and Mathematics background to begin with, and many may be of a higher ability overall. If
this trend had favoured the Intervention Group, analysis of the responses between both groups would not have been possible. However, given the observed trend in Table 8.7, a higher percentage of positive attitudes and performance in the Test for Understanding from the Intervention Group may be credited to the *Organic Chemistry in Action!* programme.

157 (76.9%) of the pupils indicated the grade they achieved in Junior Certificate Mathematics, and 112 (54.9%) of indicated the grade they achieved in Junior Certificate Science. Although a greater percentage (<5%) of the Control Group than Intervention Group scored A grades in both their Junior Certificate Science and Mathematics, this difference was not found to be significant for Mathematics ($\chi^2 = 8.162, p = 0.418$) or for Science ($\chi^2 = 3.218, p= 0.781$).

### 8.4.1.2 Attitudes to Leaving Certificate Organic Chemistry

The pupils were asked to indicate their attitudes to Organic Chemistry on a five-point Likert scale. The findings were re-grouped into three categories to facilitate the multivariable analysis between the Intervention Group and the Control Group. ‘Strongly agree’ and ‘agree’ were grouped together while 'disagree’ and ‘strongly disagree’ were grouped together also. The attitudes to Organic Chemistry of both groups are shown in Table 8.8 that follows Table 8.7. The percentage values shown in Table 8.8 indicate that the Intervention Group had a more positive attitude towards Organic Chemistry than the Control Group. A higher percentage of the Intervention Group indicated that Organic Chemistry was enjoyable to learn, easy to understand and interesting. The Pearson Chi-Square Test was used to investigate if this positive attitude of the Intervention Group was significantly different than the Control Group. As indicated by the p values given Table 8.8, the only significant difference was that the Intervention Group found Organic Chemistry more enjoyable to study than the Control Group. This indicates that these pupils enjoyed participating in the *Organic Chemistry in Action!* programme.
<table>
<thead>
<tr>
<th></th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
<th>Total (n=204)</th>
<th>Chi-Square Test statistic ($\chi^2$)</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>School Type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-Educational</td>
<td>66 (76.0%)</td>
<td>56 (47.9%)</td>
<td>122 (59.8%)</td>
<td>21.195</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Single-sex: Boys</td>
<td>0 (0%)</td>
<td>15 (12.8%)</td>
<td>15 (7.4%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-sex: Girls</td>
<td>21 (24.0%)</td>
<td>46 (39.3%)</td>
<td>67 (32.8%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>35 (41.0%)</td>
<td>40 (34.8%)</td>
<td>75 (37.5%)</td>
<td>0.853</td>
<td>P = 0.356</td>
</tr>
<tr>
<td>Female</td>
<td>50 (59.0%)</td>
<td>75 (65.2%)</td>
<td>125 (62.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Junior Certificate Science</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>79 (91.0%)</td>
<td>114 (97.4%)</td>
<td>193 (94.6%)</td>
<td>5.044</td>
<td>P = 0.169</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>6 (7.00%)</td>
<td>2 (1.70%)</td>
<td>8 (3.90%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not studied</td>
<td>1 (1.00%)</td>
<td>0 (0%)</td>
<td>1 (0.50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Junior Certificate Mathematics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>67 (77.0%)</td>
<td>104 (88.9%)</td>
<td>171 (83.8%)</td>
<td>5.917</td>
<td>P = 0.116</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>17 (20.0%)</td>
<td>12 (10.3%)</td>
<td>29 (14.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation Level</td>
<td>1 (1.0%)</td>
<td>1 (0%)</td>
<td>1 (0.50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaving Certificate Chemistry</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>73 (84.0%)</td>
<td>108 (92.3%)</td>
<td>181 (88.7%)</td>
<td>3.519</td>
<td>P = 0.061</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>14 (16.0%)</td>
<td>9 (7.70%)</td>
<td>23 (11.3%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leaving Certificate Mathematics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>49 (56.0%)</td>
<td>78 (66.7%)</td>
<td>127 (62.3%)</td>
<td>3.335</td>
<td>P = 0.189</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>37 (43.0%)</td>
<td>39 (33.3%)</td>
<td>76 (37.3%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation Level</td>
<td>1 (1.00%)</td>
<td>0 (0%)</td>
<td>1 (0.50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other Science subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biology</td>
<td>60 (69.0%)</td>
<td>95 (81.2%)</td>
<td>155 (76.0%)</td>
<td>5.068</td>
<td>P = 0.079</td>
</tr>
<tr>
<td>Physics</td>
<td>30 (34.0%)</td>
<td>28 (24.0%)</td>
<td>58 (28.5%)</td>
<td>2.732</td>
<td>P = 0.255</td>
</tr>
<tr>
<td>Agricultural Science</td>
<td>6 (7.00%)</td>
<td>11 (9.40%)</td>
<td>17 (8.30%)</td>
<td>0.410</td>
<td>P = 0.522</td>
</tr>
<tr>
<td>Physics and Chemistry</td>
<td>1 (1.00%)</td>
<td>2 (1.70%)</td>
<td>3 (1.50%)</td>
<td>0.108</td>
<td>P = 0.742</td>
</tr>
</tbody>
</table>
### Table 8.8 Comparison of attitudes to Organic Chemistry; Intervention Group vs Control Group

<table>
<thead>
<tr>
<th></th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
<th>Chi-Square Test statistic ($\chi^2$)</th>
<th>Level of Significance</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I enjoy studying Organic Chemistry</strong></td>
<td>Strongly Agree and Agree</td>
<td>61 (70.0%)</td>
<td>60 (51.3%)</td>
<td>8.853</td>
<td>P= 0.012</td>
</tr>
<tr>
<td></td>
<td>Indifferent</td>
<td>21 (24.0%)</td>
<td>38 (32.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagree and Strongly</td>
<td>5 (6.00%)</td>
<td>19 (16.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>I find Organic Chemistry is easy to understand</strong></td>
<td>Strongly Agree and Agree</td>
<td>43 (49.0%)</td>
<td>44 (37.6%)</td>
<td>6.567</td>
<td>P= 0.087</td>
</tr>
<tr>
<td></td>
<td>Indifferent</td>
<td>31 (36.0%)</td>
<td>40 (34.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagree and Strongly</td>
<td>13 (15.0%)</td>
<td>33 (28.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Organic Chemistry is one of the most interesting areas of the Chemistry course</strong></td>
<td>Strongly Agree and Agree</td>
<td>57 (66.0%)</td>
<td>60 (51.3%)</td>
<td>8.009</td>
<td>P= 0.156</td>
</tr>
<tr>
<td></td>
<td>Indifferent</td>
<td>22 (25.0%)</td>
<td>33 (28.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagree and Strongly</td>
<td>8 (9.00%)</td>
<td>24 (20.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagree</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The pupils were also asked to indicate how confident they felt in attempting an Organic Chemistry question on the Leaving Certificate examination paper. Although there was no significant difference in the responses given from both groups of pupils ($\chi^2 (2) = 2.610, p= 0.271$), the overall trend observed in Figure 8.5 suggests that the pupils in the Intervention Group felt more confident in attempting Organic Chemistry questions in the Leaving Certificate examination.

![Figure 8.5 Comparison of pupils’ confidence in attempting a Leaving Certificate Organic Chemistry examination question](image)

The pupils in both groups gave many reasons to explain their confidence or lack of confidence in attempting an Organic Chemistry examination question. The most common reasons given by those that were confident in attempting the examination questions was that the Organic Chemistry is ‘easy to understand’ (67, 32.8%) and that the pupils had ‘studied and revised the topic’ sufficiently (22, 10.8%). A higher percentage of the Intervention Group pupils (38.0 %) than Control Group pupils (29.1%) gave the reason that Organic Chemistry was ‘easy to understand’. This difference was not found to be significant ($\chi^2 (1) = 1.780, p= 0.182$). However, there was a significant difference in the percentage of Intervention Group pupils (6.00%) and Control Group pupils (14.5%) that explained their confidence to attempt the examination questions was due to ‘study and revision’ ($\chi^2 (1) = 4.000, p= 0.045$). This difference in the reasons given by both cohorts of pupils suggests that the Intervention Group
pupils may have a better understanding of Organic Chemistry while the Control Group pupils are dependent on learning and study to prepare for the Leaving Certificate examination.

The most common reason given by those that were not confident in attempting the question in the Leaving Certificate examination was simply that Organic Chemistry is difficult (37, 18.2%). A significantly higher percentage of Control Group pupils (23.1%) than Intervention Group pupils (12.0%) gave this reason for their lack of confidence in attempting the Organic Chemistry examination questions ($\chi^2 (1) = 4.509, p= 0.034$). This also suggests that the Control Group found Organic Chemistry more difficult than the pupils that had taken part in the Organic Chemistry in Action! programme.

In this Part A of both questionnaires the Intervention Group and the Control Group of pupils rated a list of Organic Chemistry topics as easy or difficult on a five-point scale. The list of topics was as listed in Table 8.9. On the scale 1= Really Easy, 2= Easy, 3= Indifferent, 4= Difficult and 5= Really Difficult. The ordinal data from this five-point Likert scale was non-parametric in nature. For this reason, the median values are included with the mean values in Table 8.9. The verbal ratings are also included to facilitate the comparison between the ratings between both cohorts of pupils.

The Pearson Chi-Square Test was used for the multivariable analysis of this qualitative data to investigate if the differences between the Intervention Group and Control Group were significant. These test statistics and p values are included in Table 8.9. The symbols used in the previous results chapters (Chapter Six and Seven) are used again to highlight the topics that the Intervention Group rated as significantly easier to learn than the Control Group: Drawing organic compounds, Isomerism, Classification, as well as the following Reaction Types- addition, substitution, elimination and redox.

The results in Table 8.9 indicate that the Intervention Group perceived more topics as easier to learn and understand than the Control Group. The median and mean ratings from the Likert scale are included. The mean ratings of topics by the Control Group are representative of the ratings given by the pupils (n=276) in the Second-Level Study that was carried out in Cycle One of this research project (Table 6.3 in Chapter Six) where Organic Reactions and Mechanisms were rated as difficult to understand. Mean values greater than 3 here indicate that the topics are perceived as difficult or really difficult by the pupils in the Control Group. Few of the mean ratings of the Intervention Group were greater than 3.
### Table 8.9 Comparison of Likert rating of Organic Chemistry topics: Intervention Group vs Control Group

<table>
<thead>
<tr>
<th>Topic</th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
<th>Chi-Square Test statistic ($\chi^2$)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drawing Organic Compounds.</strong></td>
<td>Median 1.65 Easy</td>
<td>Median 2.04 Easy</td>
<td>6.413</td>
<td>P= 0.041</td>
</tr>
<tr>
<td><strong>Naming Organic Compounds.</strong></td>
<td>Median 1.97 Easy</td>
<td>Median 2.18 Easy</td>
<td>2.386</td>
<td>P= 0.303</td>
</tr>
<tr>
<td><strong>Isomerism.</strong></td>
<td>Median 2.09 Easy</td>
<td>Median 3.04 Indifferent</td>
<td>20.163</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td><strong>Classification (functional groups)</strong></td>
<td>Median 2.24 Easy</td>
<td>Median 2.52 Easy</td>
<td>11.995</td>
<td>P= 0.007</td>
</tr>
<tr>
<td><strong>Alkanes</strong></td>
<td>Median 1.74 Easy</td>
<td>Median 1.78 Easy</td>
<td>6.000</td>
<td>P= 0.112</td>
</tr>
<tr>
<td><strong>Alcohols</strong></td>
<td>Median 1.90 Easy</td>
<td>Median 1.95 Easy</td>
<td>5.609</td>
<td>P= 0.061</td>
</tr>
<tr>
<td><strong>Alkenes</strong></td>
<td>Median 1.85 Easy</td>
<td>Median 1.85 Easy</td>
<td>2.583</td>
<td>P= 0.275</td>
</tr>
<tr>
<td><strong>Alkynes</strong></td>
<td>Median 1.93 Easy</td>
<td>Median 1.89 Easy</td>
<td>1.805</td>
<td>P= 0.405</td>
</tr>
<tr>
<td><strong>Aldehydes</strong></td>
<td>Median 2.44 Easy</td>
<td>Median 2.45 Easy</td>
<td>0.345</td>
<td>P= 0.842</td>
</tr>
<tr>
<td><strong>Ketones</strong></td>
<td>Median 2.75 Indifferent</td>
<td>Median 2.84 Indifferent</td>
<td>2.620</td>
<td>P= 0.270</td>
</tr>
<tr>
<td><strong>Carboxylic acids</strong></td>
<td>Median 2.72 Easy</td>
<td>Median 2.80 Indifferent</td>
<td>6.286</td>
<td>P= 0.043</td>
</tr>
<tr>
<td><strong>Esters</strong></td>
<td>Median 3.02 Indifferent</td>
<td>Median 3.09 Indifferent</td>
<td>2.518</td>
<td>P= 0.284</td>
</tr>
<tr>
<td><strong>Aliphatic compounds.</strong></td>
<td>Median 2.67 Easy</td>
<td>Median 2.62 Indifferent</td>
<td>1.657</td>
<td>P= 0.437</td>
</tr>
<tr>
<td><strong>Aromatic compounds.</strong></td>
<td>Median 2.83 Easy</td>
<td>Median 2.74 Easy</td>
<td>2.528</td>
<td>P= 0.470</td>
</tr>
<tr>
<td><strong>Organic Chemical Reactions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Addition</td>
<td>Median 2.61 Easy</td>
<td>Median 3.04 Indifferent</td>
<td>15.237</td>
<td>P&lt; 0.001</td>
</tr>
<tr>
<td>- Substitution</td>
<td>Median 2.30 Easy</td>
<td>Median 2.86 Indifferent</td>
<td>14.774</td>
<td>P= 0.001</td>
</tr>
<tr>
<td>- Elimination</td>
<td>Median 2.40 Easy</td>
<td>Median 2.89 Indifferent</td>
<td>11.692</td>
<td>P= 0.003</td>
</tr>
<tr>
<td>- Redox</td>
<td>Median 2.74 Indifferent</td>
<td>Median 3.19 Indifferent</td>
<td>10.489</td>
<td>P= 0.005</td>
</tr>
<tr>
<td>- Reaction as acids</td>
<td>Median 3.15 Indifferent</td>
<td>Median 3.23 Indifferent</td>
<td>1.659</td>
<td>P= 0.436</td>
</tr>
<tr>
<td><strong>Organic Synthesis</strong></td>
<td>Median 3.24 Indifferent</td>
<td>Median 3.54 Indifferent</td>
<td>3.966</td>
<td>P= 0.138</td>
</tr>
<tr>
<td><strong>Organic Reaction Mechanisms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ionic addition</td>
<td>Median 2.77 Indifferent</td>
<td>Median 3.04 Indifferent</td>
<td>2.989</td>
<td>P= 0.224</td>
</tr>
<tr>
<td>- Free Radical Substitution</td>
<td>Median 3.20 Indifferent</td>
<td>Median 3.04 Indifferent</td>
<td>5.703</td>
<td>P= 0.058</td>
</tr>
<tr>
<td><strong>Organic Natural Products</strong></td>
<td>Median 3.20 Indifferent</td>
<td>Median 3.15 Indifferent</td>
<td>1.916</td>
<td>P= 0.384</td>
</tr>
<tr>
<td><strong>Chromatography</strong></td>
<td>Median 2.43 Easy</td>
<td>Median 3.15 Indifferent</td>
<td>0.721</td>
<td>P= 0.697</td>
</tr>
<tr>
<td><strong>Instrumentation in Organic Chemistry.</strong></td>
<td>Median 3.01 Indifferent</td>
<td>Median 3.38 Indifferent</td>
<td>0.378</td>
<td>P= 0.828</td>
</tr>
<tr>
<td><strong>Laboratory work.</strong></td>
<td>Median 2.26 Easy</td>
<td>Median 2.44 Easy</td>
<td>1.781</td>
<td>P= 0.411</td>
</tr>
</tbody>
</table>
At the end of part A, the pupils were asked to list the top five topics that they have most difficulty understanding in Organic Chemistry. The topics that were listed by more than 10.0% of the total cohort (n=204) are listed in Figure 8.6. Other topics that were listed were only mentioned by a few of the pupils in both cohorts.

From Figure 8.6, it can be seen that the difficult topics listed by both cohorts follow a similar trend with Mechanisms, Reactions and Functional Groups listed as difficult by the greatest percentage of pupils in both groups. This trend was also observed in the findings of the Second-Level Study in Cycle One (Figure 6.4). Eight topics are listed in Figure 8.6. The hashed blue bars represent the cases where a greater percentage of the Intervention Group listed the particular topic as difficult than in the Control Group. In the other four cases, a greater percentage of pupils in the Control Group listed the topics as difficult.

Contrary to previous findings presented in this Section, and although the pupils in the Intervention Group displayed a more positive attitude toward Organic Chemistry, there are still some topics that they find difficult to understand. These results also suggest that the intervention programme was effective in facilitating the pupils’ understanding of the topics that were perceived as difficult in Cycle One: Mechanism, Reactions, Synthesis and Practical work.

![Figure 8.6 Comparison of topics listed as most difficult by the Intervention Group and Control Group](image-url)
8.4.2. Part B – Test for Understanding

As explained already, Part B in the questionnaires given to the Intervention Group and the Control Group were identical. This part contained a Test for Understanding of Organic Chemistry. The test was made up 10 questions, each assessing a different topic. Question Ten was taken directly from a previous Leaving Certificate examination question.

The overall performance of both groups of pupils will be compared in Section 8.4.2.1. Section 8.4.2.2 will look at the types of pupils that the *Organic Chemistry in Action!* programme had a significant effect on. Following this overview, Section 8.4.2.3 will take a brief look at the responses (correct and incorrect) given by the pupils in the Intervention Group and Control Group to each of the questions in the Test for Understanding.

8.4.2.1. Effect of the *Organic Chemistry in Action!* programme on Pupils’ Understanding in Organic Chemistry

The complete Test for Understanding that was included in Part B of the pupil questionnaires is included in Appendix H. The questions and content of the test have already been outlined in Chapter Four (Section 4.7.4).

The distributions of the overall percentage scores of both groups of pupils in the Test for Understanding were not normal using the Kolmogorov-Smirnov Test. For this reason, the test scores will be described here using the median percentage scores. The Mann-Whitney U Test was used to investigate if the difference in overall performance of the Intervention Group (median percentage score= 49%, IQR=41.50) and the Control Group (median percentage score= 44.75%, IQR=35.00) was significant. However, this difference was not found to be significant (U statistic= 4589.500, p=0.231).

The performance of both groups of pupils is compared in Table 8.10 and Figure 8.7 which follows. The median score for each question is given. The topics that were answered best and worst by both groups of pupils are highlighted (in green and red) in Table 8.10. The distribution of scores in the individual questions for both groups was not normal. For this reason, the Mann-Whitney U Test was used to investigate the significance of the difference in performance per question of both groups of pupils. The results of this test are shown in Table 8.10.
### Table 8.10 Comparison of Test performance per question: Intervention Group vs Control Group

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
<th>Mann-Whitney U Test Statistic</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drawing Organic Compounds</td>
<td>Median score: 7.0 Mean score: 6.86</td>
<td>Median score: 8.5 Mean score: 7.85</td>
<td>3952.000</td>
<td>P= 0.005 ✓ ✓</td>
</tr>
<tr>
<td>2</td>
<td>IUPAC Nomenclature</td>
<td>Median score: 5.0 Mean score: 4.99</td>
<td>Median score: 5.0 Mean score: 4.90</td>
<td>4958.500</td>
<td>P= 0.752 ✗</td>
</tr>
<tr>
<td>3</td>
<td>Isomerism</td>
<td>Median score: 8.0 Mean score: 6.14</td>
<td>Median score: 6.0 Mean score: 4.89</td>
<td>4233.000</td>
<td>P= 0.034 ✓</td>
</tr>
<tr>
<td>4</td>
<td>Electron Density and Electrophilic attack</td>
<td>Median score: 4.0 Mean score: 3.72</td>
<td>Median score: 3.5 Mean score: 3.29</td>
<td>4641.500</td>
<td>P=0.281 ✗</td>
</tr>
<tr>
<td>5</td>
<td>Organic synthesis</td>
<td>Median score: 4.0 Mean score: 3.90</td>
<td>Median score: 4.0 Mean score: 4.0</td>
<td>4978.000</td>
<td>P= 0.787 ✗</td>
</tr>
<tr>
<td>6</td>
<td>Organic mechanism</td>
<td>Median score: 2.0 Mean score: 2.52</td>
<td>Median score: 00.0 Mean score: 2.02</td>
<td>4759.500</td>
<td>P= 0.395 ✗</td>
</tr>
<tr>
<td>7</td>
<td>Classification (according to Functional Groups)</td>
<td>Median score: 7.0 Mean score: 6.45</td>
<td>Median score: 5.5 Mean score: 5.42</td>
<td>3997.000</td>
<td>P= 0.008 ✓ ✓</td>
</tr>
<tr>
<td>8</td>
<td>Properties of organic compounds</td>
<td>Median score: 4.0 Mean score: 4.43</td>
<td>Median score: 4.0 Mean score: 5.02</td>
<td>4554.000</td>
<td>P= 0.189 ✗</td>
</tr>
<tr>
<td>9</td>
<td>Shape and structure</td>
<td>Median score: 5.0 Mean score: 4.51</td>
<td>Median score: 2.75 Mean score: 3.10</td>
<td>3691.500</td>
<td>P= 0.001 ✓ ✓</td>
</tr>
<tr>
<td>10</td>
<td>Leaving Certificate Examination Question</td>
<td>Median score: 7.0 Mean score: 5.92</td>
<td>Median score: 6.0 Mean score: 5.40</td>
<td>4671.000</td>
<td>P= 0.312 ✗</td>
</tr>
</tbody>
</table>
From Table 8.10 and Figure 8.7, the trend of performance in the Test for Understanding can be observed. Pupils in the Intervention Group performed better than the pupils in the Control Group in all questions except Question One which assessed Drawing of organic compounds. This is highlighted in Figure 8.7 with the hashed bar. This was the best answered question by the Control Group. The results of the Mann-Whitney U Test presented in Table 8.10 show that the Control Group performed significantly better than the Intervention Group in Question One. However, the Intervention Group performed significantly better than the Control Group in Questions Three, Seven and Nine.

Both groups of pupils had the same median score in Questions Two, Five and Eight. Although the Intervention Group did perform better than the Control Group in Question Six assessing Organic Mechanism, this was still the poorest answered question by both groups of pupils. This corresponds with previous evidence in Cycle One of this project where Organic Mechanisms was identified as one of the most difficult topics in Leaving Certificate Organic Chemistry.
The trend observed in Table 8.7 (discussed in Section 8.4.1.1) suggested that the Control Group had a stronger Science and Mathematics background than the Intervention Group. Given that the Intervention Group out-performed the Control Group in nine of the ten test questions, this supports the success and effectiveness of the *Organic Chemistry in Action!* programme in facilitating the pupils’ understanding of Organic Chemistry.

Question Ten in the Test for Understanding was part of a question taken directly from the 2003 Higher Level Leaving Certificate Chemistry examination paper. The Intervention Group also out-performed the Control Group in this question and this suggests that the *Organic Chemistry in Action!* programme was effective in preparing the pupils for the terminal assessment of the current Leaving Certificate syllabus.

The percentages included in Table 8.11 show that most questions in the Test for Understanding were attempted by a high percentage of pupils from both cohorts. The only question that was significantly more popular with the Intervention Group was Question Three ($\chi^2 (1) = 5.421$, $p= 0.020$). A greater percentage of the Control Group attempted Questions Four, Five Six and Seven, but this difference was not found to be significant. Question Six was the least popular question amongst both cohorts. This is not surprising as it was also the poorest answered question by both cohorts (Table 8.10).

<table>
<thead>
<tr>
<th>Question</th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Attempt Order</td>
<td>Attempt Order</td>
</tr>
<tr>
<td>1</td>
<td>87 (100%)</td>
<td>117 (100%)</td>
</tr>
<tr>
<td>2</td>
<td>87 (100%)</td>
<td>115 (98.3%)</td>
</tr>
<tr>
<td>3</td>
<td>75 (86.0%) 12 (14.0%)</td>
<td>85 (72.6%) 32 (27.4%)</td>
</tr>
<tr>
<td>4</td>
<td>80 (92.0%) 7 (8.00%)</td>
<td>111 (94.9%)</td>
</tr>
<tr>
<td>5</td>
<td>69 (79.0%) 18 (21.0%)</td>
<td>101 (86.3%) 16 (13.7%)</td>
</tr>
<tr>
<td>6</td>
<td>53 (60.0%) 35 (40.0%)</td>
<td>85 (72.6%) 32 (27.4%)</td>
</tr>
<tr>
<td>7</td>
<td>80 (92.0%) 7 (8.00%)</td>
<td>110 (94.0%)</td>
</tr>
<tr>
<td>8</td>
<td>83 (95.0%) 4 (5.00%)</td>
<td>110 (94.0%)</td>
</tr>
<tr>
<td>9</td>
<td>77 (88.0%) 10 (12.0%)</td>
<td>102 (87.2%)</td>
</tr>
<tr>
<td>10</td>
<td>77 (88.0%) 10 (12.0%)</td>
<td>103 (88.0%)</td>
</tr>
</tbody>
</table>
8.4.2.2. On whom did the *Organic Chemistry in Action!* programme have the Biggest Effect?

The purpose of this Test for Understanding was to assess if the *Organic Chemistry in Action!* programme had an effect on pupils’ understanding of Organic Chemistry. Before looking at the responses given to the individual questions (Section 8.4.2.3), this Section will review the effect of the intervention programme on pupils, through an investigation of a number of factors.

As explained already, six class groups from six different schools participated in the evaluation of the intervention programme, and nine class groups from nine different schools participated in the Control Group. Table 8.12 looks at the variance between the class groups within both of these cohorts of pupils. Given that each of these 15 class groups were taught by different teachers in different schools, it is not surprising that there is a significant difference between the results of the Test for Understanding for each school in the Intervention Group and Control Group.

<table>
<thead>
<tr>
<th>School ID (n)</th>
<th>Median Test score (%)</th>
<th>Kruskal-Wallis Test Statistic</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intervention class groups</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (8)</td>
<td>64.3%</td>
<td>H(5)= 18.524</td>
<td>P= 0.002</td>
</tr>
<tr>
<td>B (7)</td>
<td><strong>25.8%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (21)</td>
<td>42.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D (19)</td>
<td>54.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E (13)</td>
<td><strong>75.0%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G (19)</td>
<td>45.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Control class groups</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J (7)</td>
<td>67.5%</td>
<td>H (8)= 27.433</td>
<td>P=0.001</td>
</tr>
<tr>
<td>K (8)</td>
<td><strong>28.6%</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L (14)</td>
<td>33.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N (12)</td>
<td>52.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O (15)</td>
<td>42.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P (15)</td>
<td>58.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R (19)</td>
<td>34.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q (9)</td>
<td>53.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S (18)</td>
<td>56.9%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It has already been shown that the Intervention Group as a whole (n=87) performed better in the Test for Understanding than the Control Group. However, as indicated by the Kruskal-Wallis Test results, there was a significant difference in the pupils’ performance between the class groups within both of the cohorts of pupils (Intervention Group and Control Group).
Further investigations between each of the six schools involved in the intervention programme using the Mann-Whitney U Test found that the pupils in School E performed significantly better than the pupils in School A (U=18.000, p= 0.014), School B (U= 16.000, p= 0.019), School C (U=47.000, p= 0.001), School D (U=59.000, p=0.013) and School G (U= 33.000, p<0.001). This suggests that the high performance of School E may be attributed to the class teacher in School E as well as the Organic Chemistry in Action! programme.

It is interesting to note that the highest overall score per class group was achieved by a school within the Intervention Group (School E); however, the lowest overall score was also achieved by one of the schools in the Intervention Group (School B). This observation suggests that an increased number of class groups taking part in the intervention programme and as controls would limit the effect of the differences between class groups within each cohort (Intervention and Control).

Table 8.13 which follows compares the median percentage test scores of the Intervention Group and Control Group with respect to gender, level of Junior Certificate Science and Mathematics and level of Leaving Certificate Chemistry and Mathematics.

The results relating to gender will be discussed here to explain the meaning of the rest of the results in Table 8.13. The males in the Control Group (median score = 42.9%) performed better in the Test for Understanding than the males in the Intervention Group (median score = 38.8%). However, this difference was not significant (U=650.000, p= 0.595). In comparison the females in the Intervention Group (median score = 63.4%) performed better than the females in the Control Group (median score= 45.3%) and this difference was significant (U=1330.500, p= 0.006).

From Table 8.13 it can be seen that the Organic Chemistry in Action! programme did not seem to have a positive effect on the test performance of males, for all those who had studied Ordinary Level Junior Certificate Mathematics and for all pupils that were studying Ordinary Level Chemistry for the Leaving Certificate. However, the programme did have a positive effect on all other groups listed in Table 8.13. The effect of the Organic Chemistry in Action! programme was found to be significantly positive for females, and for all those that had studied Higher Level Junior Certificate Mathematics as well as all those studying Higher Level Leaving Certificate Chemistry.
<table>
<thead>
<tr>
<th></th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
<th>Mann-Whitney U Test Statistic</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>38.8%</td>
<td>42.9%</td>
<td>650.000</td>
<td>P= 0.595</td>
</tr>
<tr>
<td>Female</td>
<td>63.4%</td>
<td>45.3%</td>
<td>1330.000</td>
<td>P= 0.006</td>
</tr>
<tr>
<td><strong>Junior Certificate Science</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>50.5%</td>
<td>45.0%</td>
<td>3982.000</td>
<td>P= 0.172</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>26.5%</td>
<td>25.8%</td>
<td>5.000</td>
<td>P= 0.739</td>
</tr>
<tr>
<td><strong>Junior Certificate Mathematics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>54.3%</td>
<td>47.1%</td>
<td>2831.000</td>
<td>P= 0.039</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>20.3%</td>
<td>25.3%</td>
<td>86.000</td>
<td>P= 0.479</td>
</tr>
<tr>
<td><strong>Leaving Certificate Chemistry</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>58.8%</td>
<td>46.3%</td>
<td>3.84.000</td>
<td>P= 0.013</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>15.3%</td>
<td>15.3%</td>
<td>57.000</td>
<td>P= 0.705</td>
</tr>
<tr>
<td><strong>Leaving Certificate Mathematics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Level</td>
<td>65.0%</td>
<td>53.8%</td>
<td>1606.000</td>
<td>P= 0.131</td>
</tr>
<tr>
<td>Ordinary Level</td>
<td>42.3%</td>
<td>27.8%</td>
<td>579.500</td>
<td>P= 0.140</td>
</tr>
</tbody>
</table>
8.4.2.3. Comparison of Pupil Responses in the Organic Chemistry Test for Understanding

Section 8.4.2.1 provided an overview of the pupils’ performance in the Organic Chemistry Test for Understanding; overall median scores, questions attempted, mark order etc. (Table 8.10 and Figure 8.7). This Section will now take a closer look at and compare the different responses given by pupils in the Intervention Group and the Control Group in an attempt to better understand the different trends in the performance on both groups. In comparison to the presentation of results of the Diagnostic Tests used in the Second-Level study (Section 6.2.3 of Chapter Six) and Third-Level study (Section 7.2.3 of Chapter Seven); the pupils’ responses to each part of each question are not graphed here. Instead, the researcher has chosen to focus on the implicit differences between the Intervention Group and the Control Group since that was the primary focus of this Test for Understanding.

Question One- Drawing organic compounds

In this question the Control Group (median score= 8.5) performed significantly better than the Intervention Group (median score= 7.0). The Control Group had a higher percentage of correct responses in drawing each of the seven compounds given to be drawn. Common mistakes made by more of the Intervention Group than the Control Group in drawing the condensed structure of pentane were drawing too few carbons (9, 10.0%) or giving the molecular formula instead (15, 17.0%). The most common mistake made by the Intervention Group drawing the extended structure of pentane was again drawing too few carbons (10, 11.0%). The most common mistake made by both groups in drawing the extended structure of hex-2-ene was the omission of the double bond. More of the Intervention Group (24, 28.0%) than Control Group (24, 20.5%) drew an incorrect functional group for ethanal. 13 (15.0%) of the Intervention Group incorrectly drew the alcohol functional group. Again, the most common mistake made by the Intervention Group in drawing the extended structure of methyl ethanoate was with the functional group (35, 40.0%).

The responses from the Intervention Group in this question suggests that the Organic Chemistry in Action! programme may not have been as effective as intended in facilitating the pupils’ understanding and ability to differentiate between the different functional groups: alcohol, aldehydes and esters. It is the researcher’s belief that
perhaps the emphasis placed on the use of the three-dimensional models in most of the lessons in the *Organic Chemistry in Action!* programme may have limited the pupils’ opportunity to practice drawing the two-dimensional representations of the organic compounds. In contrast, it is assumed that the pupils in the Control Group may not have had such an exposure to three-dimensional modelling and so had greater experience in drawing two-dimensional structures.

**Question Two- IUPAC Nomenclature**

There was no difference in the median scores of both groups of pupils in this question. Both groups had a median score of 5.0. During the correction of the test scripts, the researcher recorded the number of pupils in both groups that drew the extended structures of the compounds given to be named. A significantly higher percentage (p=0.003) of the Intervention Group (24, 27.0%) drew all or some of these correctly in comparison to the Control Group (22, 18.8%). It was expected that drawing out the extended structures would facilitate the pupils’ naming of the compounds. A greater percentage of the Intervention Group (58, 67.0%) named cyclohexane correctly than the Control Group (59, 50.4%). The most common mistake made by 36 (30.8%) of the Control Group was naming this compound incorrectly as benzene. This suggests that the Intervention Group may have better understood the difference between aliphatic and aromatic cyclic compounds.

Two of the compounds; butanal and 2-methylpropan-2-ol were given in both their condensed and extended structures to be named. While the same number of pupils in the Control Group (67, 57.3%) named butanal correctly when given in both structural representations, more of the Intervention Group named butanal correctly from its condensed structural formula (52, 60.0%) than from its extended formula (42, 48.3%). A greater percentage of the Control Group (12, 10.3%) than the Intervention Group (4, 5.0%) named 2-methylpropan-2-ol correctly when in the condensed formula but more of the Intervention Group (32, 37%) than Control Group (36, 30.8%) named the same compound correctly when shown in its extended structural formula.

Due to the inconsistency in the trends observed in the pupil’s attempts to name compounds given in different representations it is not possible to conclude from these
findings which type of structural representation facilitates the pupils’ naming of compounds.

**Question Three- Structural Isomers**

The Intervention Group (median score = 8.0) performed significantly better than the Control Group (median score= 6.0) in this question (p= 0.034). A higher percentage of the Intervention Group than Control Group correctly identified the structural isomers of each of the compounds listed. The same isomer was identified by the lowest percentage of pupils in both groups; only 40 (46.0%) of the Intervention Group and 44 (37.6%) of the Control Group recognised compound E (2,2-dimethylpropane) as an isomer of compound A (2-methylbutane).

**Question Four- Electron Density and Electrophilic attack**

The Intervention Group (median score= 4.0) performed better than the Control Group (median score= 3.5) in this question.

Less pupils in the Control Group (56, 47.9%) than the Intervention Group (56, 64.0%) named the chlorine free radical correctly. The most common incorrect answer given by the Control Group was naming it as ‘chlorine’ (25, 21.4%). Similarly in part (b) of Question Four a lower percentage of the Control Group (36, 30.8%) than the Intervention Group (40, 46.0%) named the bromine cation correctly. Again, the most common incorrect answer given by the Control Group (43, 36.8%) was ‘bromine’.

In part (a), the pupils were asked to indicate with arrows how the chlorine radical and methane would react. This part of the question was poorly answered by both groups of pupils. However, the Intervention Group (14, 16.1%) did have a higher percentage of correct answers than the Control Group (7, 6.0%). The most common mistake made by the Intervention Group (14, 16.0%) and the Control Group (37, 31.6%) in mapping this electron movement was the use of a double-headed arrow from the radical instead of a single-headed arrow. Both groups gave a poor explanation for their arrows drawn.

In part (b) of the question, the pupils were also asked to indicate how the bromine cation and ethene would react. Only 8 (9.0%) of the Intervention Group and 8 (7.0%) of the Control Group drew the arrow correctly. The most common mistake made by the Intervention Group (9, 10.0%) and the Control Group (30, 25.6%) in this case was
drawing a double-headed arrow coming from the bromine cation towards the ethene. It is clear that these pupils did not understand that the meaning of the double-headed arrow to represent transfer of two electrons. Given that these mistake were more common in the Control Group, this suggests that the *Organic Chemistry in Action!* programme may have been effective to some extent in facilitating the pupils’ understanding and use of arrows to show electron movement.

**Question Five- Synthesis of ethanal from ethene**

Both groups of pupils had the same median score (5.0) for this question. The pupils’ responses (correct and incorrect) were very similar for this question, with the Intervention Group performing slightly better than the Control Group in most parts. However, in naming a suitable reactant for the oxidation of ethanol to ethanal, a higher percentage of the Control Group (40, 34.2%) than the Intervention Group (24, 27.0%) answered this correctly. Despite the inclusion of potassium permanganate as an alternative oxidising agent in the *Organic Chemistry in Action!* programme, only 3 (3.0%) of the Intervention Group pupils mentioned this oxidising agent as a suitable reactant here. This suggests that the teachers may not have carried out the mandatory experiments using this alternative method.

It should be noted that in correcting this question, a high percentage of pupils in the Intervention Group (15, 17.0%) and the Control Group (19, 16.2%) classified the reaction of ethanol to ethanal as ‘elimination’. Since two hydrogen atoms are eliminated from the ethanol, this was accepted as a correct response in this case.

**Question Six-Mechanism of a reaction**

This was the most poorly answered question by the Intervention Group (median score = 2.0) and the Control Group (median score= 0.0). This question assessed the ionic addition mechanism of HCl to ethene. Only four pupils in total, one from the Intervention Group and three from the Control Group gave the complete mechanism (four steps) for the reaction correctly. Although more of the Control Group answered this question correctly, when the marks awarded for each part of the question are compared (Table 8.14), the Intervention Group performed better than the Control Group.
Table 8.14 summarises the correct and partially correct attempts made by the pupils in both groups in answering Question Six. Since this was the poorest answered question in the Test for Understanding and also the least popular, the researcher felt the need to include the responses of the pupils from both groups in this question.

The total percentage of partially correct responses given by the Intervention Group (30, 35.0%) was significantly higher than the partially correct responses given by the Control Group (24, 20.5%); (p= 0.024). Although the performance of the Intervention Group was poor, the percentage values shown in Table 8.14 indicate that their level of attempt and performance was still better than the Control Group. In Table 8.14, a trend can be observed where the Intervention Group have a higher percentage of completely correct responses and partially correct responses than the Control Group.

Table 8.14 Comparison of pupils’ attempts to write the reaction mechanism: Intervention Group vs Control Group

<table>
<thead>
<tr>
<th></th>
<th>Intervention Group (n=87)</th>
<th>Control Group (n=117)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polarisation</td>
<td>Completely correct</td>
<td>9 (10.0%)</td>
</tr>
<tr>
<td></td>
<td>Step shown without</td>
<td>16 (18.4%)</td>
</tr>
<tr>
<td></td>
<td>arrows</td>
<td>11 (9.4%)</td>
</tr>
<tr>
<td></td>
<td>Step shown with</td>
<td>1 (1.0%)</td>
</tr>
<tr>
<td></td>
<td>incorrect arrows</td>
<td>2 (1.7%)</td>
</tr>
<tr>
<td>Step 2:</td>
<td>Completely correct</td>
<td>9 (10.0%)</td>
</tr>
<tr>
<td>Heterolytic Fission</td>
<td>Step shown without arrows</td>
<td>16 (18.4%)</td>
</tr>
<tr>
<td></td>
<td>Step shown with</td>
<td>2 (2.3%)</td>
</tr>
<tr>
<td></td>
<td>incorrect arrows</td>
<td>3 (2.6%)</td>
</tr>
<tr>
<td>Step 3:</td>
<td>Completely correct</td>
<td>12 (13.8%)</td>
</tr>
<tr>
<td>Formation of the carbocation</td>
<td>Step shown without arrows</td>
<td>8 (9.2%)</td>
</tr>
<tr>
<td></td>
<td>Step shown with</td>
<td>5 (6.0%)</td>
</tr>
<tr>
<td></td>
<td>incorrect arrows</td>
<td>8 (7.7%)</td>
</tr>
<tr>
<td>Step 4:</td>
<td>Completely correct</td>
<td>11 (13.0%)</td>
</tr>
<tr>
<td>Attack on the carbocation</td>
<td>Step shown without arrows</td>
<td>11 (13.0%)</td>
</tr>
<tr>
<td></td>
<td>Step shown with</td>
<td>5 (6.0%)</td>
</tr>
<tr>
<td></td>
<td>incorrect arrows</td>
<td>3 (2.6%)</td>
</tr>
</tbody>
</table>

Question Seven- Classification of organic compounds:

The Intervention Group (median score = 7.0) performed better than the Control Group (median score = 5.5) in Question Seven. This difference between both cohorts was
significant (p= 0.008). A higher percentage of pupils in the Intervention Group correctly classified the structures into each of the families listed.

The most common mistake made by the Control Group (11, 9.4%) was incorrectly classifying compound F (propanone) as an aldehyde. Only one of the pupils in the Intervention Group made this same mistake. This suggests that the pupils who had participated in the *Organic Chemistry in Action!* programme were better able to distinguish between aldehydes and ketones. However, pupils in both the Intervention Group (9, 10.0%) and the Control Group (11, 9.4%) incorrectly classified the ester, ethyl ethanoate as a carboxylic acid. This suggests that the intervention programme may not have been as effective in facilitating the pupils’ understanding of the difference between these families of compounds.

**Question Eight- Properties of organic compounds**

There was no difference in the median score (4.0) of the pupils in both groups for this question. A higher percentage of pupils in both groups were able to identify that methanol had a higher boiling point than methane than were able to identify that it also was more soluble in water than methane.

**Question Nine- Shape and Structure**

The Intervention Group (median score =5.0) performed better than the Control Group (median score = 2.75) in this question. This difference between both groups was highly significant (p= 0.001).

Propanol was accepted as a correct answer in naming the first compound in Question Nine. Only 9 (10.0%) of the Intervention Group and fewer (6, 5.1%) of the Control Group used the correct IUPAC nomenclature in this question to name the alcohol propan-1-ol. A higher percentage of the Intervention Group (49, 56.0%) than Control Group (23, 19.7%) recognised that the H-C-H bond angle in propan-1-ol was 109.5°. A greater percentage of the Control Group (47, 40.2%) than Intervention Group (8, 9.0%) gave the incorrect answer of 90° for this part of the question. A similar significant trend (p< 0.001) was observed again where a high percentage of the Control Group (43, 36.8%) incorrectly labelled the H-C-H bond angle of propene as
90° and while the majority of the Intervention Group (46, 52.9%) correctly recognised that the bond angle was 109.5°.

In answering the bond angle correctly more of the Intervention Group pupils were also able to name the molecular shape of the bonds correctly. The better response by the Intervention Group in this case may be credited to their use of the molecular models in the *Organic Chemistry in Action!* programme.

**Question Ten- Leaving Certificate Examination Question**

Both groups of pupils performed well in this question. Although there was no significant difference in the overall scores achieved by both groups in this question, the Intervention Group (median score = 7.0) performed better than the Control Group (median score= 6.0). This question was included to assess the effectiveness of the *Organic Chemistry in Action!* programme in preparing the pupils to answer a Leaving Certificate examination question. This question was taken from the 2003 Higher Level examination paper and the marking scheme provided by the State Examinations Commission for that paper was used to mark the question (SEC 2003). A higher percentage of the Intervention Group correctly answered each part of the examination question. This trend suggests that the *Organic Chemistry in Action!* programme was effective in preparing the pupils for the Leaving Certificate examination.
CHAPTER EIGHT                                    CYCLE TWO: RESULTS (III)-ORGANIC CHEMISTRY IN
ACTION!

8.5 Summary of results from the Organic Chemistry in Action! intervention programme evaluation

As explained three main lenses were used to evaluate the effectiveness of the Organic Chemistry in Action! programme: the participating teacher, the participating pupils and comparison with a Control Group. The findings from each of these evaluations have been presented in Sections 8.2, 8.3 and 8.4 of this Chapter respectively. Figure 8.8 summarises the feedback sourced from the teachers using different research methods. The findings from each research method has been outlined individually above in Sections 8.2.1 (Classroom Observations), 8.2.2 (Teacher Diaries), 8.2.3 (Chemistry Teacher Review Questionnaire) and 8.2.4 (Chemistry Teacher Interviews).

Figure 8.8 Summary of feedback from participating teachers in the Organic Chemistry in Action! programme.
Figure 8.9 summarises the feedback from the pupils that participated in the Organic Chemistry in Action! programme. This feedback was sourced from Classroom Observations (Section 8.3.1), a Focus Group (Section 8.3.2) and Part C of the Pupil Questionnaire (II) (Section 8.3.3).

From comparison with a Control Group (n=117), the following conclusions can be made about the effect of the Organic Chemistry in Action! programme:

- Pupils involved in the intervention programme found Organic Chemistry significantly more enjoyable to learn than pupils that were taught in the traditional manner.
- The pupils in the Intervention Group rated the following topics as significantly easier to learn than the Control Group: Drawing organic compounds, Isomerism, Classification, Addition reaction, Substitution reactions, Elimination reactions, Redox reactions and Carboxylic acids.
- Pupils that had completed the Organic Chemistry in Action! programme felt more confident in attempting the questions assessing Organic Chemistry in the Leaving Certificate examination. These pupils also performed better than pupils in the Control Group on the Leaving Certificate examination question in the Test for Understanding.
- Despite having a poorer initial background in Science and Mathematics, pupils in the Intervention Group had a higher median percentage score in all topics.
assessed in the Test for Understanding, except for Drawing organic compounds, where the Control Group performed significantly better than the Intervention Group.

- The pupils in the Intervention Group performed significantly better than the Control Group on questions assessing Isomerism, Classification, Shape and Structure.
- The *Organic Chemistry in Action!* programme had a significant effect on the performance of those who had studied Higher Level Junior Certificate Mathematics, those that were studying Higher Level Leaving Certificate Chemistry and females in the Test for Understanding.

These findings will be discussed together with reference to the research questions for Cycle Two of the project in Chapter Nine that follows.
Chapter 9
Discussion of Findings
CHAPTER NINE         DISCUSSION OF FINDINGS

9.1 – Introduction
The research questions for each cycle of this research project were outlined in Chapter One (Section 1.3).

The research questions (RQ) that guided the first cycle of this project were:

1. What are the most difficult topics to teach and learn at Second-Level and Third-Level introductory Organic Chemistry?
2. Why is Organic Chemistry difficult?

RQ1 was answered in Chapters Six and Seven where the findings from the Second-Level and Third-Level studies were presented respectively. RQ2 (the reasons why Organic Chemistry is difficult) was specifically discussed in Chapter Three.
Section 9.2 will discuss the findings from Cycle One in answering RQ1 outlined above. The findings from the learners (pupils and students) will be compared with the feedback given from the teachers and lecturers of Organic Chemistry. The findings from the Second-Level and Third-Level studies will be compared with previous research carried out in these fields. In Section 9.2.3 comparisons will be made between the misconceptions and difficulties identified in both Diagnostic Tests.
Section 9.3 of this chapter addresses RQ2. The specific areas of Organic Chemistry identified as difficult in Cycle One will be discussed with reference to the relevant literature.

The research questions addressed in Cycle Two were:

3. What effect can a specially-designed teaching programme using ideas from CER, have on the attitudes and interest of pupils studying Leaving Certificate Organic Chemistry?
4. What effect can improved teaching strategies and resources have on the pupils’ understanding in Leaving Certificate Organic Chemistry?
5. What effect can a specially-designed teaching programme using ideas from CER have on the interest, motivation and teaching style of Leaving Certificate Chemistry teachers?
6. Is it feasible to improve the teaching of Leaving Certificate Organic Chemistry through use of a specially-designed teaching programme?
These research questions were guided by the findings of previous intervention programmes. Any significant intervention into a practicing classroom will have an effect. So, instead of asking ‘Was there an effect?’, the action researcher asks ‘What is the effect on all participants involved?’ (Bodner et al. 1999).

The details and successes of many innovative teaching programmes have already been outlined in Chapter Three (Section 3.5). The evaluation of these programmes involved both the pupils’ and teachers’ responses (Bennett and Holman 2005, Gräsel et al. 2005). It was important to also assess the feasibility and effectiveness of the trialled intervention programme (Boersma et al. 2005).

The findings and feedback from the evaluation of the *Organic Chemistry in Action!* intervention programme have been presented in Chapter Eight. The findings in Chapter Eight (feedback from teachers, participating pupils and comparison with the Control Group) will be discussed together to answer RQ3, RQ4 and RQ5 in Sections 9.4, 9.5 and 9.6 of this chapter respectively. Overall, the effect of the *Organic Chemistry in Action!* programme was positive given the feedback from the participating teachers and pupils. However, the restrictions (syllabus content and time constraints) of the current Leaving Certificate Chemistry curriculum and examination were recurring concerns, leading to some negative feedback from the participants. This matter will be discussed in answering RQ6, debating the feasibility of the *Organic Chemistry in Action!* programme in Section 9.7.

The limitations of this research study will be discussed in Section 9.8 along with the implications of this research with regard to the current revision of the Leaving Certificate Chemistry syllabus. The possible incorporation of elements of the programme into the pedagogy of Third-Level Organic Chemistry will also be considered.

Figure 9.5 in Section 9.9 provides a brief summary of the findings from the six research questions discussed in this chapter.
9.2 – RQ 1- What are the Most Difficult Topics to teach and learn at Second-Level and Third-Level introductory Organic Chemistry?

The main findings from the Second-Level Study were presented and analysed in Chapter Six. In this section, the main difficulties will be summarised. Comparisons will be made between the teacher and pupil feedback as well as with previous research. The results of the Third-Level study have been presented and analysed in Chapter Seven. The precise difficulties identified in each test question will be presented in this Section along with a comparison of the lecturers’ and students’ perceptions of Organic Chemistry. Findings from this Third-Level study will be compared with previous Third-Level research carried out in Ireland.

9.2.1. RQ1 (I)- Second-Level Organic Chemistry

The difficulties and misconceptions identified in each question in the Second-Level Diagnostic Test are listed in Table 9.1. The topics assessed in each question are listed in the left-hand-side column in Table 9.1. These will be compared with the difficulties identified in the Third-Level Diagnostic Test in Section 9.2.3.
Table 9.1 Summary of pupils’ difficulties identified in each question in the Second-Level Diagnostic Test (n=276)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Pupils’ difficulties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drawing Organic Compounds</strong></td>
<td>- More correct responses drawing the condensed structural formulae (242, 87.5%) than extended structural formulae (194, 70.2%).</td>
</tr>
<tr>
<td></td>
<td>- 71 (25.7%) of pupils made incorrect attempts to draw hex-2-ene; 46 (64.8%) of these did not show double bond, 10 (14.1%) put double bond in incorrect place.</td>
</tr>
<tr>
<td></td>
<td>- Incorrect attempts to draw ethanal and methyl ethanoate displayed incorrect functional groups (omission of the double bond in the carbonyl group).</td>
</tr>
<tr>
<td><strong>Naming Organic Compounds</strong></td>
<td>-16 (5.9%) more correct answers naming structural formulae.</td>
</tr>
<tr>
<td></td>
<td>- More correct responses (~7%) when naming extended structural formulae than condensed structural formulae of same compound.</td>
</tr>
<tr>
<td></td>
<td>- Naming branched alkanes- difficulty identifying the longest continuous chain (162, 58.8%).</td>
</tr>
<tr>
<td></td>
<td>- Ketone incorrectly named as an aldehyde (12, 4.3%) or ester (8, 2.9%).</td>
</tr>
<tr>
<td><strong>Isomerism</strong></td>
<td>- Most common incorrect answer (72, 26.1%) confusion between an aldehyde and alcohol, (both functional groups contain O and H) but compounds have different number of carbons.</td>
</tr>
<tr>
<td><strong>Electrophilic attack</strong></td>
<td>-47 (17%) less pupils were able to explain the reason for choosing the correct site of electrophilic attack than chose the correct site.</td>
</tr>
<tr>
<td></td>
<td>- Only 92 (33.3%) drew the correct molecule after attack.</td>
</tr>
<tr>
<td></td>
<td>- 44 (48%) of these drew the intermediate compound (bromonium ion), 48 (52%) drew the carbocation.</td>
</tr>
<tr>
<td></td>
<td>- 92 (33.3%) incorrect responses to the product formed. 27(29.3 %) of these drew bromoethene, 15 (16%) gave the carbon a negative charge.</td>
</tr>
<tr>
<td><strong>Reaction types</strong></td>
<td>- 85 (30.9%) more pupils able to classify the reaction type than complete the equation.</td>
</tr>
<tr>
<td></td>
<td>- 56 (20.3%) incorrect responses to classify the reaction as acid included substitution (21, 37.8%) and addition (23, 41%) reactions.</td>
</tr>
<tr>
<td></td>
<td>- Correct completion of the oxidation reaction (of alcohol) by 59(21.4%) of pupils; 12 (20%) of these drew carboxylic acid as product and 47 (80%) drew aldehyde as product.</td>
</tr>
<tr>
<td><strong>Reaction Synthesis</strong></td>
<td>- Poor performance in drawing intermediate and final compounds (&lt;55% correct responses).</td>
</tr>
<tr>
<td></td>
<td>- Poor identification of reactant and reaction types even though names of intermediate and product were given.</td>
</tr>
<tr>
<td></td>
<td>- Oxidation reaction classified as an elimination reaction in 16 (35%) of the incorrect responses.</td>
</tr>
<tr>
<td><strong>Reaction Mechanism</strong></td>
<td>- Equation completion similar to Q5 a), 13(4.7%) more correct answers.</td>
</tr>
<tr>
<td></td>
<td>- Poor attempt (103, 37.3%) and performance (12, 4.3% correct) in writing reaction mechanism.</td>
</tr>
<tr>
<td></td>
<td>-48 (17.4%) of curly arrows drawn in incorrect direction, 25 (9.1%) did not show any arrow movement of electrons.</td>
</tr>
<tr>
<td><strong>Classification of compounds</strong></td>
<td>- Aldehydes (71, 25.8%) and ketones (76, 27.5%) were most commonly incorrectly classified.</td>
</tr>
<tr>
<td></td>
<td>-32 (11.6%) misclassified the aldehyde as a ketone.</td>
</tr>
<tr>
<td><strong>Properties of Organic compounds.</strong></td>
<td>-41 (15%) more correct answers than correct explanations, may be due to memorisation or guessing.</td>
</tr>
<tr>
<td></td>
<td>- Reasons given included ‘OH group’ and ‘alcohols have higher BP than alkanes’ without further explanation.</td>
</tr>
</tbody>
</table>
Comparison of the pupils’ and teachers’ attitudes

Here, comparisons will be made between the Leaving Certificate Chemistry pupils’ and teachers’ attitudes towards Organic Chemistry; the topics that are perceived as difficult and easy as well as the value of practical work. The teachers’ perspectives of the pupils’ attitudes will be compared with the pupils’ own opinions. Johnstone (2000) recognised that what may be logical and simple to the Chemistry teacher, may not be so for the learner. To teach for understanding, teachers need to have an accurate awareness of their pupils’ prior knowledge, misconceptions and level of cognitive development. If teachers have a better understanding of their pupils’ opinions and attitudes, they should be better able to adapt their lessons to facilitate a more holistic understanding of the subject.

In both the Second-Level Pupil Questionnaire (I) and the Chemistry Teacher Questionnaire, respondents were asked to indicate their attitudes towards Organic Chemistry. The teachers were also asked to indicate their perception of their pupils’ attitudes. Table 9.2 compares the Chemistry teachers’ attitudes and the Second-Level pupils’ attitudes. It includes the median values for each statement (in brackets) from the Likert scales used. In all three questions, the participants responded to the same statements on a five-point Likert scale, where 1 = Strongly Agree and 5 = Strongly Disagree.

Table 9.2 Comparison of Teachers’ and Pupils’ perspectives of Organic Chemistry.

<table>
<thead>
<tr>
<th>Organic Chemistry is…</th>
<th>Chemistry Teachers’ own attitudes. (n=79)</th>
<th>Chemistry teachers’ perspective of pupils’ attitude. (n=79)</th>
<th>Chemistry teachers’ perspective of pupils’ attitude. (n=35)*</th>
<th>Second-Level Pupils’ own attitudes. (n=276)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interesting</td>
<td>Strongly agree (1)</td>
<td>Agree (2)</td>
<td>Agree (2)</td>
<td>Agree (2)</td>
</tr>
<tr>
<td></td>
<td>Enjoyable to teach / learn</td>
<td>Agree (2)</td>
<td>Indifferent (3)</td>
<td>Agree (2)</td>
</tr>
<tr>
<td></td>
<td>Easy to teach / learn</td>
<td>Agree (2)</td>
<td>Disagree (4)</td>
<td>Indifferent (3)</td>
</tr>
</tbody>
</table>

*Note: In the fourth column where n=35, this column specifies the attitudes of the 35 teachers that were teaching the 276 pupils involved in the study.
Due to the non-parametric nature of the ordinal scale, the median scores are included in the table with the corresponding responses. It is important to note here, that there are two columns listing the ‘Chemistry teachers’ perspective of their pupils’ attitudes. The column where \( n=79 \) represents the attitudes of all the teachers involved in the study. The column where \( n=35 \) is included, as these are the teachers of the 276 pupils involved in the study. It is important to investigate precisely their perspective of their own pupils’ difficulties. The teachers had assumed their pupils held a more negative view of learning Organic Chemistry than they actually did. It is important for teachers to be familiar with their pupils’ attitudes and approach to learning as well as their level of cognitive development and prior knowledge (Johnstone 2010).

In the Second-Level Pupil Questionnaire (I) and Chemistry Teacher Questionnaire, common topics were identified as easy to teach and easy to learn: Drawing organic compounds, Naming organic compounds, Oil Refining (and its products) and Chromatography. The same two topics were identified as difficult to teach and learn by both the teachers and pupils respectively: Organic Mechanisms and Synthesis. While Classification of organic compounds and Isomerism were identified as easy to teach by the teachers, they were not included as easy to learn topics by the pupils. However, when the results in the Diagnostic Test are analysed the questions assessing Isomerism and Classification ranked as the best and second best answered questions, indicating the pupils’ good understanding of these, even though the pupils had not indicated these topics as ‘easy to learn’. This evidence shows that teaching and learning are not synonymous (Anderson and Bodner 2008); because topics are identified as easy or difficult to teach does not imply they are consequentially easy or difficult to learn.

In Table 9.3 that follows, it can be seen that both teachers and pupils chose in common, four out of their top five most difficult Organic Chemistry topics. Again the teachers’ perspectives are listed in two columns: \( n=79 \) to represent all teachers involved in the study and \( n=35 \) to represent the teachers teaching the 276 pupils involved in the study. Therefore, it is clear that the topics listed in Table 9.3 are a definite area of difficulty (to teach and learn) for Leaving Certificate Chemistry teachers and pupils. This is not surprising as previous literature has also identified these topics as key areas of difficulty in Organic Chemistry (Bhattacharyya and
An understanding of Reactions and Reaction Mechanisms requires an accurate comprehension and application of a range of other topics: chemical principles, abstract theories and facts, chemical and physical concepts, as well as correctly drawing starting, intermediate and finishing materials. These topics have a high cognitive demand (Ingle and Shayer 1971) and many of these Second-Level pupils are not capable of such abstract thought (Childs and Sheehan 2010). It is important when summarising the most difficult topics (as in Table 9.3) to consider the multiple factors that contribute to each of these difficult areas.

### Table 9.3 Top five most difficult topics as rated by Second-Level Chemistry teachers and pupils.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Mechanisms</td>
<td>2nd</td>
<td>1st</td>
<td>1st</td>
<td>3rd*</td>
</tr>
<tr>
<td>Organic Reactions</td>
<td>3rd</td>
<td>4th</td>
<td>4th</td>
<td>1st*</td>
</tr>
<tr>
<td>Organic Synthesis</td>
<td>4th</td>
<td>3rd</td>
<td>2nd</td>
<td>2nd*</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>1st</td>
<td>2nd</td>
<td>3rd</td>
<td>4th*</td>
</tr>
<tr>
<td>Functional Groups</td>
<td>Not in top 5</td>
<td>Not in top 5</td>
<td>Not in top 5</td>
<td>5th*</td>
</tr>
<tr>
<td>Isomerisation</td>
<td>Not in top 5</td>
<td>5th</td>
<td>5th</td>
<td>Not in top 5*</td>
</tr>
<tr>
<td>Organic Natural Products</td>
<td>5th</td>
<td>Not in top 5</td>
<td>Not in top 5</td>
<td>Not in top 5*</td>
</tr>
</tbody>
</table>

*Note: In the fourth column where n=35, this column specifies the attitudes of the 35 teachers that were teaching the 276 pupils involved in the study.

**Comparison of results with previous research.**

The five-point Likert scales used in the Second-Level study to investigate the pupils’ attitudes to the different Organic Chemistry topics was the same as that used by Bojczuk (1982) and Ratcliffe (2002) to assess A-level pupils’ attitudes towards Chemistry in the UK. While both of these studies investigated the difficulties of Chemistry in general, Organic Chemistry was identified as an area of difficulty in both. Bojczuk (1982) and Ratcliffe (2002) did not provide the mean or median values of their data, but instead the percentages of pupils who rated each topic as difficult /
really difficult. These percentage values are included in Table 9.4 where the findings from this study are also presented as percentage values to allow for valid comparisons to be made. It can be seen from Table 9.4 that same four topics that were identified as difficult and very difficult by Leaving Certificate pupils in this study were also identified as difficult by the A-Level pupils in the UK. It should be noted in the Ratcliffe (2002) study that the reference to instrumentation was specifically related to spectroscopy. This is only one of the topics of instrumentation in the Leaving Certificate syllabus. Instrumentation was not identified as an area of difficulty by Bojczuk (1982).

### Table 9.4 Comparison of findings with previous research in the UK (Bojczuk 1982, Ratcliffe 2002)

<table>
<thead>
<tr>
<th></th>
<th>Bojczuk (1982) (UK) (n=277)</th>
<th>Ratcliffe (2002) (U.K.) (n=65)</th>
<th>This Second-Level Study (n=276)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrumentation</td>
<td>-</td>
<td>39% Difficult / Very difficult (Spectroscopy)</td>
<td>22.8% Difficult / Really Difficult</td>
</tr>
<tr>
<td>Organic Reactions</td>
<td>35% Difficult</td>
<td>43% Difficult / Very difficult (of arenes)</td>
<td>40.6% Difficult / Really Difficult</td>
</tr>
<tr>
<td>Organic Mechanisms</td>
<td>41% Difficult</td>
<td>34% Difficult / Very difficult</td>
<td>50% Difficult / Really Difficult</td>
</tr>
<tr>
<td>Organic Synthesis</td>
<td>56% Difficult</td>
<td>52% Difficult / Very difficult</td>
<td>48.2% Difficult / Really Difficult</td>
</tr>
</tbody>
</table>

A five-point Likert scale (with the same ratings) was also used by Childs and Sheehan (2009) in assessing Leaving Certificate pupils’ attitudes to Chemistry in Ireland. The mean values of the organic topics from Childs and Sheehan (2009) are listed in Table 9.5 which follows. These mean values can be compared with the mean values from this study.
Childs and Sheehan (2009) rated topics having a mean value $2.5 \leq x \geq 5$ as being difficult. In this Second-Level study, topics with a mean rating above 3 were considered as difficult. It can be seen in Table 9.5 that the previous findings by Childs and Sheehan (2009) support the evidence obtained in this Second-Level study. It should be noted that rating of organic reactions in the Childs and Sheehan (2009) study were only in reference to reactions of alcohols and redox reactions. The Likert rating in this Second-Level study was with reference to all organic reactions in general.

Research carried out by Jimoh (2005) also investigated the difficulty of Second-Level Chemistry topics in Nigeria, but using a three-point Likert scale where 1= Easy, 2= Average and 3= Difficult. On this scale, Organic Chemistry scored a mean value of 1.72. This was not included in Table 9.4 because comparison of the three and five point Likert scales would not have been valid. Tables 9.4 and 9.5 clearly show that the same topics that were identified as difficult in previous UK and Irish studies were again identified as difficult in this Second-Level Study; Instrumentation, Reactions, Mechanisms and Synthesis. This persistent trend of difficulty with these topics validates the findings of this Second-Level study, as they are consistent with previous literature.

Conversely, the same topics were identified as easy or really easy in the two previous studies and in this study; Naming organic compounds, Oil refining and Fuels, Isomerism and Chromatography.
30% of A-Level teachers (n=25) in a study carried out by Ratcliffe (2002) rated Organic Reaction Mechanisms as difficult / very difficult. In the same study 42% of the teachers rated Instrumentation as difficult / very difficult. These same topics were identified as difficult to teach by the Irish Second-Level Chemistry teachers involved in this Second-Level study. In total 37% of the Irish Chemistry teachers rated Organic Reactions as difficult / very difficult to teach and 49% rated Instrumentation as difficult / very difficult to teach also. It should be noted here that the A-Level syllabi go into greater depth in Chemistry, and in Organic Chemistry and Instrumentation in particular than the Irish Leaving Certificate Chemistry syllabus. The standard of A-Level Chemistry would be between Leaving Certificate Chemistry and Introductory Third-Level Chemistry courses in Ireland.

9.2.2. RQ1 (II) - Introductory Third-Level Organic Chemistry

The students’ correct and incorrect responses for each of the questions in the Diagnostic Test have been presented and analysed in Chapter Seven (Section 7.2.3). The factors affecting the students’ performance in the Diagnostic Test were also investigated in Section 7.2.4 of Chapter Seven.

The difficulties and misconceptions arising from the Third-Level Student Diagnostic Test are listed in Table 9.6 which follows. These will be compared with the difficulties arising from the Second-Level Diagnostic Test in section 9.2.3.
Table 9.6 Summary of students’ difficulties identified in each question in the Third-Level Diagnostic Test (n=121).

<table>
<thead>
<tr>
<th>Test Question</th>
<th>Student difficulties</th>
</tr>
</thead>
</table>
| 1 – Drawing organic compounds | -Low correct response in drawing extended (33, 27.5%) and skeletal (34, 28.8%) structures.  
                              | -Poor recognition of cyclic compounds; 52 (42.9%) of students represented cyclohexene as linear, 37 (30.6%) of students represented benzaldehyde as linear. |
| 2 – Identifying organic species| -Poor recognition of ethene (C=C double bond) as a nucleophile (13, 10.7% correct).  
                              | -31 (25.7%) of students incorrectly identified OH⁻ as an electrophile.  
                              | -35 (29%) more students recognised the atomic radical than the alkyl radical. |
| 3- Electron density           | -48 (19.7%) of students listed carbon as the atom of lowest electron density instead of hydrogen in ethanal.  
                              | -Students incorrect use and direction of electron movement arrow: coming from the hydrogen proton (40, 33.1%) or from the double bond in the carbonyl group (44, 36.4%) instead of the oxygen lone pairs. |
| 4- Nomenclature               | -41 (33.9%) did not identify the longest carbon chain correctly.  
                              | -Esters were incorrectly named as carboxylic acids or ketones.  
                              | -Ketones were incorrectly named as aldehydes.  
                              | -Aldehydes were incorrectly named as carboxylic acids or alcohols. |
| 5- Classification of organic compounds | -12 (9.9%) of students classified a haloalkane as an alkane.  
                              | -10 (8.3%) classified as ether as an ester.  
                              | -7 (5.8%) classified a ketone as an ester.  
                              | -7 (5.8%) classified a carboxylic acid as an alcohol. |
| 6 – Isomerism                 | -24 (19.8%) more students recognised 2-methylpropan-2-ol as an isomer of butanol than recognised the ether as an isomer.  
                              | -16 (13.3%) incorrectly identified butanal as an isomer of butanol.  
                              | -22 (18.3%) incorrectly listed cyclohexene as an isomer of cyclohexane. |
| 7- Shape and structure        | -44 (36.4%) gave an incorrect bond angle for methane (90° or 120°).  
                              | -Unable to give correct hybridisation of the carbon atom in methane (69, 57%) and in ethyne (81, 66.9%). |
| 8- Mechanism of reaction      | -41 (33.9%) drew a major product with a double (C=C) bond and the minor product as diatomic.  
                              | -21 (17.4%) drew the correct reaction product for electrophilic substitution without showing any mechanism (arrows).  
                              | -12 (9.92%) drew the arrow coming from the electrophile |
Comparison of students’ and lecturers’ results

This section will compare some of the key findings from the Organic Chemistry Lecturer Questionnaire and the Third-Level Student Questionnaire. In both questionnaires, the participants were given a table of Organic Chemistry topics to rate on a five-point Likert scale. The students rated the topics as easy or difficult to learn while the lecturers rated the topics as easy or difficult to teach. The same five-point scale was used in both questionnaires where 1 = really easy, 2 = easy, 3 = neutral, 4 = difficult and 5 = really difficult. Table 9.7 shows the median ratings that the students (n=121), lecturers (n=20) and lecturers of the participating students (n=4) gave to represent their respective attitudes towards learning and teaching the Organic Chemistry topics that are listed.

Table 9.7 Comparison of attitudes (median ratings) towards the Organic Chemistry topics listed in Student Questionnaire and Lecturer Questionnaire.

<table>
<thead>
<tr>
<th></th>
<th>Students’ attitudes to learning (n=121)</th>
<th>Lecturers’ attitudes to teaching (n=20)</th>
<th>Attitude of the lecturers teaching the 121 students (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing organic compounds.</td>
<td>Easy 2</td>
<td>Easy 2</td>
<td>Neutral 2.75</td>
</tr>
<tr>
<td>Naming organic compounds.</td>
<td>Neutral 3</td>
<td>Easy 2</td>
<td>Easy 2.25</td>
</tr>
<tr>
<td>Isomerisation.</td>
<td>Neutral 3</td>
<td>Neutral 2.5</td>
<td>Neutral 2.5</td>
</tr>
<tr>
<td>Classification of organic compounds.</td>
<td>Neutral 3</td>
<td>Easy 2</td>
<td>Easy 2.25</td>
</tr>
<tr>
<td>Physical characteristics of organic compounds.</td>
<td>Neutral 3</td>
<td>Neutral 2.5</td>
<td>Neutral 2.5</td>
</tr>
<tr>
<td>Aliphatic compounds.</td>
<td>Neutral 3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aromatic compounds.</td>
<td>Neutral 3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Organic reaction types.</td>
<td>Difficult 4</td>
<td>Neutral 3</td>
<td>Neutral 2.75</td>
</tr>
<tr>
<td>Organic mechanisms.</td>
<td>Difficult 4</td>
<td>Difficult 4</td>
<td>Difficult 3.5</td>
</tr>
<tr>
<td>Organic synthesis.</td>
<td>Difficult 4</td>
<td>Difficult 4</td>
<td>Neutral 3</td>
</tr>
<tr>
<td>Laboratory work.</td>
<td>Neutral 3</td>
<td>Easy 2</td>
<td>Neutral 2.5</td>
</tr>
<tr>
<td>Organic natural products.</td>
<td>*</td>
<td>Difficult 4</td>
<td>Easy 2</td>
</tr>
<tr>
<td>Oil refining and products.</td>
<td>*</td>
<td>Neutral 2.5</td>
<td>Easy 1.67</td>
</tr>
<tr>
<td>Chromatography.</td>
<td>*</td>
<td>Neutral 3</td>
<td>Easy 2</td>
</tr>
<tr>
<td>Instrumentation.</td>
<td>*</td>
<td>Neutral 3</td>
<td>Easy 2</td>
</tr>
</tbody>
</table>

*Note: The last four topics (Laboratory work, Organic natural products, Oil refining and products, Chromatography and instrumentation) were not listed in the Likert scale on the Third-Level Student Questionnaire.
The median ratings for all groups are included in table 9.7 to support the verbal rating. The median values are shown as the data was ordinal and non-parametric. A trend can be observed in Table 9.7 where common topics are perceived as easy and difficult by lecturers and students. However, it is important to highlight that these students’ attitudes to the particular Organic Chemistry topics were not accurately reflected in their performance in the Diagnostic Test (Table 7.14 in Section 7.2.4).

Not all of the topics which the lecturers found easy to teach were considered easy to learn by the students. A number of topics rated easy to teach by the lecturers were rated as neutral on the Likert scale by the students. Students only identified one topic as easy to learn (Drawing), while the lecturers identified four topics as easy to teach (Drawing, Naming, Classification and Laboratory work).

Two of the three topics identified as difficult by both students and lecturers were the same: Reaction Mechanisms and Synthesis. The lecturers also listed the top five topics that they perceived their students to find most difficult in Organic Chemistry (Figure 7.44 in Chapter Seven). Reaction Mechanisms was listed as the first or second most difficult topic by 18 (90%) of the lecturers. The question in the Diagnostic Test assessing Mechanism was one of the most poorly attempted and poorly answered questions by the students. This gives further evidence that the lecturers held an accurate perception of their students’ attitudes and abilities in Organic Chemistry.

The common topics identified as difficult by Second-Level teachers and pupils were listed in Table 9.3. These results (Table 9.7) show that many of the same problems and difficulties persist at Third-Level. Therefore, it is of vital importance to address these topics when they are first introduced to novice learners; at Second-Level.

**Comparison of results with previous research**

The findings from this Third-Level study are supported by previous research carried out at Third-Level. Childs and Sheehan (2009) carried out a Third-Level study involving first, second and third year university students. This study (n=121) also involved students from two institutes of technology. The university students involved in this study were in first and second year. The same Likert scale ratings were used in both studies. Childs and Sheehan (2009) reported the mean values for each of the
topics assessed in their study. For this reason, the mean values of the same topics for this Third-Level study are included in Table 9.8 below to allow for comparison.

*Table 9.8 Comparison of Findings with previous research. (Childs and Sheehan 2009)*

<table>
<thead>
<tr>
<th></th>
<th>Childs and Sheehan (2009) First Year students (n=136)</th>
<th>Childs and Sheehan (2009) Second and Third Year students (n=55)</th>
<th>This Third-Level Study (n=121)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Naming Organic Compounds</strong></td>
<td>3.40</td>
<td>3.00</td>
<td>2.81</td>
</tr>
<tr>
<td><strong>Isomerisation</strong></td>
<td>3.23</td>
<td>3.13</td>
<td>3.27</td>
</tr>
<tr>
<td><strong>Organic Reactions</strong></td>
<td>3.69 (of alcohols)</td>
<td>3.38 (of alcohols)</td>
<td>3.44</td>
</tr>
<tr>
<td></td>
<td>3.58 (redox)</td>
<td>3.45 (redox)</td>
<td></td>
</tr>
<tr>
<td><strong>Organic Mechanisms</strong></td>
<td>3.70</td>
<td>3.46</td>
<td>3.67</td>
</tr>
<tr>
<td><strong>Organic Synthesis</strong></td>
<td>3.20</td>
<td>3.45</td>
<td>3.75</td>
</tr>
</tbody>
</table>

Comparisons can only be made between these five topics, as these were only topics common to both investigations. Organic Reactions were rated on the Likert scale in this study as a whole. However, the Organic Reactions were rated individually in the study carried out by Childs and Sheehan (2009). For this reason, separate mean values are provided for reactions of alcohols and redox reactions. Childs and Sheehan (2009) rated topics having a mean value $2.5 \leq x \leq 5$ as being difficult. The same topics were identified as difficult at first, second and third year in their study. These same topics were again identified as difficult by the first and second year students involved in this Third-Level study. From Table 9.8, it is obvious that the findings from this Third-Level study are in agreement with previous research and are indicative of the main areas of difficulty in Organic Chemistry.

**9.2.3. Areas of Difficulty in Second-Level and Third-Level introductory Organic Chemistry**

In this section, the areas of difficulty identified in the Second-Level study and Third-Level study will be compared. The topics given to the pupils in the Second-Level Pupil Questionnaire (I) and to the students in the Third-Level Student Questionnaire to rate on the five-point Likert scale were not completely similar. For this reason, only topics common to both are listed in Table 9.9 below. Table 9.9 compares the median
values of the responses to each of the topics on a scale where 1 = Really Easy and 5 = Really Difficult.

Table 9.9  Median values of Second-Level pupil and Third-Level student difficulties for common topics.

<table>
<thead>
<tr>
<th>Organic Topic</th>
<th>Second-Level Pupils (n=276)</th>
<th>Third-Level Students (n=121)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nomenclature</td>
<td>2 Easy</td>
<td>3 Indifferent</td>
</tr>
<tr>
<td>Classification</td>
<td>3 Indifferent</td>
<td>3 Indifferent</td>
</tr>
<tr>
<td>Characteristics</td>
<td>3 Indifferent</td>
<td>3 Indifferent</td>
</tr>
<tr>
<td>Isomerisation</td>
<td>3 Indifferent</td>
<td>3 Indifferent</td>
</tr>
<tr>
<td>Organic Reactions</td>
<td>3 Indifferent</td>
<td>4 Difficult</td>
</tr>
<tr>
<td>Organic Mechanisms</td>
<td>4 Difficult</td>
<td>4 Difficult</td>
</tr>
<tr>
<td>Organic Synthesis</td>
<td>4 Difficult</td>
<td>4 Difficult</td>
</tr>
</tbody>
</table>

The inclusion of the corresponding verbal ratings makes it easier to compare the median values included in Table 9.9. The Second-Level pupils and Third-Level students both identified Mechanisms and Synthesis as difficult. The Second-Level pupils identified Nomenclature as easy. However, the Third-Level students were indifferent in their response to Nomenclature (neither rating is as easy or difficult). The Third-Level students also rated Reactions as difficult even though the Second-Level pupils were indifferent to this topic. It is clear from these results that both cohorts of learners follow the same trend in their perception of the Organic Chemistry topics, with the Third-Level cohort finding some topics more difficult than the pupils at Second-Level. It is necessary at this point to highlight that the Third-Level students are required to have a deeper understanding of the topics than the Second-Level pupils.

As well as some of the same topics being rated on the Likert scales in both questionnaires, many of the same topics were assessed in the Diagnostic Tests. The pupils’ and students’ performance (percentage score) in the topics assessed in both Diagnostic Tests is shown in Figure 9.1 below. While, the specific questions asked in each of the tests were different, the standard and depth assessed was appropriate to the level and standard of Organic Chemistry of the learners.
Figure 9.1 Overview of performance of Second-Level pupils (n=276) and Third-Level students (n=121) in topics assessed in their respective Diagnostic Tests.

Note: Only the performance of topics that were commonly assessed in both Diagnostic Tests are included in Figure 9.1

The results in Figure 9.1 are deceptive in suggesting that the Second-Level pupils performed much better in their Diagnostic Test than the Third-Level students. However, this is not a valid observation. Although the same topics were assessed, they differed substantially in the style and presentation of the question and also in their degree of complexity. Figure 9.1 should only be used to observe a trend in the pupils’ and students’ performance in the Organic Chemistry topics, rather than a comparison of performance. Drawing organic compounds was first topic assessed in both Diagnostic Tests and was the most popular question also. This may have been due to its position as Question One and may also imply that it is an easy topic to understand. The question assessing Mechanism was the least popular question in the Second-Level Diagnostic Test, while the question assessing Isomerism was the least popular in the Third-Level Diagnostic Test.

Drawing organic compounds and Isomerism were the best answered questions in the Second-Level Diagnostic Test while Classification of organic compounds and
Identification of Electron Density were the best answered questions in the Third-Level Diagnostic Test. While the best answered questions differed for both cohorts of participants, the same topics were the worst answered in both cases: Nomenclature and Mechanism. Mechanisms were rated as difficult by the learners at both Second-Level and Third-Level (Table 9.9), so poor performance in this topic is not surprising. However, Nomenclature was not rated as difficult by either cohort of participants despite their poor attempt in answering the Nomenclature question in the both Diagnostic Tests. Such poor performance in a topic that both cohorts identified as easy and enjoyable in part A of the respective questionnaires highlights a disparity between the learners’ perceptions of their own ability and their actual ability. It was expected by the researcher that identifying a topic as easy and enjoyable would indicate competence in the same topic. However, this was not true in this study. This finding signifies the importance of assessing the learners’ understanding of topics through a diagnostic instrument, to reinforce and validate findings from questionnaires that simply rate the learners’ attitudes and opinions. It is also possible that the way the question was presented was unfamiliar to the participants and may thus have affected their performance.
9.3. RQ 2- Why is Organic Chemistry Difficult?

9.3.1. Factors Contributing to the Difficulty of Organic Chemistry

Figure 9.2 provides a summary of the factors that contribute to the difficulties experienced by those learning Organic Chemistry. The extrinsic difficulties and intrinsic difficulties listed in Figure 9.2 have already been discussed in detail in Chapter Three (Sections 3.2 and 3.3 respectively). For this reason, they will not be outlined individually here again.

Figure 9.2 Summary of factors contributing to the difficulty of Organic Chemistry.
9.3.2. Explaining the Learners’ Difficulties with the Most Difficult Topics.

In answering RQ1, five areas of difficulty of Organic Chemistry have been identified at Second-Level and Third-Level Organic Chemistry:

- IUPAC Nomenclature.
- Functional groups.
- Characteristics of organic compounds.
- Reactions: types and mechanisms.
- Practical work.

The questions that identified these difficulties were listed in Tables 9.1 and 9.6. Each of these will now be discussed below individually with reference to relevant literature in an attempt to explain why these topics are perceived as difficult for those learning Organic Chemistry. In this discussion, the Second-Level pupils and Third-Level students will be grouped as one cohort and called ‘learners’.

IUPAC Nomenclature

The learners’ understanding (or lack of) of the IUPAC nomenclature system and rules affected their ability to correctly answer the questions assessing naming and drawing in the Diagnostic Tests. Learners had to be able to apply the rules of IUPAC nomenclature systematically to name the compounds given, and also to deduce the meanings and parts of the names to draw the compounds that were named. Structure is a critical element when learning Organic Chemistry (Hassan et al. 2004). It forms the basis for predicting reactivity and physical properties.

In the questions assessing Drawing and Nomenclature, some learners did use and apply the IUPAC rules. However, many learners omitted some part of the rules for naming. The most common mistake made by those who named compounds incorrectly was not identifying the longest carbon chain, although most did apply the IUPAC system of naming i.e. [number]–[substituent] [stem] [ending]. The punctuation (use of commas and hyphens) in the naming was correct suggesting that the pupils had learned and understood the IUPAC nomenclature system. However, the learners didn’t correctly identify and name the longest carbon chain. This may have been due to the presentation of the structure of the compounds.
It is clear from many of the learners’ responses when drawing organic compounds, that many did not use the IUPAC names of the compounds that were given to draw the two-dimensional structures. This was most evident with the number of Third-Level students that attempted to draw cyclohexene and benzaldehyde as linear compounds. It is evident that these learners did not infer from the names ‘cyclo’ and ‘benz’ that these compounds would contain a carbon ring. Many learners also omitted the double bond in drawing hex-2-ene, suggesting that they did not recognise from the IUPAC name that it was an alkene. Such incorrect responses and approaches to naming compounds may suggest that the learners were not using a systematic approach, but instead relying on memorisation and recognition of part of the IUPAC name.

In the assessment of drawing organic compounds, the learners’ lack of understanding of the IUPAC nomenclature was also evident. Many of these students did not recognise from the nomenclature ‘cyclo-’ and ‘benz’- that these structures were cyclic. Perhaps the condensed structures which were given may have contributed to the students’ misunderstanding (as these structures are written as linear).

In addition some inconsistency was observed in the students’ linear representations. Eight of the students who attempted to show the extended structure of cyclohexene as cyclic, attempted to show the skeletal structure as linear. Conversely, seven of the students who attempted to show the extended structure of cyclohexene as linear, attempted to show the skeletal structure as cyclic. This certainly suggests further confusion and contradiction in the students’ own understanding. Similarly four students who attempted to draw the extended structure of benzaldehyde as cyclic attempted to draw its skeletal structure as linear. Also five of the students who attempted to draw the extended structure of benzaldehyde as linear attempted to draw the skeletal structure of the compound as cyclic. This suggests that the students did not understand that the skeletal structure is a shorthand representation of the same extended structure, but without showing the carbon or hydrogen atoms. Confusion between functional groups such as aldehydes and ketones resulted in incorrect naming also. Functional groups will be discussed in more detail below.

The different types of structural formulae used and mentioned in this study were defined in Chapter Three (Table 3.8, Section 3.4.4). While some previous research has
identified condensed structural formulae as an area of difficulty for Organic Chemistry students (Katz 1996), there were more correct answers in naming and drawing organic compounds in their condensed structural formulae rather than with the extended or skeletal structural formulae in this study. The same observation was made by Kellet and Johnstone (1980), who looked at how students see organic formulae. It was found that the vast majority of students read the formulae from left to right. The condensed structures were much more successfully recalled than the extended structural formulae. Students in that study (Kellet and Johnstone 1980) explained that they memorised every chemical symbol and every bond as a symbol. This explains how there was a poorer performance in answering and drawing the extended formulae, as these required more memorisation. However, when the learners were given the same molecule to name in both structure types (condensed and extended), there were more correct answers naming the compound in the extended structural formula. The Third-Level students made a poor attempt of naming the structures in the skeletal structural formulae.

Johnstone (1997) described the ‘Information Processing Model’ as one way to interpret how learners understand complex topics in Organic Chemistry. Johnstone (1981) recognised that the learners’ perception of a problem is dependent on the size of each piece of information presented to them. The extended structure of ethyl methanoate, for example, can been seen as 27 pieces of information (each bond and each letter), as two pieces (the ethyl group and methanoate) or as one piece. An expert and novice learner will perceive it differently. Converting the skeletal structures to extended structures occupies some of the working space in the Short Term Memory, leaving less available space to think and recognise the given compound. Reid (2008) recognised that if neither the way of presentation nor the way of assessment require the learner to hold more information than the capacity of their Working Memory, then their performance will relate to their knowledge and skill in the subject area and not to their working memory capacity. If the conversion of the skeletal structures occupied most of the students’ Working Memory Space, this may have been a factor contributing to the poor performance of the students in drawing organic compounds.
Functional Groups

Domin et al. (2008) found that the critical attribute used as the basis of categorisation of organic compounds is not static. The attribute changes as the learner progresses through their Organic Chemistry course, focusing on different characteristics such as structure, functionality and stereochemistry. However, Domin et. al. (2008) found that functionality remained the predominant attribute chosen by learners. This attribute of classification was assessed in both Diagnostic Tests in this study.

Most of the learners’ confusion and mistakes relating to functional groups was in distinguishing aldehydes from ketones. Domin et al. (2008) found that categorisation of compounds can be rule-based or similarity-based. The rule-based approach requires procedural knowledge resulting in rigid yes/no decisions. In comparison, the similarity-based approach depends on the learner’s perception of a common attribute. When categorising compounds in both Diagnostic Tests, the common attribute was functionality. It is easy to understand how the learners may incorrectly classify ketones and aldehydes, as both functional groups contain the carbonyl group. Alcohols were also classified incorrectly as aldehydes (due to the presence of the oxygen and hydrogen in the functional group). While both functional groups contain oxygen and hydrogen, butanal and butanol are not isomers. It is apparent that these pupils counted the number of carbons and components of the functional group to identify a suitable isomer. A contrary misconception was identified in an extensive study (n=7441) by Schmidt (1992), where it was found that the students perceived that organic compounds could only be isomers of compounds in the same functional group. Both the misconception identified in this research and by Schmidt (1992) highlight the fact that learners’ ideas are often in conflict with the scientific concepts of experts. Schmidt (1992) called such misconceptions ‘alternative frameworks’, since the learners simply apply their own (incorrect) perceptions correctly to deduce an incorrect answer. Confusion between carboxylic acids and aldehydes was identified by the SEC (2008). Johnstone (1981) found that only 13% of those entering undergraduate (Third-Level) study understood functional groups correctly. In comparison, the median scores of the participants in the Second-Level and Third-Level Diagnostic Tests in the Classification questions were both 60%, indicating both cohorts had a reasonable understanding of this topic.
In the questions assessing naming and classification of organic compounds, there is a persistent trend in the learners’ mistakes in recognising functional groups. There is much confusion between the compounds containing the carbonyl (C=O) group. It is apparent that the many learners are not paying enough attention to the position of this carbonyl group (internal for a ketone, terminal for an aldehyde or carboxylic acid). In many cases the students have counted and named the carbons in the main chain correctly, but classified the compound incorrectly due to negligence about the functional group. Confusion between aldehydes and ketones was also recognised by Hassan et al. (2004). In other cases, functional groups within the compounds are classified incorrectly e.g. an ether –O- instead of an ester – COO-. ‘At times Organic Chemistry becomes a strange world where the manipulation of the symbols C, H and O develop a confusing algebra of its own’ (Hassan et al., 2004, p. 41). From the responses in both Diagnostic Tests, it is clear that the learners were better able to classify organic compounds correctly when the functional group was at the end of the compound, rather than within the compound. When the functional group is at the end of the compound, it easier to identify the atoms and to recognise the whole functional group. In such cases, the learners are better able to ‘recognise the signal from the noise’(Johnstone 1981). In a large compound, it is easier to recognise and identify a functional group at the end of a compound rather than when it is within the compound. It is unknown from the research in Phase One whether the incorrect responses given by learners when identifying functional groups were due to the learners’ inability to name the functional group or correctly or in fact their inability to identify the whole functional group within the compounds given.

**Characteristics of organic compounds**

When assessed about the physical characteristics of organic compounds, fewer learners were able to provide an explanation for the physical properties than were able to identify the properties of the compounds correctly. Similarly, fewer learners were able to provide a correct reason for choosing the correct site of electrophilic attack on the ethene molecule. Taagepera and Noori (2000) outlined critical learning pathways for both experts and novices. Properties such as boiling points and solubility were rated as third and fourth level of difficulty on the expert pathway (of nine levels in total). Identifying the physical properties requires knowledge from more than one
level: firstly recognition of electronegativities to determine polarity and then an understanding of the influence polarity and hydrogen bonding has on intermolecular forces. Many learners simply gave statements such as ‘like dissolves like’ or ‘due to the OH group’ to explain the solubility of methanol in water. However, the use of such ambiguous explanations does not clearly illustrate the learner’s understanding that both water and methanol are polar compounds and why each of them are polar compounds, and the resultant hydrogen bonding that will occur. Statements such as the examples given imply that even though the correctly chosen answer may not just be a guess, it may be a result of rote memorisation without any clear understanding.

Hassan et al. (2004) recognised that while the nature of covalent bonds and bond polarity are developed at Second-Level, the significance of these ideas in the context of organic reactivity may not always be apparent to students meeting organic reactions for the first time at Third-Level. It is important to recognise the significance of a good understanding of other areas of Chemistry for a clear understanding of Organic Chemistry. Electronegativity, polarity, the concept of what happens when something boils, solubility, and bonding are elements of prior understanding that the Organic Chemistry teacher or lecturer can often assume to be understood by the learners. Misapplication or lack of transter of discipline-specific concepts as well as previously learned concepts from other Chemistry disciplines, is a major source of confusion and error for students (Rushton et al., 2008). To understand the behaviour of organic compounds, learners have to retrieve information from their Long Term Memory and apply it to their knowledge of Organic Chemistry.

This application of prior knowledge to understand organic compounds was evident in the students’ understanding of the hybridisation of the carbons atoms in methane and ethyne molecules. The students needed an understanding of bond angles and molecular shape to answer this question correctly. It may have been easier for the students to predict (or guess) an answer for the ethyne molecule as its two-dimensional structure is linear and has a bond angle of 180°. Of those who gave the correct hybridisation of the carbon atom in methane, only two thirds gave the correct (H-C-H) bond angle. Fewer students gave the correct hybridisation of the carbon in the ethyne molecule, while almost all of who attempted the question gave the correct bond angle and most of them gave the correct molecular shape for ethyne. If these
students had a correct understanding of hybridisation, those who answered that part of the question correctly, should have given the correct bond angle and molecular shape also.

Reactions: Types and Mechanisms

Confusion between nucleophiles and electrophiles

Poor performance by the pupils and students in questions assessing electron densities and identifying electrophiles and nucleophiles may have contributed to the poor performance in questions assessing Reactions and Mechanisms. An understanding of the former is necessary to predict intermediates and products for reactions. While the learners did exhibit a satisfactory understanding of the concept of polarity, many were still unable to identify the most or least electronegative atom in a given molecule. This tendency for novice learners to focus on the properties of individual atoms rather than looking at the structures and properties of the whole molecule was also identified by Anderson and Bodner (2008). This inability to assess the molecule as a whole resulted in incorrect answers when asked to identify sites of attack e.g. an electron-rich double bond for an electrophilic attack. Subsequently, poor attempts were made to draw the molecules after attack and to predict products for given reactions. More students correctly identified the carbocation and the radicals, than identified the nucleophiles and electrophiles correctly. The most common incorrect answer given when identifying a nucleophile was the electrophile, NO$_2^+$. Conversely, the most common incorrect response given when identifying an electrophile was the nucleophile, OH$^-$. This suggests some confusion and misunderstanding between what is meant by a nucleophile and electrophile. Perhaps the stems of the words ‘electro-’ and ‘nucleo-’ are causing concern for the pupils as they suggest a meaning of something ‘negative’ or something ‘positive’ respectively. Previous research carried out with learners in the UK found that a high number of learners perceive words incorrectly, and as a result interpret them to mean their opposite (Johnstone 1991). This may be the case leading to such confusion between electrophiles and nucleophiles observed in this study. Poor recognition of ethene as a nucleophile and poor recognition of the proton as an electrophile may explain the learners’ lack of ability to correctly show the steps involved in substitution and addition reactions.
**Organic Reactions**

The Second-Level pupils were able to classify the reactions when given the reactants, but yet unable to complete the reactions. Taber (2002) acknowledged that only a limited number of types of reactions are commonly considered in Second-Level Chemistry. Taber (2002) also acknowledged that these categories are not mutually exclusive and thus can lead to confusion. There was some confusion in the Second-Level study between the following pairs of reaction types: reaction as acids and substitution, substitution and addition, oxidation and reaction as acid. Questions in both Diagnostic Tests assessing Reactions and Mechanisms required knowledge on three levels: electronegativity, identification of the nucleophile and the electrophile, and determining the product of the reaction (Taagepera and Noori, 2000).

From the students’ responses to questions assessing substitution (Question Seven) and addition reactions (Questions Three and Eight), it is apparent that in many cases, the students are able to predict and draw the correct intermediate or final product for the reaction without showing how this compound is formed. This ability to draw the correct final products may indicate that the students have memorised the products that will be formed from the particular reactions. The students were specifically asked in the questions to show ‘how’ the products were formed as well as drawing the product. Failure to show how the correct product is formed suggests that those students don’t understand how the particular products were formed. Drawing the intermediate does suggest that the students have some understanding of the steps to the formation of the final product, but without the use of arrows to show the electron movement, it suggests some memorisation or lack of understanding of and use of the appropriate representation methods (curly arrows, radicals etc.).

There was considerable misunderstanding and confusion about the major and minor products in the Third-Level study. The words ‘major’ and ‘minor’ were written over the boxes provided for the products of the addition reaction. In this case the words referred to the Markovnikov’s major and minor products. However, from the students’ responses to the questions, it is apparent that many did not recognise this as a Markovnikov addition. This was evident from the students’ drawings of larger molecules with carbon double bonds (C=C) as the major product and smaller diatomic molecules as the minor products (e.g. H-Br or H₂).
Organic Mechanisms

The SEC (2008) identified a limited understanding of the mechanism involved in the halogenation of alkanes and the mechanism of the ionic addition to alkenes. This same difficulty was identified in the Second-Level Diagnostic Test when pupils were asked to draw the compound after the reaction of bromine and ethene. Bowen and Bodner (1991) found that learners solve problems in three stages: preparation, production and evaluation. These stages usually develop into a cyclical process rather than a linear process. During this cyclical process, tactical and strategic decisions needed to be made by the learners (Bodner and Bowen 1991). It is clear from the incorrect responses, that such strategic thinking was not carried out by many learners. There are many factors impeding the learners’ ability to make the correct tactical and strategic decisions when writing mechanisms. Rushton et al. (2008) found that learners had more correct answers when evaluating a static image e.g. the axial or equatorial orientation of a molecule than when evaluating a dynamic system e.g. reaction mechanism. The poor results in questions assessing Mechanisms and Synthesis are consistent with the Irish learners’ identification of Mechanisms as the most difficult topic in Organic Chemistry. This was previously found by Childs and Sheehan (2009) with an earlier cohort of Irish Second-Level pupils and Third-Level students, as well as in other international studies. Taber (2002) observed that many of the incorrect answers and attempts given by learners when writing reaction mechanisms are because the learners have tried to memorise the reaction pathway rather than understand it. For example in the reaction mechanism of bromine and ethene, the learner may recall that ‘a positive carbocation is formed when the bromine atom joins and the other bromine atom has a negative charge’. However, the danger of simply recalling this, can result in an alternative conception where the carbon that the bromine atom joins, becomes the carbocation (positively charged), even though it has a valency of four. Taber (2002) observed that learners select the wrong intermediates in mechanisms and through their explanations, a limited understanding of the mechanism and its representation can be identified. In this study, the participating pupils and students were not given the opportunity to verbally explain their reaction pathway represented for the mechanism.
Mapping electron movement

From the poor performance in the questions assessing electron density and reaction mechanism in the Diagnostic Tests, it is evident that many of the learners have a very poor knowledge of the use and application of arrows to map the movement of electrons in a reaction mechanism. Incorrect responses suggest that the curved / curly arrows held no physical meaning for many of the learners. Some of these arrows were pointed in the wrong direction, with double and single heads used inappropriately. Learners showing arrows coming from areas of low electron density (e.g. a proton) to areas of higher electron density (e.g. carbon double bonds (C=C) or carbonyl groups (C=O)) suggests that the students do not understand what the curly arrows represent. It also shows a misunderstanding through the mixed use of single and double headed arrows. The use of naive mapping strategies resulted in nonsense intermediates as learners forced certain reactions to fit. These learners need to be aware that arrow-pushing serves a function. The incorrect use of arrows inhibits the learners’ ability to represent the mechanism of the reaction accurately. As mentioned above, in some cases the students drew the correct intermediate or final products without showing any electron movement (curly arrows). This may simply have been because the learners were unable to use and apply the arrows accurately. However, because only written Diagnostic Tests were used in the Second-Level and Third-Level studies, it is not known if the learners would have been able to explain the mechanism verbally better than they were able to do so, on paper.

Many of these learners may not be the cognitive stage of development to understand fully the concept of reaction mechanisms (Bhattacharyya and Bodner, 2005). Many of the factors contributing to learner’s difficulty with mechanisms have been outlined by Ferguson and Bodner (2008). It is apparent that many of the learners have developed misconceptions in their use of arrows. This factor, combined with poor recall and application of previously learned relevant content (e.g. electron densities, polarity, intermolecular forces etc.), results in a number of barriers to understanding organic reactions and mechanisms.
Practical Work

While laboratory work was not directly assessed or investigated in the Second-Level and Third-Level questionnaires, feedback from the learners about laboratory exercises, as well as related performances in the Diagnostic Tests, suggest that for many, their laboratory experiences did not provide worthwhile learning. Traditionally, the aim of practical work in Chemistry is to support and complement the theory learned in the classroom. However, performance in the Diagnostic Test questions suggest that pupils and learners are not able to recall what was learned in laboratory exercises when asked again in a different manner. In the Second-Level Questionnaire, the pupils were asked to draw the intermediate compound in the synthesis of ethanal from ethene as well as naming the reactants and the reaction types. This question was poorly answered even though the preparation of ethanal is a mandatory Leaving Certificate experiment (DES 1999a). The researcher was involved in preparing designing and running an Organic Chemistry Workshop for Second-Level Chemistry teachers in January 2010. Discussion and feedback from the teachers at this workshop highlighted the difficulties experienced in the Second-Level school laboratories. Lack of equipment, poor laboratory facilities and limited class time increase the challenge for Second-Level teachers to deliver fully the outcomes of practical work as expected by the syllabus.

These findings from the Diagnostic Test results, as well as feedback from part A in both questionnaires suggest that the outcomes of the laboratory experiences of the learners at both Second-Level and Third-Level involved in this research, were not as successful in attaining long term understanding and learning as intended. These brief findings about laboratory work are contradictory to the traditional learning outcomes that are ideally associated with practical work. Some laboratory initiatives have previously been outlined and discussed in Chapter Three (Section 3.2.4).
As already explained a mixed-methods approach was used when analysing the effectiveness of the *Organic Chemistry in Action!* programme. For this reason, the following research questions will be addressed using the feedback from the qualitative (Classroom Observations, Focus Group, Teacher Interviews) and quantitative (Pupil Questionnaires (II) and Chemistry Teacher Review Questionnaire) methods of analysis used in Cycle Two.

Details of the effectiveness of the teaching strategies used in other research have been outlined in Chapter Three (Section 3.5). The key design criteria of the *Organic Chemistry in Action!* programme were outlined and explained in Chapter Five (Figure 5.1). The effectiveness of the intervention programme will be addressed in the Research Questions 3, 4, 5 and 6 with reference to the design criteria of the *Organic Chemistry in Action!* programme.

9.4 - RQ 3-What Effect can a Specially-designed Teaching Programme using ideas from CER have on the Attitudes and Interest of pupils studying Leaving Certificate Organic Chemistry?

A number of the design criteria of the intervention programme were included to increase the pupils’ interest and attitude to Organic Chemistry. These criteria were designed using ideas from CER and other previous successful interventions. The effectiveness of these criteria in improving the pupils’ attitudes and interest in Organic Chemistry will be discussed here.

9.4.1. Integration of the Context-based Approach

Following the success of the context-based approach in previous Chemistry curriculum initiatives such as SAC in the U.K. (Bennett and Lubben 2006), *ChiK* in Germany (Parchmann *et al.* 2006) and *ChemCom* in the U.S. (Schwartz 2006), this approach was also integrated into the *Organic Chemistry in Action!* programme.

From what has been discussed in Chapter Three (Section 3.2.2), it is easy to understand how this approach of introducing new concepts and ideas through contexts and applications that are familiar to the pupils, facilitates their ability to link these with previous knowledge, and thus develop clear frameworks for understanding in
their Long Term Memory. Ausubel (1968) explained how our prior knowledge and experiences determine what we can learn in the future. Reid (2000) criticised how the applications and contextual examples are added in towards the end of a chapter or topic in traditional Chemistry curricula. The pupils involved in the intervention programme appreciated the integration of the applications of Organic Chemistry throughout the lessons and where they were used to introduce topics. Quotes from the Teacher Interviews included in Chapter Eight (Section 8.2.4.3) support the effectiveness of the incorporation of contextual examples and real-life Chemistry in the intervention materials. There is much evidence from the feedback from teachers and pupils to suggest that this allowed for valuable discussion among pupils. Knowledge must be based on the learners’ perceptions of the real world for understanding to be constructive (Bodner 1986). The contextual examples included throughout the *Organic Chemistry in Action!* programme may have contributed to the pupils in the Intervention Group reporting Organic Chemistry as, easier to understand, more interesting and significantly more enjoyable to learn than the pupils in the Control Group (Table 8.8 in Chapter Eight).

While most of the feedback from the participating teachers was in favour of the context-based approach used, some of the teachers felt that the links made to Organic Chemistry should be more closely linked to the Organic Chemistry content of the Leaving Certificate syllabus.

### 9.4.2. Integration of Practical Work

Practical work was incorporated into the *Organic Chemistry in Action!* programme in a number of ways: traditional and alternative procedures for the mandatory experiments, non-mandatory pupil investigations and Teacher Demonstrations. The participating pupils rated all of these aspects of the programme as helpful in their understanding of Organic Chemistry (Table 8.5 in Chapter Eight). The element of practical work that seemed to have the most impact on the pupils’ attitudes and interest in Organic Chemistry was the Teacher Demonstrations. Although all of these demonstrations were not completed by any of the teachers involved (due to time constraints for the most part), the demonstrations that were carried out did stimulate
inquiry, interest and excitement in the classrooms, as was evident from the insights given by the teachers in Chapter Eight (Section 8.2.4.3).

One of the main reasons for introducing micro-scale laboratory techniques into Organic Chemistry was to reduce the use of the potentially hazardous organic solvents and other chemicals, reduce waste and reduce the amount of time required for the procedures (Zipp 1989). However, the micro-scale apparatus recommended for use was not available in all of the schools. Teachers participating in the intervention programme were still concerned about the length of time required to carry out some of the mandatory Organic Chemistry experiments in the traditional manner. Teachers explained how they had to use lunchtimes and after school periods to complete this practical work. The teachers welcomed the use of the alternative preparations and procedures for the mandatory experiments, as these allowed all of the pupils to carry out the investigations and tests. Allowing the pupils to carry out these by themselves, rather than just observing a demonstration of the mandatory practicals, was useful in facilitating the pupils’ recall of these mandatory experiments.

9.4.3. Use of Learning Resources and Games to involve pupils.

The ‘cone of learning’ (Figure 3.27 in Chapter Three) summarises the effectiveness of active learning methodologies in maximising the amount of content that the learner can remember (Hyland and Dale, 2008). All feedback sourced from the participating pupils (Classroom Observation, Focus Group and Part C of the Pupil Questionnaire II), suggests that they enjoyed the use of molecular models, plastic building blocks, paperclips, poppit beads etc. The pupils enjoyed the activity in the lessons in contrast to the more traditional teaching approach where they would ‘sit and learn’. Feedback from the teachers also reinforced how enthusiastic the pupils were about using the resources. Quotes from the Teacher Interviews report pupils rushing to use the resources, racing and competing to make different isomers of compounds and asking to take the game cards home to play with. These insights suggest that the resources prepared for the Organic Chemistry in Action! programme were effective in motivating the pupils and improving their attitudes to learning Organic Chemistry. As explained by one pupil in the Focus Group, they didn’t expect that Organic Chemistry could be so enjoyable and almost fun!
Research by Dougherty (1997) has shown that a co-operative learning experience results in increased learning and retention. Comments from Teachers B, E and D in their Teacher Interviews have indicated how they saw themselves as facilitators in the learning of Organic Chemistry, which was in many cases more directed by the learners’ themselves.

9.4.4. Guided-Inquiry Learning

Chemistry needs to be taught in a way that allows learners to construct their own knowledge, rather than simply memorising unrelated poorly understood facts. For this reason a guided-inquiry approach was integrated into the intervention programme. As outlined by Taagepera and Noori (2000) this was useful in facilitating the thinking pattern of the novice learners. Rather than being given the definitions of new concepts such as ‘isomerism’ and ‘homologous series’, for example, the pupils in the intervention programme discovered these for themselves through a guided investigation approach. The Intervention Group pupils in turn displayed a better understanding of these topics than the pupils in the Control Group (Figure 8.7 in Chapter Eight). This guided-inquiry approach was also found to be effective in improving pupils’ understanding and attitudes in the PIN-Concept that was used for teaching Organic Chemistry in a previous study in Germany (Barke et al. 2012).

This guided-inquiry approach facilitated the intrinsic motivation of the pupils involved in the intervention programme. Hussein (2006) reported how specifically designed teaching materials, appropriate to the cognitive ability and Working Memory Space of the learners, can have a positive influence on the learners’ attitudes. The approaches included in the Organic Chemistry in Action! programme, for example where the pupils had to ‘crack the code’ to determine the general formula for the families of hydrocarbons, provide the pupils with probing questions and allow them to discover the correct answers for themselves. Approaches such as this may help to explain why a greater percentage of the Intervention Group pupils compared to Control Group pupils, found Organic Chemistry easier to understand and one of the most interesting areas on the Leaving Certificate Chemistry course (Table 8.8 in Chapter Eight).
9.4.5. Changing Attitudes to Organic Chemistry

The pupils in the Intervention Group displayed a much more confident and positive approach towards Organic Chemistry. A higher percentage of the Control Group had studied Science and Mathematics at Higher Level for their Junior Certificate. A higher percentage of the Control Group had also continued to study Higher Level Mathematics and Chemistry for the Leaving Certificate (Table 8.7 in Chapter Eight) than the Intervention Group. This suggests that the Control Group probably had a stronger Science and Mathematics background than the Intervention Group, and overall were better pupils. Despite this, the Intervention Group were more confident in their intentions to attempt a question on Organic Chemistry in the Leaving Certificate examination. Such confidence among the pupils differs from previous Chief Examiner’s Reports, claiming that most pupils tend to avoid the Organic Chemistry question on the Leaving Certificate paper or only answer it as a last resort (SEC 2008, SEC 2005, SEC 2002).

This suggests that these pupils had a more positive experience of Organic Chemistry and had developed a better understanding of the topic. The following topics in particular were rated as significantly easier to learn by the pupils in the Intervention Group than those in the Control Group: Drawing organic compounds, Isomerism, Classification, Carboxylic acids as well as addition, substitution, elimination and redox reactions (Table 8.9, Chapter Eight).

Such evidence by comparison with the Control Group, suggests that the Organic Chemistry in Action! programme was effective in changing pupils’ attitudes towards learning Organic Chemistry and increasing pupils’ confidence in the subject, which is perceived as difficult by so many.
9.5- RQ 4- What Effect can the use of Improved Teaching Strategies and Resources have on the Pupils’ Understanding in Leaving Certificate Organic Chemistry?

9.5.1. Use of Visual Aids

There were many different types of visual aids used in the *Organic Chemistry in Action!* programme. These varied from PowerPoint presentations in every lesson, which included videos and animations, as well as the contents in the Teacher Resource Kit (to facilitate representation of abstract concepts). Unanimous feedback from the teachers involved in the intervention programme recognised the benefit and value of the PowerPoint presentations for each of the lessons (Table 8.2 in Chapter Eight). In contrast to the Pupil Workbooks, which had to be printed in greyscale (due to limited funding available), the PowerPoint presentations provided the pupils with colourful and interesting pictures and animations to facilitate their learning in more ways than were possible than from the Pupil Workbook alone. Some of the teachers suggested including the PowerPoint slides as useful summaries for the lessons in the Pupil Workbook. Most of the teachers had printed and given the PowerPoint slides to the pupils for their own use for reading and revision.

Suggestions made by Rushton *et al.* (2008), to reduce the misconceptions in Organic Chemistry, include increasing active learning in the classroom and increasing the use of visualisations and animations to facilitate the learners in developing a comprehensible and holistic understanding of the organic molecules and techniques used in Organic Chemistry. The teachers valued the PowerPoint presentations in particular for teaching topics such as Instrumentation and Oil refining etc. The teachers appreciated that without the videos, photographs and animations, it would have been very difficult for the pupils to understand these topics, which are not part of the pupils’ everyday lives. The use of videos and animations made them more real and facilitated the pupils’ understanding of these processes and techniques.

Previous research by Fleming *et al.* (2000) has shown how computer models, animations and simulations can be useful in facilitating the learners’ understanding of chemical reactions and mechanisms, which are often the most difficult aspects of Organic Chemistry for the novice learner. Step-by-step animations of the reactions
and mechanisms of the Leaving Certificate course used in *Organic Chemistry in Action!* facilitated the pupils’ understanding of these.

### 9.5.2. Effectiveness of the Molecular Models

The Pupil Model Kits and the Teacher Model Kit were undoubtedly the most popular and most-used resources included in the Teacher Resource Kit. Molecular modelling has proven to be a compelling and effective learning resources (Tasker and Dalton 2006). The pupils listed the models kits as their favourite and the most effective element of the programme. Evidence from the Teacher Interviews, Teacher Questionnaires and Classroom Observations support the effective use of the molecular models. Prior to this intervention programme, many of the teachers said that they had used the molecular models in their teaching of Organic Chemistry. However, most of the teachers had only used models for demonstration purposes or in the teaching of Isomerism. The molecular models were an integral part in most lessons of the *Organic Chemistry in Action!* programme. The participating teachers learned to see the benefit and advantage of the continued use of the models throughout the whole Organic Chemistry section.

The Intervention Group performed significantly better than the Control Group in the assessment of their understanding of molecular shape and structure. This improved performance may be credited to the pupils’ use, manipulation and understanding of the three-dimensional shape of organic compounds. The use of modelling can help to increase the learner’s understanding and retention of the topic by enabling them to picture the Chemistry as it happens (Smith and Metz 1996). Johnstone (1991) outlined the three conceptual levels of Chemistry (Figure 3.2 in Chapter Three). One of the greatest difficulties for novice learners in Chemistry is to be able to relate the macroscopic, sub-microscopic and symbolic levels of Chemistry. Learners need to be able to move backwards and forwards between two-dimensional and three-dimensional representations using physical models and paper representations (Hassan *et al.* 2004). The teachers involved in the intervention programme appreciated how working with the three-dimensional models e.g. modelling the reactions, facilitated the pupils’ understanding. Feedback from the Teacher Diaries illustrated how the molecular models were effective in facilitating the pupils’ understanding of
isomerism, the structure of benzene, the reactivity of pi bonds, functional groups and reaction mechanisms (Section 8.2.2.5 in Chapter Eight).

9.5.3. Improved Understanding of Difficult Topics

In Cycle One of this project, a number of topics were identified as particularly difficult for Leaving Certificate pupils to learn: IUPAC Nomenclature, Functional groups, Characteristics of organic compounds, Reaction types, Mechanisms and Practical work.

There is much evidence to suggest that the *Organic Chemistry in Action!* programme was effective in facilitating the pupils’ understanding of these topics; pupils involved in the intervention group performed better than pupils from the Control Group in questions that assessed these topics (Table 8.10 in Chapter Eight). The pupils involved in the intervention programme also perceived each of these topics as easier to learn and understand than pupils in the Control Group (Table 8.9 in Chapter Eight).

Green and Rollnick (2006) introduced fundamental ideas such as arrows and electron mapping for reaction mechanisms early in their Organic Chemistry course. This same approach was used in the intervention programme, where the mechanistic tools (arrows, radicals, bond fission) were introduced and taught before the introduction of mechanisms. This approach was effective in equipping the pupils with the necessary fundamental concepts to attempt to predict reaction mechanisms.

Feedback from students in research carried out by Ferguson and Bodner (2008) suggested that teaching Organic Chemistry through themes and through discussion would be more beneficial for the learner, rather than learning the details of specific reactions. This approach was incorporated into the *Organic Chemistry in Action!* programme. Teachers D, E and G in particular commended this approach and felt that having completed the intervention programme, their pupils had a greater understanding of reaction mechanisms and would be able to predict the mechanism even for a previously unseen reaction. This confidence in the pupils’ ability suggests that the pupils had clearly understood the topic which has been previously perceived as difficult by many.
Although the pupils in the Intervention Group performed better than those in the Control Group when the understanding of these topics were assessed (Figure 8.7 in Chapter Eight), many of the participating teachers made recommendations to further improve the teaching of these difficult topics. Recommendations included not teaching Instrumentation together in one class, as this may lead to memory overload and confusion (Teacher A), a greater use of the white-board to facilitate the pupils’ mapping of electron movement and the continuous propagation steps in reaction mechanism (Teacher E) and also brief summary sheets to allow the pupils to see all steps of the reaction mechanism close together (Teacher C).

There was no difference in the median percentage score in the Test for Understanding between the Intervention Group and the Control group for the pupils studying Ordinary Level Leaving Certificate Chemistry. The median score for both cohorts was just 15.3% (Table 8.13 in Chapter Eight). This suggests that the Organic Chemistry in Action! programme may not have influenced the understanding of Ordinary Level pupils as well as it did for the Higher Level pupils. There were some mixed responses in the Teacher Interviews (Section 8.2.4.5 in Chapter Eight) relating to the unequal benefit for Higher and Ordinary Level pupils. Some teachers felt that spiralling introduction of topics was too slow and staggered and frustrated the Higher Level pupils. However, others felt that some of the questions in the Pupil Workbook and Homework Assignments (although designed to facilitate cognitive development) were too higher-order and demanding for the Ordinary Level pupils.

The Control Group had a stronger background in Science and Mathematics (Table 8.7 in Chapter Eight) than the Intervention Group. A greater percentage of pupils in the Control group had studied or were studying Science subjects and Mathematics at Higher Level for their Junior Certificate and Leaving Certificate. The ability to study these cognitively demanding subjects at Higher Level suggests that these pupils may have had a stronger Science and Mathematics background. Therefore, the Control Group would be expected to outperform the Intervention Group (weaker Science and Mathematics background) in the Test for Understanding. However, the Intervention Group surpassed the Control Group in their performance in the Test for Understanding, based on a question by question analysis. The pupils in the
Intervention Group also performed better in the sample examination question (Table 8.10 and Figure 8.7 in Chapter Eight).

9.5.4. Facilitation of Cognitive Development

The Curriculum Analysis Taxonomy designed by Shayer and Adey (1981) was used to analyse the curriculum content of Leaving Certificate Organic Chemistry (Table 3.5 in Chapter Three). Much of the Organic Chemistry requires the pupils to be operating at the formal stage of cognitive development. Previous research carried out in Ireland has established that the majority of Second-Level pupils are still operating at the concrete stage (Childs and Sheehan 2010). This high cognitive demand helps to explain why Organic Chemistry in the Leaving Certificate is a difficult topic for many pupils.

As well as improved performance in the Test for Understanding, feedback from the teachers involved in the intervention programme indicated that they believed their pupils had certainly gained a better understanding of Organic Chemistry. Extracts from Teacher Interviews and quotes from the teachers given in Chapter Eight (Section 8.2.4.8) provide evidence of the teachers’ recognition of improved understanding among their pupils. The teachers also provided much evidence indicating that the presentation of the content in the Pupil Workbooks, the practical investigations and the Teacher Demonstrations were effective in ‘getting the pupils thinking’. Presenting and illustrating such difficult topics in a hands-on, step-by-step and inquiry-based manner, facilitated the understanding of these abstract concepts for pupils operating at the concrete stage of cognitive ability, and also stimulated cognitive development.

Most of the design criteria incorporated in the Organic Chemistry in Action! programme (visualising the sub-microscopic, improving practical work, using a contextual approach and re-arranging the sequence of topics in the curriculum) contribute to facilitating the cognitive development of the pupils. Reid (2008) and others have recommended the value of pre-laboratory sessions to prepare the learners for the laboratory session. Teacher C, in their recommendations for modifications to the course, suggested the inclusion of a pre-laboratory session to facilitate the pupils’ preparation for and understanding of the practical work.
The use of these improved teaching strategies and appropriate presentation of new information can help to allow for true understanding for the concrete operational learner, in allowing them to develop abstract thought (Figure 3.16 in Chapter Three).

The success of the “ITS Chemistry” programme (Sheehan 2010) has also illustrated how the incorporation of appropriate and specific teaching approaches and strategies can be effective in facilitating the cognitive development of the learner. The evaluation of the Organic Chemistry in Action! programme did not involve the assessment of the cognitive level of the pupils.

9.5.5. Identification of Misconceptions

The possible pupil misconceptions were outlined in the Teacher Guide at the beginning of each lesson in the Organic Chemistry in Action! programme. In the feedback from the Teacher Interviews (Section 8.2.4.9 in Chapter Eight), the teachers acknowledged the effect of the intervention programme in identifying and alleviating possible misconceptions. In the Teacher Questionnaires, four of the teachers indicated that they felt more aware of the possible learning difficulties and misconceptions in Organic Chemistry after teaching the programme. This indicates that improving the curriculum means changing the teachers as much as their pupils.

The recommendations by Nakhleh (1992) were implemented and were effective in the Organic Chemistry in Action! programme. New words, and definitions were explained clearly and the meaning of the words (often of Greek origin) were defined for the pupils to facilitate their understanding of the terms. Taber (2002) recommended the use of ‘scaffolding’ as a balance between spoon-feeding learners and expecting them to cope without support. In the Organic Chemistry in Action! programme, new concepts and topics were presented in a drip-feed manner to prevent cognitive overload. With appropriate support from the teacher by demonstrations and explanation at the beginning, the pupils were in turn then able to develop a better and more accurate understanding of the concepts. Comments from Teacher G provide evidence of this approach; the pupils were able to accurately predict the reaction mechanism (before the steps were introduced by the teacher) from their previous understanding of bonding and reactivity. The use of molecular models (already discussed in Section 9.5.2 above) was also effective in alleviating the misconceptions.
relating to the bond angles and the shape of functional groups and organic compounds.

9.6 - RQ 5- What Effect can a Specially-Designed Teaching Programme using ideas from CER have on the Interest, Motivation and Teaching Style of Leaving Certificate Chemistry teachers?

9.6.1. Influence of Individual Teaching Styles on Pupil learning

The Teacher Interviews were most insightful in providing the researcher with information about the teachers involved in implementing the Organic Chemistry in Action! programme. The teachers had different backgrounds; while one teacher had been teaching for more than 25 years, others had completed post-graduate research in different areas of Chemistry or worked in the chemical and pharmaceutical industry prior to their teaching career.

These different backgrounds provided each of the teachers with different interests and motives in their teaching of Leaving Certificate Organic Chemistry. The teachers with longer teaching experience felt more aware of possible misconceptions and had devised their own ‘tried and trusted’ teaching strategies for approaching certain topics. There was some diversity between the six teachers in terms of the focus of their teaching. Some teachers were driven by and focused on the terminal Leaving Certificate examination, while others were more concerned about developing the pupils’ interest and understanding of Organic Chemistry, to prepare pupils for further study of Chemistry at Third-Level or to stimulate interest in careers in Science. This issue of the conflicting motivation of the Leaving Certificate Chemistry teachers, merits further discussion and will be addressed in discussing the feasibility of Organic Chemistry in Action! programme (Section 9.7 that follows).

Taber (2002) and Childs (2009) have highlighted the effect of the role of the teacher in influencing pupil learning. An effective teacher should understand their learners’ cognitive ability and also have the necessary content knowledge and pedagogical knowledge (Taber 2002). Although the same Organic Chemistry in Action! teaching materials were used by the six teachers involved in the implementation of this programme, disparity in the performance in the Test for Understanding (Table 8.12 of
Chapter Eight) between these six class groups suggests that other factors may have had an effect on the pupils’ performance in the test. It is evident that the personal implementation of the programme was not uniform in each of the six school settings.

The results in Chapter Eight (Table 8.12) also illustrate the significant differences between class groups within the Control Group also. This provides further evidence of the effect of individual teachers and pupils’ abilities on pupil learning. Individual teachers and diverse school settings are among the external factors that may have influenced the implementation of the programme in both positive and negative ways.

The trial of this intervention programme was dependent on how consistently the programme was implemented by the six participating teachers. A significant concern for this research project, and other similar interventions, is the extent to which teachers used the innovation in the ways intended by the developer. This factor is seen as crucial to the success or otherwise of the intervention (Bennett and Millar 2005). Other intervention programmes have looked in closer detail at the actual classroom practice of their participating teachers (Grásel et al. 2005). While Classroom Observations were carried out in some cases during the implementation phase of this programme, further insight into the actual practices of Irish Leaving Certificate classrooms would be beneficial in the preparation and planning of innovative teaching programmes.

9.6.2. Teachers’ Intentions to Integrate use of the Organic Chemistry in Action! criteria in Future Teaching

As already mentioned in Section 9.6.1 above, most of the teachers had developed their own techniques and strategies for approaching and teaching certain Organic Chemistry topics. While some of the teachers did indicate that they intended to resort to their own methods for teaching particular topics in the future, all of the teachers were intent on incorporating some or all aspects of the Organic Chemistry in Action! programme in their future teaching of Organic Chemistry (Table 8.3 in Chapter Eight).
The main design criteria that the teachers expressed interest in were the spiral curriculum, formative assessment methods, using a variety of teaching approaches, as well as the PowerPoint presentations and molecular modelling kits.

**Spiral Curriculum**

All six teachers agreed that the spiral introduction of topics was ‘really helpful’ in their teaching of Organic Chemistry in the Leaving Certificate (Table 8.3 in Chapter Eight). These teachers recognised the need for particular concepts and topics to be presented in a manner that accounts for the psychology of the learner rather than just the logic of the subject (Reid 2000, Hassan et al. 2004, Johnstone 2000b). All of the teachers found that the sequencing and drip-feed introduction of topics (Figure 5.2 in Chapter Five) used in the intervention programme was an effective approach for teaching the Organic Chemistry on the Leaving Certificate syllabus. Such appropriate presentation of curriculum content has been found to facilitate pupil understanding and learning in previous studies also (Bodner 1992, Hassan et al. 2004). Many of the applications and contextual examples recommended by Johnstone (2010) were included in the *Organic Chemistry in Action!* materials. These links to the pupils’ lives were effective in stimulating pupil interest and facilitating understanding. The participating teachers appreciated these links to the pupils’ lives and to industrial Chemistry and intended to use these again in the future rather than their traditional approaches. The drip-feed and gradual introduction of topics, as well as the frequent revision and recall of topics covered helped the teachers to re-emphasise important concepts and to check for pupil understanding at frequent intervals in the course.

The teachers valued the use of knowledge learned in previous lessons as building blocks for further pupil learning. Since the pupils were prepared for the new information, this helped to ensure that the working memory space was not overloaded, and therefore, was able to operate at its full capacity (Figure 3.14 in Chapter Three). This psychological organisation of the curriculum content facilitated the learners’ understanding better than the traditional, logical approach.
Formative Assessment

The formative assessment tools included in the intervention programme were well received by the teachers involved. All of the teachers involved used the ‘What have I learned?’ summaries at the end of the lessons and the Homework Assignments included in the Pupil Workbooks. Teacher C, in particular, explained how the Homework Assignments were useful for both the pupils and teacher. In previous years, the teachers would have waited until all of the Organic Chemistry was taught before assessing the pupils’ understanding through use of the Leaving Certificate examination questions.

The teachers also indicated their intention to use some of the other resources in the Teacher Resource Kit. Teachers that used the Classroom Response Cube found this resource very useful in checking for pupil understanding.

Variety of Teaching Approaches

A number of different teaching strategies were incorporated into the Organic Chemistry in Action! programme. The skeletal style of the Pupil Workbooks encouraged an inquiry-based approach where the pupils, in many cases, had to work through a number of probing questions to achieve their learning outcomes. This specific design of the teaching materials was a necessary requirement to enable the learners to learn by themselves, and enable the teachers to take the role of facilitators (Dinan and Frydrychowski 1995)

Much of the practical work with molecular modelling and other resources in the Organic Chemistry in Action! programme was carried out in small groups, of two or three pupils. This was primarily due to restricted availability of the resources. The co-operative learning environment was observed by the researcher during the Classroom Observations (Section 8.3.1 of Chapter Eight). The success of such co-operative learning enables the pupils to discover, discuss and challenge concepts before they are fully exposed or explained to them by the teacher (Hagen 2000). The success of team-learning and co-operation between learners has already been reported in previous studies (Katz 1996, Paulson 1999). Some of the teachers explained that in previous years, they would have only used the molecular models for teacher demonstrations,
but having seen the success and effectiveness of allowing the pupils to manipulate these themselves, they were intent on implementing the same in the future teaching.

It was evident from the Classroom Observations in all three schools that the teachers facilitated the lessons, but the pupil activities and questions in the Pupil Workbooks directed the lessons. Bodner (1992) outlined many advantages of this two-way dialogue between teacher and pupils where pupils, are discovering and investigating new concepts and meanings from their perspective (Section 3.5 of Chapter Three). This approach was useful in giving the pupils more ownership and responsibility of their learning. This was evident in discussion with the pupils in the Focus Group (Section 8.3.2 of Chapter Eight).

9.7 - RQ 6- Is it Feasible to Improve the Teaching of Leaving Certificate Organic Chemistry through use of a Specially-Designed Teaching programme?

Platt et al. (2008) and Childs (2009) made many recommendations to ensure the long-term sustainability and success of intervention programmes. Special consideration was taken in the design of this intervention programme to involve the practitioners (teachers) as much as possible in the selection of content and design criteria (Section 5.2.1 of Chapter Five). This teaching intervention placed special emphasis on the cognitive level and learning needs of the Leaving Certificate Chemistry pupils. Comparison with the Control Group showed that the pupils involved in this intervention programme displayed more positive attitudes to Organic Chemistry as well as a higher level of understanding. Such positive findings would suggest that the Organic Chemistry in Action! programme is a value-added method of teaching Leaving Certificate Organic Chemistry. However, before this conclusion can be made, it is important to look at the viability of the programme within the current Second-Level school system in Ireland. Almost all of the negative feedback and recommended changes to the intervention programme were motivated by the teachers’ and pupils’ focus on the Leaving Certificate Chemistry syllabus and examination.

It is understandable that pupils and teachers are focused on the Leaving Certificate examination, as pupils’ results determine their entry to Third-Level education. This
extrinsic motivation of examinations is not unique to the Irish school system and has also been observed in the U.K. (Ratcliffe 2002).

The *Organic Chemistry in Action!* programme was designed to specifically include the Organic Chemistry content on the Leaving Certificate Chemistry syllabus (DES 1999a). For this reason, it was hoped that the programme would be able to achieve the same objectives as teaching the Leaving Certificate Organic Chemistry course in the traditional manner (i.e. prepare the pupils sufficiently for the Leaving Certificate examination). However, through the specific design criteria incorporated in the intervention programme, attempts were also made to change the objectives of teaching Organic Chemistry, away from recall and towards understanding and applications. For this reason, the evaluation of the effectiveness of the intervention programme assessed other factors (attitudes, interests and understanding) as well as the objectives of the Leaving Certificate Chemistry examination. Comparing the performance of pupils from the Intervention Group and Control group in Question Ten (examination question) of the Test for Understanding, it is clear that both cohorts did perform well in this question. However, the Intervention Group (median score = 7.0) performed better than the Control Group (median score = 6.0). This finding verifies the effectiveness of the intervention programme in achieving the same outcome as the traditional teaching of Leaving Certificate Organic Chemistry; preparation for the Leaving Certificate examination. Figure 9.3 illustrates this.

![Figure 9.3 Approaches x and y: comparable pathways to achieving outcome z (Adapted from Millar, 2005).](image-url)
However, the implicit claim of the *Organic Chemistry in Action!* programme is not solely that the intervention programme (approach y) is better the traditional teaching (approach x) in preparing the pupils for the Leaving Certificate Organic Chemistry examination questions (outcome z). Instead, the design criteria and philosophy of the *Organic Chemistry in Action!* programme imply that successful examination performance (outcome z) should not be the most desirable and eminent outcome of teaching. This possibility of alternative outcomes has been highlighted in previous evaluations of educational programmes (Millar 2005).

Figure 8.7 and Table 8.10 in Chapter Eight compare the performance of the Control Group and the Intervention Group in the Leaving Certificate question and the other questions for understanding, where the Intervention Group outperformed the Control Group.

As illustrated in Figure 9.4 that follows, both teaching approaches can prepare the pupils for the Organic Chemistry section of the Leaving Certificate examination. However, a more aspirational outcome in this case is for the learner to develop true understanding in addition to successful performance in the examination (outcome w). Figure 9.4 helps to illustrate how approaches x (traditional) and y (intervention strategies) are not necessarily only two ways of achieving the same learning - which might therefore be compared. They are instead different routes to two rather different targets and are therefore incommensurable (Millar 2005).

*Figure 9.4 Approaches x and y: enhanced approaches for enhanced outcomes.*
Most of the criticisms and negative feedback relating to the intervention programme arose from the pupils’ and teachers’ concerns about time constraints within the given Leaving Certificate Chemistry syllabus and frustration with the inclusion of ‘irrelevant’ material that was not specifically listed on the syllabus content. The attitudes expressed in the Teacher Interviews (Section 8.2.4.7 of Chapter Eight) indicated that teachers felt pressured to focus closely on curriculum content only. The reasons given by teachers for omitting much of the Teacher Demonstrations and optional practical work were time constraints. It was evident from discussion with the teachers that most were aiming to complete the two-year Chemistry course before the mock examinations (February) or by the Easter holidays (April). It is understandable that the teachers need to allow for revision at the end of the two year course and to practice examination techniques etc. with the pupils. All teachers involved in the intervention programme admitted that implementing the Organic Chemistry in Action! programme had required more time than outlined (12 weeks) in the Teacher Guide and much more time than if they had used their own teaching methods.

While some of the teachers admitted omitting certain aspects of the programme (non-mandatory practical work and contextual links beyond the scope of the syllabus) in an attempt to make up for this lost time, overall feedback from the teachers suggests that they were happy to have spent longer teaching Organic Chemistry, in the good faith that their pupils had developed a better understanding of the topic.

As already mentioned, alternative procedures for the preparation of ethanal and ethanoic acid were provided in the intervention programme. These involved the use of permanganate as the oxidising agent instead of dichromate which is banned for use in Second-Level schools. It is important to acknowledge that this ban was only introduced recently (DES 2011a). Therefore there is still much confusion among teachers as the syllabus and examination require pupils to know the oxidation states and colour changes for chromium, but they are not allowed to see them in practice. In the Teacher Interviews, it transpired that some of the teachers did not carry out the mandatory experiments using the alternative oxidising agents as they felt the different colour changes would cause confusion among pupils, as the colour changes for permanganate would not be accepted in the Leaving Certificate examination. This issue illustrates in one case how the Leaving Certificate examination determines what
and how teachers teach, and also the inability of the current system to adapt quickly to necessary changes.

The use of arrows for mapping electron movement in reaction mechanisms was discussed in the Teacher Interviews (Section 8.2.4.6 of Chapter Eight). While some of the teachers understood and valued the purpose of the arrows in teaching and understanding mechanisms, evidence from other teachers suggested that the arrows did not need to be learned and understood by the pupils 'because they are not required in the examination marking scheme'.

Examples such as these issues that arose in the Teacher Interviews, highlight how the content of the syllabus and even more so, the terminal examination, are dictating what and how teachers teach. While the trial of the *Organic Chemistry in Action!* programme has had positive effects on both the teachers and pupils involved; it is still debatable whether such a teaching approach is feasible within the framework of the current Leaving Certificate Chemistry syllabus and examination. This and other arising issues will be discussed below.

### 9.8 – Limitations, Arising issues and Implications

#### 9.8.1. Limitations of this Research Study

The limitations of Cycle One and Cycle Two of this research study have been outlined in Chapter Four (Sections 4.8.1 and 4.8.2). However, in light of the discussion in answering the research questions above, some further limitations have been identified in relation to the preparation of the *Organic Chemistry in Action!* intervention programme and the evaluation.

**Preparation for the Organic Chemistry in Action! Intervention**

Much of the criticism from the participating teachers was in relation to the poor timing of the intervention programme. Much of the feedback in the Teacher Diaries (Section 8.2.2.2 in Chapter Eight) reflected the inaccurate timing of activities and lessons. It was evident that the realities of the dynamic Second-Level classroom were not accommodated for appropriately in the development of the intervention
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programme. It should be noted also that schools differ in the length of periods and hence the teaching time available.

The *Organic Chemistry in Action!* resources were prepared for dissemination to the nine schools that agreed to participate in the implementation of the intervention. The required number of Pupil Workbooks and molecular modelling kits etc. were prepared for each school. However, due to the expense of preparing resources to accommodate for 151 pupils (complete sample size), it was necessary that the Pupil Workbooks be printed in greyscale. Feedback from the teachers and pupils involved in the evaluation of the intervention suggested that the inclusion of colour in the Pupil Workbooks, at least, would have facilitated pupil understanding and learning. Pictures and diagrams would have been more vivid, the safety notes would have been highlighted better and the ‘Important Note boxes’ would have been highlighted also. This may have helped the pupils in recognising ‘what they need to learn for the examination’, which was a concern expressed by many pupils.

In preparation for the implementation of the *Organic Chemistry in Action!* programme, the teachers had limited exposure to the philosophy and values of the programme. Details of the Teacher Training Workshop held in August 2011 have been outlined in Chapter Five (Section 5.3.2). Evidence from discussion with some teachers (Section 8.2.4.8 in Chapter Eight) indicates that some of the teachers understood and appreciated the aims of the *Organic Chemistry in Action!* programme better than others. It is the researcher’s belief that if the teachers had been better informed and educated about the CER background supporting the design criteria of the programme, the teachers may then have been better prepared to implement the programme more accurately and as was intended. The teachers admitted omitting activities and lessons that they perceived to be ‘irrelevant’. However, although these may not have been directly related to the Leaving Certificate syllabus or examination, they were relevant for the pupils’ understanding and interest. It was also clear that the teachers’ understanding and appreciation of the programme changed during their teaching of it.

This Teacher Training Workshop was held during the teachers’ Summer holidays. While lunch was provided for the teachers, no further expense could be provided for. As mentioned already, due the geographical location of the participating teachers in
relation to the University of Limerick, it was not reasonable to ask the teachers to commit to a two or three-day training programme in August. From the teacher feedback (Section 8.2 of Chapter Eight), sourced through the evaluation of the programme, there is evidence of much agreement between teachers on certain elements of the programme and disparity about other issues arising. This suggests that a one-day focus group mid-way through the implementation phase (October midterm from school) and / or after completion of the implementation (February mid-term), may have been insightful and effective in providing further feedback for the evaluation and modification of the teaching materials.

**Evaluation of Organic Chemistry in Action! Intervention**

Although nine schools had committed to participating in the *Organic Chemistry in Action!* programme, only six schools fulfilled this commitment and completed all of the required evaluation (Table 5.6 in Chapter Five). Some conflicting feedback from teachers and pupils in their evaluation of the programme highlights the subjective nature of some of the feedback given by these individuals. Through this small sample size (six schools) the differences between the participating schools were highlighted (Table 8.12 in Chapter Eight). This emphasises the limitation of the small sample size that were involved in the implementation phase (6 teachers and 87 pupils). If it were possible and affordable to include more schools in trialling the programme, the feedback attained may have been more general, and thus increase the validity of the results.

The types of schools involved in the intervention and as part of the control, were well matched (Table 5.8 in Chapter Five). However, there was a significant difference in numbers of pupils attending each type of school. (Table 8.7 in Chapter Eight). Perhaps if the schools evaluated were better matched (according to school type), and if a larger sample trialled the intervention programme, the comparison between both cohorts of pupils would have been more valid.

Research questions Three and Four were addressed above (Sections 9.4 and 9.5). These questions assessed the effectiveness of the *Organic Chemistry in Action!* programme on improving pupils’ attitudes, interest and understanding of Organic Chemistry. It is evident from the discussion that these research questions about the
effect of the programme on the pupils were answered, using a lot of the insight provided by the teachers of the participating pupils. Using the teachers’ perspectives in this respect was useful as the teachers had a better evaluation of the effectiveness of the teaching materials, through comparison with teaching methods and pupils’ attitudes from previous experience. The pupils in comparison, had no previous experience of learning Organic Chemistry, and therefore had no benchmark expectations. Despite the value of the teachers’ insights into the pupils’ perspectives, interviews or focus groups with some pupils from each of the schools would have been beneficial to the evaluation. This may have provided the researcher with a greater insight into the pupils’ perspective on the Organic Chemistry in Action! programme.

In evaluating the effectiveness of the Organic Chemistry in Action! programme, it is difficult to specifically identify which aspects of the design criteria were implicitly effective in contributing to the positive effects observed. While certain elements such as the molecular models, PowerPoint presentations and spiral introduction of topics were highlighted as beneficial, the multi-faceted nature of the programme means that the success of the programme may be credited to the combined use of the design criteria (Figure 5.1 in Chapter Five), rather than any of the individual criterion.

9.8.2. Implications of this research for Curriculum Development

The Leaving Certificate Chemistry syllabus (DES 1999a) is currently under revision by the NCCA. A draft proposal for the new syllabus was released in 2011 (NCCA 2011b). The Organic Chemistry sections of both these syllabi are included in Appendix A. The content in both syllabi has already been compared and discussed in Chapter Two (Section 2.3.3). The Vision of Learning of the proposed new Senior Cycle (NCCA 2011b) has been outlined in Chapter Three (Figure 3.7). Issues relating to curriculum revision have been discussed Chapter Three (Section 3.2.5) also and so will not be repeated here.

It is important in discussing the findings of this research project to consider the implications of the Organic Chemistry in Action! programme with respect to the current revision of the Leaving Certificate Chemistry syllabus. The Organic Chemistry in Action! programme is not essentially a curriculum innovation, since it is
circumscribed by the content of the current Leaving Certificate Chemistry curriculum. (It was necessary to confine the intervention programme to the requirements of the Chemistry curriculum to obtain the participation of the Chemistry teachers and sixth year pupils). Instead, the *Organic Chemistry in Action!* programme may be best described as a pedagogical initiative within the constraints of the current curriculum content. Although there is some additional content (Table 2.20 in Chapter Two) included in the proposed new syllabus that was not on the current syllabus, the teaching materials and resources designed and prepared in the *Organic Chemistry in Action!* programme are adaptable and could be used to facilitate teaching of the proposed new Leaving Certificate Chemistry syllabus.

The ten design criteria (Figure 5.1 in Chapter Five) of the *Organic Chemistry in Action!* programme agree with the knowledge, skills, attitudes and values that have been proposed by the NCCA (2011) to be integrated into the revised Leaving Certificate Chemistry syllabus. The following key skills have been identified as central to teaching in senior cycle: information processing, communicating, critical and creative thinking, working with others and being personally effective (NCCA 2011b). The proposed new Chemistry syllabus (NCCA 2011b), like the *Organic Chemistry in Action!* programme, supports the use of a wide variety of teaching approaches: engaging the pupil to assume more responsibility for their learning, developing communication skills through group work, integrating knowledge and understanding of Chemistry with real-life applications of Chemistry and debating public contemporary scientific issues. The current Leaving Certificate Chemistry syllabus is assessed through a written examination worth 100%. The limitations and unfairness of this mode of assessment were expressed by many of the teachers involved in the intervention programme. The proposed new syllabus has included a second component of assessment (worth 20%). 5% will be credited to reports on mandatory laboratory work written in a laboratory notebook and 15% will credited for a practical examination. There is certainly need for more practical assessment, and if possible continued assessment in Chemistry, in an effort to get away from the terminal written examination.

The findings of this pedagogical intervention for Leaving Certificate Chemistry are very pertinent at a time when the syllabus is being revised. Intervention programmes
such as *Organic Chemistry in Action!* and *ITS Chemistry* (Sheehan 2010) have proven to be effective in increasing pupils’ interest, attitudes and understanding of Chemistry. Both of these programmes have been designed and trialled within the Leaving Certificate Chemistry syllabus requirements. The success of such interventions should be considered, and aspects of them incorporated in the revision of the current Leaving Certificate Chemistry syllabus. The findings and resource materials form the *Organic Chemistry in Action!* intervention programme have been used to inform and guide a proposal of new Leaving Certificate examination questions for the proposed new syllabus.

As the Leaving Certificate Chemistry curriculum undergoes revision, it is essential that the those responsible for the curriculum development seriously consider the feedback from practicing teachers, evidence from intervention programmes such as those named above and the dynamic nature, realities and constraints of the Second-Level school system to ensure the proposed changes are effective and attainable. Bennett and Millar (2005) proposed the idea that curriculum innovation should aim for an ‘improvement rather than just change’. The revision of the Leaving Certificate Chemistry curriculum needs to improve Chemistry education at Second-Level, rather than merely changing the content of what is taught. Enriched learning outcomes, however, are dependent on enhanced teaching approaches (Figure 9.4). As was outlined in Section 9.8.1 above, one of the limitations of Cycle Two in this research study was the limited preparation and training provided for the teachers before the implementation phase. For curriculum change to be effective, and for an improvement to be observed, teachers will require more than just once-off teacher training or in-service days. While the curriculum developers are aware and informed about CER and its implications, it is important to educate teachers, the practitioners, appropriately to equip them to implement curriculum changes more accurately and as intended by the developers.

### 9.8.3. Implications for Teaching Organic Chemistry at Third-Level

The difficulties experienced by those learning Organic Chemistry at Second-Level underpin the difficulties perceived at Third-Level (Hassan *et al.* 2004). As was established in Cycle One of this research project (Table 9.9 in Section 9.2.3), many of the Organic Chemistry topics are perceived in the same manner by those studying it at
Second-Level and Third-Level. In particular, it easy to understand how students without Leaving Certificate Chemistry learning Organic Chemistry for the first time at Third-Level are faced with the same difficulties and challenges as Leaving Certificate pupils also facing the topic for the first time.

Given the positive effect of the Organic Chemistry in Action! programme at Second-Level, this suggests that teaching approaches and design criteria incorporated in the programme may be beneficial to Third-Level students. Although the depth of treatment is much greater at Third-Level than in the Leaving Certificate Chemistry syllabus, many of the same topics are taught. Approaches taken to teaching these topics that were effective at Second-Level e.g. use of analogies, contextual examples, guided inquiry, molecular modelling etc. may also be effective for Third-Level students. Previous research has shown that many of Third-Level students are still operating at the concrete stage of cognitive development (Childs and Sheehan 2010) and therefore should benefit from the design criteria incorporated in the Organic Chemistry in Action! programme. These intervention materials could easily be modified and made available as separate activities for different topics. This would allow elements of the programme to be integrated into existing Third-Level modules.

As was mentioned in Chapter Five (Section 5.3.4), a workshop was held in another Irish university with Chemistry lecturers and postgraduate students. Following the positive feedback from this workshop, one of the lecturers decided to implement elements of the Organic Chemistry in Action! programme into his laboratory sessions. Another Organic Chemistry lecturer has also implemented parts of the Organic Chemistry in Action! programme in their teaching in an Institute of Technology. They used some of the activities in tutorial classes, where the numbers of students were less than in the large lecture groups. Informal feedback from both of these lecturers was positive. This suggests that the teaching approaches and strategies incorporated into the intervention programme, which was explicitly designed in relation to the Leaving Certificate syllabus may also have potential in facilitating the teaching of introductory Third-Level Organic Chemistry.
9.9 Summary

The six research questions that guided Cycle One and Cycle Two of this research project have been addressed and discussed in this chapter. Further issues arising from this research have also been outlined in section 9.8.

Figure 9.5 below provides a brief summary of the outcomes of both cycles of this research project. The timeline and summary of work carried out in each cycle of the project were represented in Figure 1.1 in Chapter One. The colours blue and red were used to distinguish the work carried out in Cycles One and Two of the research project. Research questions One and Two were addressed in Cycle One (highlighted in blue in Figure 9.5) and questions Three, Four, Five and Six were addressed in Cycle Two (highlighted in red in Figure 9.5).
RQ 1: What are the most difficult topics to teach and learn at Second-Level and Third-Level introductory Organic Chemistry?

- IUPAC Nomenclature
- Classification of Functional Groups
- Reactions; types and mechanisms
- Characteristics of organic compounds
- Practical Work

RQ 2: Why is Organic Chemistry difficult?

- Extrinsic reasons: Multidimensional nature of Chemistry, complex language, relationship with Mathematics, laboratory work, Chemistry curricula.
- Intrinsic reasons: Cognitive ability of the learner, Information processing, attitudes to learning, learners' misconceptions.

RQ 3: What effect can a specially-designed teaching programme using ideas from CER have on the attitudes and interest of pupils studying Leaving Certificate Organic Chemistry?

- The inclusion of contextual insights, integration of practical work, fun resources and games and the guided inquiry approach increased pupils' interest.
- Pupils found Organic Chemistry more enjoyable, easier and interesting.
- Pupils were more confident in their intention to attempt an Organic Chemistry question in the Leaving Certificate examination paper.

RQ 4: What effect can the use of improved teaching strategies and resources have on pupils' understanding of Leaving Certificate Organic Chemistry?

- The use of visual aids and molecular models were effective in facilitating pupil understanding.
- Teachers recognised an increased level of understanding among pupils and acknowledged how the presentation of topics in the OCIA! materials facilitated cognitive development.
- Pupils outperformed those in a Control Group in the Test for Understanding and in an examination question.

RQ 5: What effect can a specially-designed teaching programme using ideas from CER have on the interest, motivation and teaching style of Leaving Certificate Chemistry teachers?

- All teachers involved were enthusiastic and positive about trialling the intervention.
- Feedback from the six participating teachers was subjective in nature.
- Acknowledging the benefits observed, teachers were intent on incorporating all or aspects of the OCIA! programme in their future teaching of Organic Chemistry.

RQ 6: Is it feasible to improve the teaching of Leaving Certificate Organic Chemistry through use of a specifically designed teaching programme?

- Most of the negative feedback and criticisms of the OCIA! programme were related to poor timing and irrelevant (non-syllabus) content.
- Teachers and pupils are examination-focused and hence teaching and learning in the classroom is dictated by the syllabus and assessment.
- The design criteria and teaching approaches of the OCIA! programme are in-line with guidelines for the proposed revised Leaving Certificate Chemistry syllabus.

Figure 9.5 Summary of findings from the Research Questions
Chapter 10

Conclusion
10.1 –Introduction

The aims of this research project were outlined in Chapter One:

- To investigate the difficulties in teaching and learning Organic Chemistry in Ireland.
- To develop an intervention programme to target the difficult topics in Organic Chemistry by promoting real understanding and positive attitudes towards the subject.

The research questions guiding the two cycles of this Action Research project have each been addressed and discussed in Chapter Nine (summarised in Figure 9.5). The findings from this research project may contribute to improving the teaching and learning of Organic Chemistry in Ireland by providing a greater insight into the problems that exist and possible solutions to alleviate these.

The main findings of this research project are outlined in Section 10.2 that follows. The recommended future work related to the project is outlined in Section 10.3. Section 10.4 provides the final remarks highlighting how this research project has provided a unique contribution to CER.

10.2- Main Findings

The main findings of this research project are summarised in Figure 10.1 below.
The findings listed in Figure 10.1 are outlined briefly here.

1. **Organic Chemistry is an Area of Difficulty in Ireland:**
   
   Prior to this research study, much research into the difficulties experienced by those teaching and learning Organic Chemistry had been carried out in other countries. However, no detailed investigation had been carried out in Ireland. The findings from Cycle One of this project has confirmed that many of the same difficulties experienced by those teaching and learning Organic Chemistry in other parts of the world and in other education systems also exist in Ireland.

2. **Novice learners at Second-Level and Third-Level experience Common Difficulties:**
   
   The findings from the Second-Level study and Third-Level study that were carried out in Ireland as part of Cycle One of this research project exhibited many commonalities. This suggests that those learning Organic Chemistry at Third-Level (often without Second-Level Chemistry) experience many of the same difficulties as those learning Organic Chemistry for the first time at Second-Level.

3. **CER findings can Inform and Improve Classroom Practice in Second-Level Irish schools:**
   
   While much research has been carried out in the area of Chemistry pedagogy, it is important that these findings from CER are made known to curriculum and policy developers so that they can be implemented in classroom practice. The design and development of the *Organic Chemistry in Action!* programme established that ideas from CER, and evidence from previous successful Chemistry pedagogy initiatives, can be incorporated into Irish Second-Level Chemistry education. Findings from the evaluation of the trialled intervention showed that this intervention had a positive influence on pupils’ attitudes, interest and performance in Organic Chemistry.
4. **Effect of the ‘Points-race’ on Teaching and Learning in the Leaving Certificate programme:**

Despite the availability of a wide variety of resources and teaching materials to stimulate inquiry and enjoyment in the *Organic Chemistry in Action!* programme, much of the teaching and learning in the intervention classrooms was dictated by the Leaving Certificate syllabus and driven by the examination requirements. Within the current Second-Level education and examination system, innovative teaching approaches such as the *Organic Chemistry in Action!* programme may not be achievable, as the outcomes (improved attitudes, performance and understanding) are beyond the narrow outcomes required in the current system (ability to answer eight of the eleven questions in the Leaving Certificate examination paper). As a result, many teachers are reluctant to try out new approaches to teaching Chemistry.

5. **Effect of the Chemistry teacher’s Attitude to Teaching and Learning in the Leaving Certificate programme:**

As discussed above, the focus of most pupils in the Leaving Certificate programme is on the terminal examination. However, given the subjective nature of some of the feedback from the teachers that trialled the *Organic Chemistry in Action!* programme, evidence suggests that the attitude and teaching approach adopted by the Chemistry teacher can have an effect on how the pupils are focused and motivated. While some of the teachers were blinkered in their focused preparation for the Leaving Certificate examination, others referred to the importance of preparing the pupils with the skills and understanding to equip them for further study of Chemistry at Third-Level and in preparation for careers in the chemical and pharmaceutical industries.

6. **Timely implications for the Current Revision of the Leaving Certificate Chemistry syllabus:**

Much of the negative feedback from the evaluation of the *Organic Chemistry in Action!* programme was related to the restrictions of the current Leaving Certificate examination system. Chemistry teachers and pupils are limited to the specified syllabus content that has to be taught in less than 180 hours in
preparation for a terminal three-hour written examination. Although many positive effects of the intervention programme were observed, the feasibility of such a teaching intervention at Senior Cycle in Irish Second-Level classrooms is dependent on a change in how Leaving Certificate Chemistry is taught. In revising the current syllabus, as well as reviewing and modifying the curriculum content, appropriate teaching strategies also need to be introduced to facilitate pupil understanding as well as pupil learning. The execution of improved teaching strategies and methods will only be put into practice if the assessment methods are changed, moving from rote-learning and recall (lower-order questions) towards assessment of true understanding (higher order questions).

7. **Limitations of Teacher Preparedness:**

One of the factors that may have hindered the effectiveness of the trialled implementation of the *Organic Chemistry in Action!* programme was the limited training and preparation provided for the participating teachers before dissemination of the teaching materials. If the introduction of new pedagogical methodologies is expected to be effective and implemented correctly in the classroom, teachers need to be informed and educated appropriately to do so. Teachers, the practitioners, may not be as familiar with CER findings and literature as educational developers and curriculum makers. Single-day training workshops and short in-service courses cannot provide sufficient training to prepare teachers to implement correctly new teaching strategies. Perhaps, for real change to be effective, improvements in Chemistry pedagogy need to be introduced as a gradual transformation rather than as an immediate revolution. The spiral approach used in the *Organic Chemistry in Action!* programme should perhaps be used in the pedagogical innovation.
10.3- Future work

Some of the findings in this research project are unsettling and merit further investigation and research. The immediate issues to be addressed are outlined here:

1. **Further Evaluation of the Organic Chemistry in Action! programme:**

   Comparison of performance between the Intervention Group and Control Group on the Leaving Certificate examination question given to both cohorts found that the Intervention Group performed better in this question, as well as in the other questions that tested for understanding of Organic Chemistry. This finding suggests that the pupils in the Intervention Group should be more willing to answer and perform better in the Organic Chemistry questions in their Leaving Certificate examination in June 2012. It would be worthwhile for the researcher to pursue the performance of these pupils when the Leaving Certificate examination results are released in August 2012.

   Feedback from some of the teachers that participated in the Organic Chemistry in Action! programmes suggested that they felt their pupils were better prepared to study Chemistry at Third-Level having completed the programme. The Organic Chemistry in Action! programme was also effective in improving pupils’ attitudes and interest in Chemistry. It would be interesting to follow the Third-Level pathways chosen by the pupils who participated in the programme; to investigate if they pursued further study of Chemistry and if so, if their improved understanding of Organic Chemistry was beneficial to them. It is hoped that the promotion of real understanding in the Organic Chemistry in Action! programme should contribute to more effective long-term gains.

   Two schools (School F and School H) for different reasons did not trial the Organic Chemistry in Action! materials with their sixth-year pupils. Instead the teachers in these schools chose to trial the materials with their-fifth year Chemistry classes in the Spring term 2012. Feedback from these teachers and pupils needs to be gathered and analysed to investigate the effectiveness and appropriateness of the programme for use in fifth-year (year one of the two year Leaving Certificate Chemistry programme).
2. **Revision and Further Dissemination of the Organic Chemistry in Action! programme:**

Using feedback from those involved in all trials of the *Organic Chemistry in Action!* programme, the teaching materials will be revised (Figure 4.3 in Chapter Four). Recommended changes related to content, timing, presentation and accessibility of the teaching programme will be made as required.

It is apparent from feedback given by the teachers involved in the implementation phase, and because of the restrictions of the current Leaving Certificate syllabus that the materials may be more effective for use in Irish Second-Level classrooms if they were more teacher-orientated. The content (activities, lessons, resources) of the teaching programme could be restructured as individual teaching units to be incorporated into the Chemistry teacher’s own teaching approach. Such a mode of implementation would provide the teacher with greater flexibility in comparison to the confinement of the guided lessons in the current 12-week programme. Such materials could also be used in tutorial settings for introductory Third-Level Organic Chemistry courses.

The effective dissemination of these individual teaching units may be more practical and achievable than dissemination of the complete teaching programme. As already mentioned, appropriate teacher training will be required to ensure the accurate implementation of the teaching materials and to ensure the aim of the *Organic Chemistry in Action!* programme in facilitating true understanding and positive attitudes to Organic Chemistry are achieved.

The revised *Organic Chemistry in Action!* materials will be disseminated in the following ways:

- Training workshops with practicing Chemistry teachers to inform them about CER findings that have informed the *Organic Chemistry in Action!* programme. Following this, the teachers can then avail of the teaching materials for implementation in their own classrooms.
- Individual teaching units (teacher information and pupil activities) for different Organic Chemistry topics on the Leaving Certificate course will be published as a series of articles (stand-alone activities) in the...
Chemistry in Action! magazine, which is circulated to Chemistry teachers in Ireland and the U.K.

- The resource materials will be made available to all of the lecturers that participated in the Third-Level study, for use in their own teaching of introductory Organic Chemistry. The published material from this research will also be disseminated to these Third-Level lecturers.
- The *Organic Chemistry in Action!* resources such as PowerPoints, videos, pupil worksheets, homework assignments, game cards etc. will be made available for teachers to download from the online forum *Sugar Sync* and also on the Royal Society of Chemistry (RSC) *Learn Chemistry* database for teaching and learning resources. The researcher will be also able to provide interested teachers with custom-made molecular model kits for their pupils. Such model kits are designed to include the necessary contents for the activities included in the *Organic Chemistry in Action!* programme.

3. **Move to Revise how Leaving Certificate Chemistry is Assessed**

The researcher is currently involved in organising a one-day and later a Summer workshop in collaboration with the NCCA and National Centre for Excellence in Mathematics and Science Teacher and Learning (NCE-MSTL). These workshops will involve working with practicing Leaving Certificate Chemistry teachers to write new assessment questions for Leaving Certificate Organic Chemistry. The assessment questions will be designed to include unseen reactions and compounds, and therefore aim to assess the pupils’ true understanding. They will aim to include both lower and higher order question types.
10.4 Unique Contribution of this Research Study

The findings from Cycle One of this study have provided clear evidence of the difficulties experienced by those learning introductory Organic Chemistry at Second-Level and Third-Level in Ireland. While these findings were useful in informing and guiding Cycle Two of this research project, they are also insightful for those involved with the teaching, curriculum development and assessment of Organic Chemistry at Second-Level and Third-Level, and will be published in Chemistry Education Research journals.

This research project has effectively combined the findings from CER in the development of the *Organic Chemistry in Action!* teaching materials. A number of strands of research were combined in the development of the intervention programme. These included the use of a spiral curriculum, facilitation of cognitive development, guided-inquiry learning, a context-based approach and integration of practical work amongst other approaches. Teaching strategies and materials previously suggested in these strands of research were effectively combined to form the *Organic Chemistry in Action!* teaching materials. The development of this programme for teaching Leaving Certificate Organic Chemistry in Ireland has resulted in a unique set of resources and materials specifically designed for teaching of introductory level Organic Chemistry.

The results of the *Organic Chemistry in Action!* intervention programme have demonstrated successfully a proof of concept, that it is possible to improve the way Organic Chemistry is taught in Irish Second-Level schools by applying ideas from CER, while still working within the constraints of the syllabus.

While this research project has not explicitly investigated the reasons for learners’ misconceptions in Organic Chemistry, it has instead focused on implementing the relevant findings from CER in Irish Second-Level classrooms through the intervention programme. It is the researcher’s opinion that CER will only be effective where it can be put into practice. Through investigation of difficult topics (Cycle One) and intervening to alleviate these difficulties (Cycle Two), this Action Research project has helped to bridge the gap between research and practice and Chemistry Education.
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