A Comparative Study of

Leaving Certificate Chemistry in Ireland and

Advanced Placement Chemistry

in the United States

Dr Niamh McGoldrick

Master in Education

University of Dublin

Trinity College

Supervisor: Prof Joseph Roche

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Dr Niamh McGoldrick

Summary

This research project was inspired by a lecture series on teaching methods that I completed in the first year of this programme and the experiences that I have encountered throughout my years in a university chemistry department. Using these events as inspiration, the aims and the accompanying research questions were created for this project.

This research aims to compare the Leaving Certificate Chemistry programme in Ireland with Advanced Placement Chemistry in the United States. By examining their entry requirements, curriculum design and assessment criteria, an overall understanding of both programmes has been established in the context of science education today. This research project also includes a separate study of examination papers from both programmes using the six cognitive objectives outlined in Bloom's Taxonomy. The frequency of each individual objective was recorded throughout annual examination papers over a five-year interval. These individual values were summed so that an overall picture could be established and that the importance of the taxonomy to each programme assessment could be determined.

The comparative education method was used as the methodology for this project, specifically the science (new) approach, which has been used for similar international studies in comparative education. By using this method to create the parameters of this study, the curriculum, experimental content and assessment documents of both programmes were assessed using a range of relevant qualitative and quantitative resources.

This research project highlighted aspects of the Leaving Certificate and Advanced Placement programme that were found to be either beneficial or uncomplimentary to second level science education. By identifying these characteristics, it is hoped that chemistry education "best practise" for this educational cohort has be established. Recommendations have been made so that the design of future syllabi and assessments can include the favourable

elements of the findings of this study. These recommendations include requesting the inclusion of a practical assessment which both programmes currently omit.

Acknowledgements

Firstly, I would like to thank my supervisor Prof Joseph Roche, whose support and advice have been so influential in the design and execution of this project. More importantly, I will be forever grateful for the kindness and understanding that you have shown throughout this experience, especially in year one when it looked as though I may not complete the M.Ed. programme. A special note of thanks also to Prof Colette Murphy, who inspired the original idea for this study through lectures on learning theories and extended discussions.

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supply of tea and biscuits, along with his encouraging words of love and support will always be remembered.

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Glossary

ACT	American College Test
AP	Advanced Placement
CAO	Central Applications Office
ED -	U.S. Department of Education
F1-F8	Leaving Certificate Foundation Level Grading System
H1-H8	Leaving Certificate Higher Level Grading System
HL	Higher Level
HOL	Higher Order Learning
HOS	Higher Order Skills
IDA	Industrial Development Authority
ISTA	Irish Science Teachers Association
MCQ	Multiple Choice Tests
NCCA	National Council for Curriculum and Assessment
NaCl	Sodium Chloride Salt
NaOCl	Sodium Hypochlorite
NCES	National Center for Education Statistics
NEDA	National Defense Education Act
NFQ	National Framework Qualifications
NGSS	Next Generation Science Standards
NSF	National Science Foundation
O1-8	Ordinary Level Leaving Certificate Grading System
OECD	The Organisation for Economic Co-operation and Development
OESE	The Office of Elementary and Secondary Education
OL	Ordinary Level
PhD	Doctor of Philosophy
PISA	Programme for International Student Assessment
PSSC	Physical Sciences Study Committee
SAT	Scholastic Assessment Test
SMSG	School of Mathematics Study Group
STEM	Science, Technology, Engineering and Maths

U.S.	United States (of America)

Chapter 1: Introduction

1.1 Rationale of the study

This research project describes a comparative educational study between the Irish Leaving Certificate and the Advanced Placement chemistry programmes in the United States. This study focuses on the content of both syllabi, the associated practical work and the resulting examination system, while assessing the extent to which both systems prepare a student for a chemical science degree at university.

My background is in chemistry, I completed both my undergraduate and PhD in the subject. During my PhD, I was required to teach the undergraduate cohort during weekly practical undergraduate classes. Frustrated with the prescriptive view towards scientific inquiry that undergraduate students had acquired led me to question both the current Leaving Certificate chemistry programme and other international second level courses that our undergraduate students had stemmed from. These frustrations developed into an interest and then a desire to develop a depth of understanding about the curriculum design of the Leaving Certificate programme and compare it with similar courses internationally.

My research questions are rooted in a professional interest that I developed in my current role as a university staff member; my job connects the university's international office with the Schools of Chemistry and Physics. This role requires me to support the university's international recruitment strategy and to provide pastoral care to registered international science students. The work requires an in-depth understanding of the challenges that face a student during their undergraduate science experience at university so that suggested solutions can be provided. To do this job as effectively as possible, it seems practical that this project should also focus on a recognised high school programme overseas.

Most of the university's first year undergraduate science class have progressed through the Irish Leaving Certificate cycle, yet this overall percentage is expected to gradually decline as internationalisation continues to strengthen in

Ireland. Currently, the largest cohort of international undergraduate science students originates from the United States. This group, compared with the national cohort of students, are very different in terms of expectations and educational experiences. This has led me to question whether these variances can be related to each programme that the cohorts have graduated from, and whether there are tangible differences between the two systems that third level institutions should be aware of.

1.2 Research Aims and Questions

This study aims to identify the key differences between the Irish Leaving Certificate Chemistry and Advanced Placement Chemistry programmes and to establish if the graduates from both programmes are equally prepared to undertake a science degree in an Irish university environment. Throughout this study, this work will examine factors such as teaching approaches, syllabus, exam questions and laboratory components to establish whether these differences exist and, if possible, identify which has the greatest impact on a student's secondary/ high school chemistry education. The research area that will be analysed in this study and the associated research question(s) are outlined in Table 1.1.

Table 1.1: *Research Questions*

Research Area	Associated Research Question
Programme Requirements	Are the entry requirements of both programmes the same and how it science education in second level education perceived?
Curriculum Design	How do both chemistry programmes differ in content, subject matter and structure? How is practical work incorporated into the curriculum and how is it assessed?
Examination Style and associated importance	How do examination structures differ in question style and range of material covered? Do both programmes successfully adhere to Bloom's Taxonomy by incorporating all six cognitive objectives into their assessment? How do both contribute to entry into undergraduate science programmes?

1.3 Outline of this study

This study, although primarily desk based, will focus on establishing an understanding of both programmes before completing an analysis of their associated exam papers according to the classification outlined in Bloom's Taxonomy. This understanding will be developed by conducting a literature review of science education and the current respective education system that exists in Ireland and the United States. Once completed, this will form a backdrop for the next phase of the study, a comparison of the curriculum content, the practical content and methods used in the Leaving Certificate and Advanced Placement chemistry programmes. This process will require reviewing both common course textbooks, revision books and online materials, as well as discussions of both systems in the literature. The second phase of the project involves an extensive classification of exam questions produced for both programmes according to the six objectives of Bloom's Taxonomy. The recommendations from this research and suggestions for future work will then be outlined in the final chapter of this thesis.

1.4 Structure of the thesis

Chapter two describes the political, social and educational background in Ireland and the United States from the early 19th century to the present day. This history specifically references relevant national events that have impacted the evolution of scientific education in both countries. A summary of the two educational pathways leading to second level graduation is also explained, as well as a description of the format of the Leaving Certificate and Advanced Placement programmes. The resulting grading system for both programmes is also described. This chapter will ultimately provide a contextual backdrop for the comparative study that follows and the associated findings from all parts of the project.

Chapter three outlines the methodological theory considered in the design of this study and the associated framework adopted. Relevant works from other comparative educational studies, both national and international, will be referenced as well as the history of Bloom's Taxonomy, which inspired the classification of the selected exam papers. This chapter also describes the limitations and potential avenues of personal bias in the project, and the suggested actions that will be taken to compensate for them.

Chapter four describes the process that will be used during the data analysis and the associated outcomes of this work. The results if this analysis will be presented graphically, and initial findings will be presented accordingly. Aspects of both programmes will also be compared in a sequential order, including a discussion of their curriculum content. Omissions will be contextualised against other recognised international chemistry programmes so that the importance of any omissions can be fully explained. A special emphasis will also be placed on the experimental contributions of both courses, as the researcher attributes a personal importance on the value of practical work in a chemistry programme.

Chapter five will summarise the main findings from this comparative study and will discusses possible features of a proposed new curriculum in Leaving Certificate Chemistry. The strengths and weaknesses of both programmes will be discussed, and based on these findings, a 'best practise' curriculum for second level chemical education will be accompanied by suggestions for potential methods of assessment. The implications of the project and directions for future research will also be identified.

The appendices include comparative excerpts from the syllabi of both programmes (see A-1 and A-2). Online access details of the full syllabus have also been included. A-3 includes a sample multiple choice exam from the Advanced Placement website which will be used in the analysis completed in Chapter 4 (Section 4.3.7.4). A-4 is a description of the Rasch Model, referred to in the future work section of Chapter 5 (Section 5.6).

Chapter 2: Literature Review

2.1 Introduction

This chapter focuses on the context of the political environments in Ireland and the United States and how these developments have shaped the educational landscape both in terms of administration and curriculum content over the last century. This chapter also compares the general format of the secondary school and high school systems, and the student requirements of both programmes to be deemed eligible for graduation. Above all, this chapter aims to set a context for the research project which will support the further pedagogical exploration of the syllabus and assessments that follow in the subsequent chapters.

To understand post-primary and third-level education systems in Ireland and the US, it is first necessary to compare and contrast how both have developed from the twentieth century onwards.

2.2 Ireland and the United States: Context

Ireland and the United States are vastly different in terms of population, geographical scale, history, and political climate. Despite being deemed to be part of Western civilisation, both countries have a turbulent political history which has left its mark on their national archives. The influence of Irish immigrants in the United States is well documented and the significant presence of the Irish American is evident even in present day (Little, 2018; Various, 2007). Both countries have similar religious beliefs. Christianity is the predominant national religion with faith having a consequential role to play in the establishment of the Irish and American education systems (Zuckerman, 2016). English is the predominant language of both countries, yet both are adapting to the benefits and the challenges of a multicultural society (Bryan, 2009; Thompson, 2010). Although Ireland and the United States are different, there are many parallels to be drawn from both societies.

2.2.1 Ireland

2.2.1.1 The Social and Political Landscape of Ireland in the 20th century

Ireland had a turbulent political history under the rule of Great Britain which lasted from the 12th century to the early 20th century. The Irish people organised a number of uprisings against British rule between 1916 and 1923 including the Easter Rising (1916), the Irish War of Independence (1919-1921) and the subsequent Irish Civil War (1922-1923) (Bowden, 1973). Under the Anglo-Irish Treaty, Ireland was made a free state by Britain in 1922. Between 1922 and 1937, Ireland was considered a dominion of Britain (a semi-independent entity, similar to that of Canada and Australia) (McMahon, 2008). In 1949, 26 of the 32 counties of Ireland were officially declared part of the new republic and were ruled by an independent, elected government. It was only then that Ireland was elected as an official member of the European Union (Hoffman, 1989).

Since becoming a republic, the role of Prime Minister has been initiated and is globally referred to as the Taoiseach of Ireland. As the head of the government, the Taoiseach is appointed by the elected President who is the head of state of the country. The Taoiseach must maintain favour of the majority of the Dáil, the Irish government, to stay in power (Department of the Taoiseach, 2001).

The six remaining counties remain part of Northern Ireland and are governed by the United Kingdom.

2.2.1.2 Ireland: Secondary Education in a Newly Formed Republic (1922-1960)

In the early 1920's, several major changes happened to the Irish education system. For the first time, the conflict over education that had existed between church and state was minimal and as a result, there was an increase in the amount of public funding available to secondary schools across Ireland. This included privately-run denominational secondary schools which were largely managed by the Catholic Church (Coolahan, 2005).

Up until 1923, the Board of Commissioners for Intermediate Education made all educational decisions in Ireland, including the organisation of Irish public education examinations and the administration of finances for all Irish schools (Department of Education, 1925). This Board was officially dissolved in 1923, and was replaced by two Intermediate Education Commissioners, Proinnsias O'Dubhthalaigh and Seosamh O'Neill (Coolahan, 2005). Following these two appointments, the Department of Education was created in 1924 under the Ministers and Secretaries Act and was subsequently followed by the introduction of the Intermediate Certificate cycle (for 12 to 15 years old) and the Leaving Certificate cycle (for 16 to 18-year olds) into Irish second level education (Department of Education, 1923-1924, 1925; Harford, 2009). The Department was responsible not only for primary, secondary and university education, but for technical and vocational training, industrial schools, endowed schools and reformatories. Amongst its duties included responsibility for the National Gallery of Ireland as well as museums (such as the National Museum of Science and Arts), and the National Library. In 1997, the Department's name was adjusted to the Department of Education and Science and then in 2010, became the Department of Education and Skills (Government of Ireland, 2010).

In 1924, the Irish government, Dáil Éireann, recommended a number of changes to the Irish secondary education curriculum. These changes included mandating basic science education and introducing oral Irish examination. This combined with the recognition of approximately 200 secondary schools across the country, meant that enrolment in recognised schools increased significantly over the next two decades from 20,776 to 54,019 pupils (Coolahan, 2005). In terms of science education, the consequences of this decision were clear. In 1931, there were less than 15,000 students in Ireland studying science subjects excluding what was referred to as domestic science (now known as home economics) (Healy, 2015). By 1957, this had more than doubled to 31,881. The subject of science had finally been given importance in the eyes of the Irish education system (O' Raifeartaigh, 1959).

2.2.1.3 The Post Primary Curriculum and Science Education from 1960 onwards

Although the senior state exam, referred to as the Leaving Certificate, was established in 1924, it was not until the 1960's that the Irish people saw the expansion of second level education not just in terms of curriculum, but in its funding structure and national availability. Before 1960, Intermediate Certificate science was a requirement to enter a Leaving Certificate science subject. Since Intermediate Certificate science was not available in secondary schools across the country, this restricted the number of potential science students electing to study science at a senior level. It was also eight times more likely to be offered in male secondary schools than in female secondary schools. The content of all Leaving Certificate science subjects was also out of date. Science syllabi had remained unchanged for half a century and as a result, students could not relate to its unsuitable curriculum content (Wallace, 1972). Major reform was undoubtedly needed if any progression was going to be made in national science education.

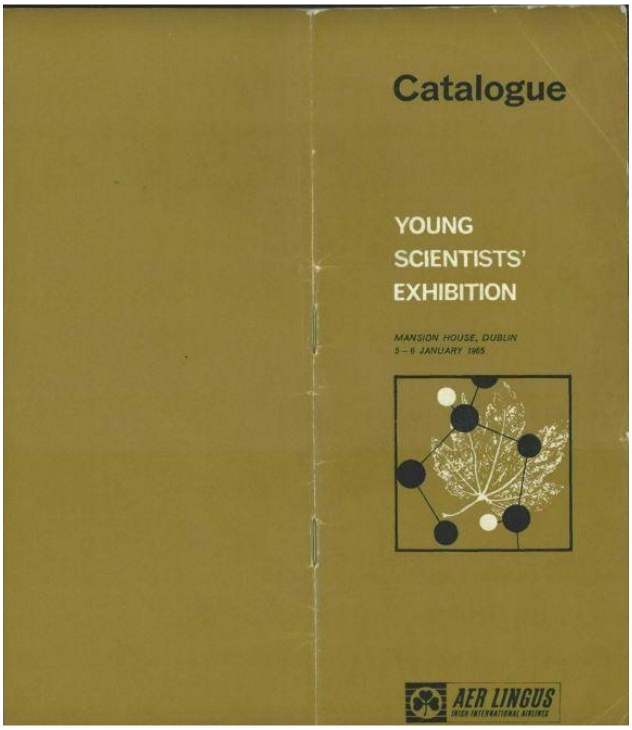

Figure 2.1: *The Young Scientists Exhibition catalogue (1965)*

After 1960, Irish science education was finally given a more experimental foundation, and financial grants were made accessible for improvements to science laboratories around the country (Wallace, 1972). Special grants were also made available to science graduates with the hope of encouraging them to enter teaching as a profession. To promote interest in science amongst the public, a national science competition was established called the “Young Scientist Exhibition” and was sponsored by Aer Lingus, Ireland’s national airline (Young Science Exhibition Organising Committee, 1966). This competition recognised the importance of science education in second level students in the public domain, a move which was nationally significant in the development of science education as a subject. The exhibition, now referred to as BT Young Scientists Exhibition, is the longest running school science project fair of its kind in the world.

2.2.1.4 The Irish Economy and its Reliance on Science and Technology (1980- present day)

Since the 1980’s, the pharmaceutical and technology sector in Ireland has grown from strength to strength and has steadily expanded its national presence through the relocation of companies to our shores. Today, 24 of the world’s leading pharmaceutical and biotechnology companies alone are located here, including Pfizer, Merck and Eli Lilly (Burke, 2017). This sector produced more than €50 billion in Irish exports in 2016. Chemical and related exports accounted for 55% of Ireland’s exports in the same year (Central Statistics Office, 2017). This has resulted in a huge demand on Irish science, technology, engineering, and mathematics (STEM) graduates across the country, with Ireland now promoting itself as a highly educated workforce to attract potential international companies (Industry Development Authority (IDA) Ireland, 2018).

2.2.1.5 Current Challenges in Leaving Certificate Science

There has been a noticeable decline in the number of students taking senior cycle science in secondary school since the early 1990’s, particularly in the areas of chemistry and physics. Biology is often perceived by students to be an easier subject, one where high grades and more importantly high points, are considered to be more achievable than in chemistry or physics (The STEM Education Group, 2016; McGuire, 2016). This perception caused a 4% reduction in the number of students taking either chemistry or physics as a Leaving Certificate subject from 1990 to 2001. In reality, all three subjects have an equal rate of failure (9-10 %), a student is just as likely to fail chemistry or physics as they are biology (Murray, 2016). Furthermore, there are approximately three times the number of qualified biology teachers registered with the Teaching Council of Ireland as there are physics and chemistry teachers (The Teaching Council, 2014). This shortage has led to secondary schools across the country relying on biology teachers to teach Leaving Certificate Chemistry and Physics which has ultimately affected both the educational experience and the results of potential STEM degree applicants (Dempsey, 2014).

2.2.1.6 Secondary School Education today; format and structure

Today, Irish education is mandatory for all students from the ages of 6 to 16 years, or until the Junior Certificate examination cycle is completed (Citizen Information Board, 2013). The Junior Certificate cycle covers 1st to 3rd year of secondary school education (Figure 2.2) and is followed by a discretionary year known as Transition Year. Transition Year does not require students to undertake formal examinations and allows students to experience subjects outside of the traditional Irish curriculum such as law and interior design (State Examinations Commission, 2017).

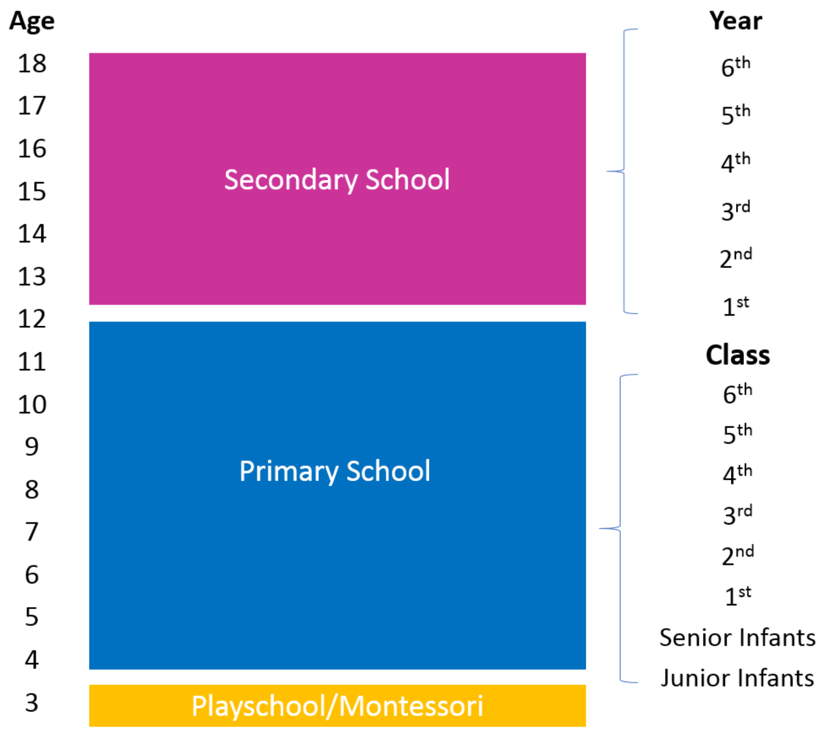

Figure 2.2: *The Educational System in Ireland*

The senior cycle of Irish secondary education is referred to as the Leaving Certificate cycle (Childs & Sheehan, 2009). The Leaving Certificate is two years in duration and the overall examination requirements are dependent on the subject being tested. The Leaving Certificate language subjects have both an oral and an aural examination. These are typically scheduled in the March and June of the second year of the programme respectively. Certain subjects, such as art and engineering, have a practical examination in the month of May. All subjects conclude with a written examination which typically takes places in June of the programme's final year (State Examination Commission, 2017). Today, the Leaving Certificate is overseen by the State Examinations Commission of Ireland on behalf of the Department of Education and Skills.

There are 30 subjects recognised as part of the Leaving programme by the State Examinations Commission, with students required to sit a minimum of six for entry into third level education. Not all subjects are offered by all secondary schools (Department of Education, 2018). Irish, mathematics and English must be chosen as three of the six subjects for matriculation into third level education in Ireland. A science subject is required for entry into many science programmes, but the science subject presented for admission can be unrelated to the degree programme chosen e.g. Leaving Certificate Biology can be presented as a science subject for entry into a chemical sciences degree.

Each subject is offered at a minimum of two levels, known as higher and ordinary level. Irish and mathematics are also offered at foundation level and each level is assigned a corresponding result scale (Irish Universities Association and the Institutes of Technology Ireland, 2015). The maximum number of points that can be obtained on the higher-level scale is 100, the minimum is zero. The points allocated according to each of the scales are distributed according to Table 2.1 below. The only exception to this scale is higher-level mathematics which entitles the student to an additional 25 points if they obtain a score of H6 or above.

Table 2.1: *The maximum and minimum number of points awarded by each level in the Leaving Certificate examination.*

Percentage	Grade	Points Allocated		
		Higher	Ordinary	Foundation
90-100%	H1-O1-F1	100	56	20
80-89%	H2-O2-F2	88	46	15
70-70%	H3-O3-F3	77	37	10
60-69%	H4-O4-F4	66	28	5
50-59%	H5-O5-F5	56	20	0
40-49%	H6-O6-F6	46	12	0
30-39%	H7-O7-F7	37	0	0
0-29%	H8-O8-F8	0	0	0

The grades awarded in one sitting of the Leaving Certificate examination across six subjects are used for national matriculation. Each third level course is assigned a score which is published annually by the Central Applications Office (Central Applications Office (CAO), 2016). These scores are based on demand

and the published quotas for each course. They are typically published in mid-August every year.

2.2.2 Second Level Teaching Requirements in Ireland

To be eligible to teach in Ireland, prospective teachers must first complete a relevant undergraduate degree that enables them to teach at least one of the approved subjects of second level education. In addition, they must complete a postgraduate education qualification (such as the Professional Master of Education (PME)) or complete an integrated qualification in one of the approved curricular subjects that includes professional students, foundation studies and a school placement (The Teaching Council, 2013).

To be eligible to teach a specific subject, the undergraduate degree pursued must be a Level 8 degree under the National Framework of Qualifications (NFQ) and the intended teaching subject must be taught in the third year or above. The subject must carry a minimum of 60 European Credit Transfer Credits (ECTs) in the degree subject with the degree not being less than 180 ECTS in total. At least 10 ECTS must be in the third year of the degree or above (The Teaching Council, 2013).

Once these qualifications are obtained, annual registration with the professional teaching body in Ireland (the Teaching Council) is mandatory. If this registration is not completed, a teacher will not receive payment from the Department of Education in Ireland.

2.2.2.1 Leaving Certificate Science

Leaving Certificate science refers to a group of subjects which includes biology, chemistry, physics, agricultural science and physics & chemistry. Students are not permitted to take physics & chemistry with the individual subjects of physics or chemistry. Science subjects are not mandatory, but one must be taken for entry into a third level science course, many of which also require a minimum grade in mathematics. Biology is the most popular science subject with the total number of students registered to take it in 2017 being more than three times the volume of the next most popular subject (Table 2.2). As Ireland has historically relied on farming to sustain much of the country's economic output, the number of students taking Leaving Certificate Agricultural Science remains at a constant 14-15 % of the overall total of Leaving Certificate students nationally (Hurley, 2018).

Table 2.2: *The total number of Irish Leaving Certificate science students by subject in 2017.*

Science Subject	Students
Agricultural Science	7,866
Biology	35,012
Chemistry	9,736
Physics	7,848
Physics & Chemistry	615
Total	55,731

Having now completed an introduction to Ireland and Irish science education, this literature review will now focus on a corresponding introduction to the United States and the country's approach to second level education, specifically focussing on senior second level science education.

2.2.3 The United States of America

The United States of America is a federal republic that consists of 50 states, a federal district (Washington D.C.) and 5 self-governing territories. It is similar in geographical area to Europe. The country's capital Washington D.C. is on the east coast and is at the heart of the country's political force. All three branches of the U.S. federal government are based here; the President (executive), the U.S. Congress (legislative) and the U.S. Supreme Court (judicial) (Abbott, 1999).

The first inhabitants of the United States were thought to be the Paleo Indians who originated from Siberia more than 15,000 years ago. The country was colonized by Europe in the 16th century and after many turbulent centuries of power struggles, the county has emerged as one of the primary powers of the world (Leckie, 1981).

2.2.3.1 A brief history of the educational system in the United States

The first example of American schools originates back to the 17th century when 13 colonies began developing a permanent status in the United States. These colonies opened educational institutions across the original American states and Boston Latin School in Massachusetts is believed to be the first documented public high school in America (Abdulkadiroğlu, Angrist, & Pathak, 2014; Goldin, 1998). This school, still in existence today, is an example of how the original mindset of educational institutions were rooted in traditional English education, holding the classics as an integral part of the curriculum.

2.2.3.2 The "High School Movement" (1910-1940)

From 1910 to 1940, the United States led the global stage in terms of the population's access to publicly funded high school education. In 1910, only 9% of American students earned a high school diploma, but by 1940 this figure had risen to 40% of the eligible student population (Goldin, 1998). This rapid progression in educational history became known as the "High School Movement". It is believed that this movement was primarily driven by financial means but other factors such as ethnic, social and the division of religious groups are believed to have affected the rapid progression of the movement (Rosen, 1954).

2.2.3.3 The School Curriculum Reform Movement

In 1958, the Eisenhower administration passed the National Defense Education Act (NDEA) (Steeves, Bernhardt, Burns, & Lombard, 2009). This act was driven by members of the American Association of Professors who outlined the deficiencies in the American education system. These deficiencies were summed up in the successful Soviet launch of Sputnik 1 in 1957. It was claimed that the Soviet education system was superior to the American system in reading, writing and mathematics, and that this knowledge deficit had contributed to the failure of the United States in the first chapter of the space race (Urban & Wagoner Jr, 2014).

Once the NDEA had been written and approved, a change to the national educational curriculum was inevitable. This change was called the School Curriculum Reform Movement and was supported by many, most importantly in the context of this work, the National Science Foundation (NSF) (Bybee, 1995). Curriculum developments across mathematics, physics, biology and chemistry were implemented but these changes were now the result of recommendations of relevant scholars of the disciplines. These panels included the Physical Sciences Study Committee (PSSC) and the School of Mathematics Study Group (SMSG) (Urban & Wagoner Jr, 2014).

In 1959, further developments were afoot when a group of scientists and psychologists met in Wood Hole, Massachusetts. This meeting resulted in the publication of "The Process of Education", a publication which was instrumental in determining the need for an academic structure to be introduced into learning (Bruner, 2009). This publication, along with the recommendations of the School Reform Movement, resulted in significant changes to the existing science and mathematics curricula of schools. These changes were also followed by considerable amendments to the history and social sciences curriculum.

2.2.3.4 The United States Department of Education (1980-present)

The United States Department of Education (ED) was first known as the Office of Education and was founded under the administration of President Andrew Johnston in 1867. Initially, the office was under the remit of the United States Commissioner of Education, Henry Bernard. Over the next century, the office underwent many changes in title and administrating power until President Jimmy Carter advocated for the Department to be not only of cabinet level but under the remit of the residing US. Secretary of Education (Radin & Hawley, 1988).

Today, it is responsible for administering a range of programmes under the U.S. government including the Direct Federal Student Loan programme, grants and special education. High school education is administered by The Office of Elementary and Secondary Education (OESE) (U.S. Department of Education (ED), 2018). The office is responsible for directing and coordinating the following:

- Equipping local educational agents with funding for federal activities.
- Encouraging national and local educational improvements.
- Assisting local and state agents with raising the educational performance of schools.
- Ensuring that all children have equal access to education including minorities such as Native Americans, migrant children and those who are educationally disadvantaged.

2.2.3.5 The structure of the current American educational system

The mandatory age for education in the United States varies by state, but typically ranges from 5 to 8 years of age and ends between 16 and 18 years of age (Landis, 2010; National Center for Education Statistics (NCES), 2015). The span of the accepted school system covers four possible educational routes and is illustrated in Figure 2.3. In all cases, elementary school education is required and accounts for grade 2 to 5 inclusively.

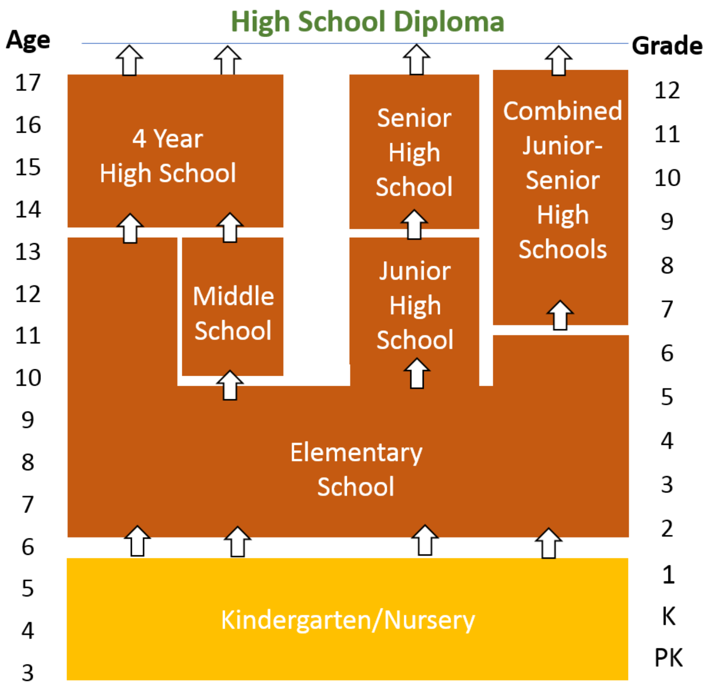

Figure 2.3: *Recognised educational pathways in the United States (pre kindergarten (PK) to grade 12)*

An additional year in elementary school is incorporated into three of the four possible routes shown i.e. those that do not require middle school. High school refers to pre-college (second level) and can incorporate grade 7 to grade 12. However, as evident in Figure 2.3., there are multiple definitions of high school. For the purposes of this comparative study, the term high school will refer to grade 9 to 12 inclusively.

2.2.3.6 High School Curriculum in the United States

The high school curriculum is roughly divided into four core subject areas namely English, social sciences, mathematics and science (see Table 2.3). Courses are typically worth either 1 credit (full year course) or 0.5 credits (one semester). Students must fulfil the minimum credit criteria of each subject area to be eligible to graduate, although specific credit requirements can vary by state. For example, students must obtain as low as 2 and as high as 4 credits in mathematics courses (The Centre for Public Education, 2013). Students are also obliged to take elective courses as part of their educational programme. These typically include visual and performing arts, computer science, foreign languages and vocational subjects (e.g. woodwork or technical drawing). The range of electives on offer is dependent on the type of high school and the district where the school is located. In additional, some schools may offer Advanced Placement subjects in the senior years of high school.

Table 2.3: *Eligibility criteria for students to graduate from high school in the United States.*

Subject	**Credits**
English/Language Arts	4
Mathematics (Algebra, Geometry, Statistics, Probability)	3
Science (must include 1 credit of Biology)	3
Social Studies (e.g. U.S. History, Geography, Economics)	3.5
Art	1
Electives	7
Total	21.5

2.2.3.7 High School Teaching Requirements in the United States

To be eligible to teach in an American high school, teachers must have a bachelor's degree in their chosen field. Once their degree is awarded, teachers must have a specific number of hours in a supervised teaching environment to earn a teaching license. This number varies by state. In addition to obtaining a license, many teachers are also required to earn a general teaching certificate (Learn How to Become, 2018).

2.2.3.8 Next Generation Science Standards and the America COMPETES Act

The "*America COMPETES Act*" was signed into law under the Bush administration in 2007. This act was designed to allocate funding to a number of cohesive science education programmes across North America so that the United States could adequately benchmark itself against its international peers in education (Brainard, 2007). In 2009, the Carnegie Foundation published a report urging the nation to drastically increase the science and mathematics component of student's education, and encouraged both states and districts to examine their science and mathematics curriculums as a whole (The Carnegie Corporation of New York, 2009).

“The nation’s capacity to innovate for economic growth and the ability of American workers to thrive in the modern workforce depend on a broad foundation of math and science learning, as do our hopes for preserving a vibrant democracy and the promise of social mobility that lie at the heart of the American dream.”

The Carnegie Foundation (p. 9)

In response to this call, a project called *Next Generation Science Standards* (NGSS) was launched across many North American states in 2013. The NGSS aimed to reform science education at elementary, middle and high school level across the country. This programme was developed by the National Science Teachers Association, the American Association for the Advancement of Science, the National Research Council as well as a group of 26 states across the country (Robelen, 2012). The design of NGSS is intended to address many of the concerns that Americans have about science literacy today and its relevancy in modern society by adopting what is termed a *3D core structure*. This core structure is designed to address three themes; (i) practices, (ii) cross-cutting concepts and (iii) disciplinary core ideas (Pruitt, 2017). These themes are integrated into every stage of the curriculum and aims to motivate students to examine the plausibility of an idea based on scientific evidence. The programme requires students to learn less topics, but to study each topic in more breadth than previous programmes and encourage them to make the link between and idea and the world around them. States are not mandated to enact the programme but by November 2017, 19 states had commenced implementing NGSS and another 21 states had committed to adopting the programme in the foreseeable future (National Center for Science Education, 2013). When the programme is fully implemented, it is likely to further strengthen the quality of high school students entering the Advanced Placement Chemistry programme in the coming years.

2.2.4 The Advanced Placement Programme

The Advanced Placement programme was originally introduced in the United States after a study was conducted in 1957 across three high schools (Andover, Exeter and Lawrenceville) and three Ivy League universities (Harvard, Princeton and Yale) by the Ford Foundation for the Advancement of Education. The Foundation recommended the introduction of an examination programme to assist academically capable and hard-working students. These examinations, 11 in total, were initially designed to be equivalent to first year degree level courses and the main science subjects were amongst those offered i.e. chemistry, physics and biology. The course content was created by a panel consisting of high school teachers and college academics, called the School and College Study of Admissions with Advanced Standing, thereby ensuring that it was both of a high school level ability and a college course mindset (Nugent & Karnes, 2002; Tapper, 2009).

By 2016, the College Board reported the Advanced Placement programme had more than 2.5 million registered students and of these, more than 150,000 students were registered to take Advanced Placement Chemistry (The College Board, 2017).

2.2.4.1 The Advanced Placement Programme for College Admission

Each subject's Advanced Placement curriculum content is created and updated by a mixture of university faculty and those deemed to be Advanced Placement expert teachers. This ensures that the course and examination are both relevant and appropriate for college admissions and are regularly revised to reflect any changes to the subject. Schools who wish to offer Advanced Placement subject examinations must participate in the Advanced Placement course audit. The course audit requires all eligible teachers to have their proposed syllabi assessed by a panel of college faculty educators. This ensures that clear guidelines are adhered to by both high school teachers and administrators, as well as the availability of all identified resources required in the proposed syllabus. This process also ensures that students applying for college admission have correctly identified Advanced Placement subjects on their high school transcripts (Ewing, 2009).

Although an Advanced Placement examination is not required for admission into university, many high school students take an Advanced Placement subject to gain exemption from relevant first year college courses in the United States. With an Advanced Placement subject, it is also possible to gain additional credit before entering third-level courses. In addition to their standard workload, high-achieving students can elect to take an Advanced Placement subject to illustrate their subject competency and interest in a related undergraduate degree e.g. Advanced Placement Calculus for a physical science degree (Warne, 2017). To my knowledge, Irish universities do not require a specific Advanced Placement subject for admission, but it is looked upon favourably if there is a surplus of qualified applicants above the quota. Because of this, potential applicants from the United States are encouraged by their high school advisors to undertaking the Advanced Placement programme in their senior years of high school.

2.2.4.2 The Format and Scoring of Advanced Placement Examinations

All Advanced Placement examinations comprises of two sections, a multiple-choice section (Section 1) and the free-response section (Section II). The free-response section contains both short and long questions and are worth 4 and 7 marks respectively. Each multiple-choice question is worth one mark. All questions in both sections are compulsory.

The exam is scored by two methods. Section 1 is marked automatically by machine and Section II is marked by a group of elected markers known as the Advanced Placement Exam Readers. This group consists of both university faculty and high school teachers. The scores from both sections are combined and weighted accordingly to generate a raw score. This raw score is converted into the overall Advanced Placement score which ranges from 1-5. The associated recommendation is then awarded (see Table 2.4) on a student's transcripts for university application.

Table 2.4: *The Advanced Placement scoring system*

Advanced Placement Score	Recommendation
5	Extremely well qualified
4	Well qualified
3	Qualified
2	Possibly qualified
1	No recommendation

To clarify the recommendations of the grading system, the lowest mark that merits a score of 5 is assumed to be equivalent to an average A grade for first year college students. Similarly, a score of 4 indicates a B grade and so on. In 2017, the majority of Advanced Placement science students received a score of 3 or lower (approximately 70%) (The College Board, 2018). From these success rates, it is evident that the minority of science students are equivalent to either an A or B grade first year college student, a result which is reasonable given the programmes participants.

2.3 Conclusion

This chapter summarizes the political, social and educational background in Ireland and the United States since the early 19th century. A summary of both countries educational pathways leading to second level graduation is presented, as well as an introduction to the format of the Leaving Certificate and Advanced Placement programmes. Each programme's respective exam systems and an explanation of their accompanied grading system is covered in this chapter. It is hoped that this chapter has provided a contextual backdrop for the comparative study that follows and the associated findings from all parts of the project.

Chapter 3: Methodology and Methods

3.1 Introduction

The objective of this chapter is to describe the methodological design adopted to investigate the research questions posed in this project. This chapter opens by stating the research questions as derived from the objectives before describing how the study has been approached. This chapter will examine other relevant international comparative studies for the purpose of serving as a reference, including those that have centred around Bloom's Taxonomy. The process of data collection is described as well as a consideration of how limitations and personal bias is acknowledged before the study's analysis commences.

3.2 Research Questions

This study aims to identify the factors that account for the similarities and differences between the Leaving Certificate Chemistry and Advanced Placement Chemistry programmes. The researcher will examine factors such as entry requirements, teaching approaches, syllabus content and subject matter, exam questions and laboratory class components using the comparative study methodology. As part of this process, the content of both programme's curriculum will be analysed and an assessment examination papers from both programmes will be carried out according to Bloom's Taxonomy.

The research questions to be considered in this project will cover three different aspects of the programmes to be reviewed. These areas and their associated research questions are as follows.

Table 3.1: *Research Questions*

Research Area	Associated Research Question
Programme requirements	Are the entry requirements of both programmes the same and how it science education in second level education perceived?
Curriculum design	How do both chemistry programmes differ in content, subject matter and structure?

	How is practical work incorporated into the curriculum and how is it assessed?
Examination style and associated importance	How do examination structures differ in question style and range of material covered? Do both programmes successfully adhere to Bloom's Taxonomy by incorporating the six cognitive objectives into their assessment? How do both contribute to entry into undergraduate science programmes?

By answering these research questions, this researcher hopes to gain an understanding of the level of chemistry education that graduates have upon completion of each programme, and to understand if both programmes equally prepare a student to undertake a science degree, particularly within an Irish university.

3.3 Main Research Methodologies

This study will initially focus on a comparison of both the theoretical and practical aspects of programmes curriculum and how each fulfils the expectations of a senior second level science programme. To investigate both programmes systematically, a comparative study will be conducted which will include an analysis of each programme's annual examination papers according to the six cognitive objectives outlined in Bloom's Taxonomy. An explanation of a comparative study, specifically in the field of education and a full description of Bloom's Taxonomy are all contained in the following section.

3.3.1 Comparative Studies and Comparative Education

"*Since there are no absolute standards of educational achievement or performance, comparative studies are vital to policy makers in setting realistic standards and in monitoring the success of educational systems*"

Norman M. Bradburn, p. 1

(Board on National Comparative Studies in Education, 1990)

A comparative study is one that identifies and classifies the differences and similarities between the two or more items under review. It is defined by Collier as "the methodological issues that arise in the systematic analysis of a small number of cases, or a small N[-1]"(Collier, 1993). The objective of such a study is to provide a more comprehensive understanding to both the researcher and the reader of the factors that influence and those that create correlations or distinctions between two items (Sothayapetch, 2013). The comparative method is normally classified by either comparing distinct fields of study (e.g. social science and economics) or by the comparison of a specific number of case studies. This method is commonly chosen over alternative approaches (such as the experimental or the statistical method) as it enables intensive analysis of a few cases to be conducted if time or resources are restricted (Otwombe, Petzold, Martinson, & Chirwa, 2014; Ross, 2005). The comparative analysis method also has several weaknesses; namely studies using the comparative method typically use large number of variables for small numbers of cases making it less reliable then other methods. According to Lijphart, potential solutions to this include (1) increasing the number of case studies, (2) focussing on comparable cases or (3) reducing the number of variables to be studied (Lijphart, 1971). In this study, two chemical education programmes for similar age groups in senior high school education will be studied. This project will therefore only focus on truly comparable cases.

3.3.1.1 Background to Comparative Education

The field of comparative education was first developed in the early nineteenth century in the United Kingdom with the introduction of national education across the country. It wasn't until the twentieth century, with publications like those from Nicholas Hans and Michael Sadler, that it became an independently recognised field of research (King, 1969; Phillips, 2006). According to Noah and Joubish, the purpose of comparative education is to objectively explain educational systems and processes, to assist in the development of educational practices or institutions, to highlight the connections between education and society and to establish common statements about education that can be extended beyond one country (Noah, 1984). A study carried out by researchers in the field is defined by Wilson as "an intersection of the social sciences, education and cross-national study which attempts to use cross-national data to test propositions about the relationship between education and society and between teaching practices and learning outcomes" (Wilson, 2003).

One of the largest international comparative studies in education was conducted in 2002 by the Organisation for Economic Co-operation and Development (OECD). The report, called the Programme for International Student Assessment (PISA) evaluated the reading, writing, mathematics and student literacy of 15-year-old students across OECD member states (Simola, 2007). In particular, this study highlighted the excellence of certain education systems such as Singapore and Finland, a result which has been echoed in subsequent PISA tests (Ahtee & Pehkonen, 2008; Soh, 2014). PISA reports are now published every three years and Ireland has consistently outperformed the United States in mathematics and science over the duration of these publications. From this result, we can conclude that an average 15 year old student in Ireland who has completed second level is academically more advanced in science and maths than their counterpart in the United States (The Organisation for Economic Co-operation and Development, 2016).

PISA reports have successfully stimulated further comparative studies by other OECD members. In 2013, Sothayapetch investigated science education at primary school level in both Finland and Thailand and attributed that significant difference between the PISA scores of Finland (placed first) and Thailand (found to be statistically below the OECD average) as her motivation for conducting the comparative study. She established that Finnish science education strongly emphasised conceptual knowledge (e.g. concepts and contexts) while the Thai science education programme concentrated on procedural knowledge such as the scientific process (Sothayapetch, 2013).

3.3.1.2 Classifying a Comparative Study

There are at least six different approaches that can be taken in comparative education studies: historical, social, methodological, philosophical and scientific (classic or new). The differences between each approach is fully described by

Khakpour, but depends on the type of analysis conducted, and the basis of the evidence to support the arguments throughout the study (Khakpour, 2012). From this list, the research project will be conducted using the scientific (new) approach as it uses a mixture of qualitative and quantitative data to conduct the analysis required by the study. The other approaches rely on either qualitative or quantitative data and require resources that are beyond the scope of this project.

3.3.2 Bloom's Taxonomy and its adaption to this study

Bloom's Taxonomy was originally produced by a group of educational professionals following multiple conferences on the design of curricula and examinations held from 1949 to 1953. Amongst their findings, the group, chaired by Benjamin Bloom (an American educational psychologist), produced an important classification known as Bloom's Taxonomy. The taxonomy classifies objectives or terms that are frequently used to analyse the educational learning so when used correctly, it guides the development of curriculum, assessments and instructional methods The taxonomy was designed in three parts known as the cognitive, affective and psychomotor domains (Bloom, 1968).

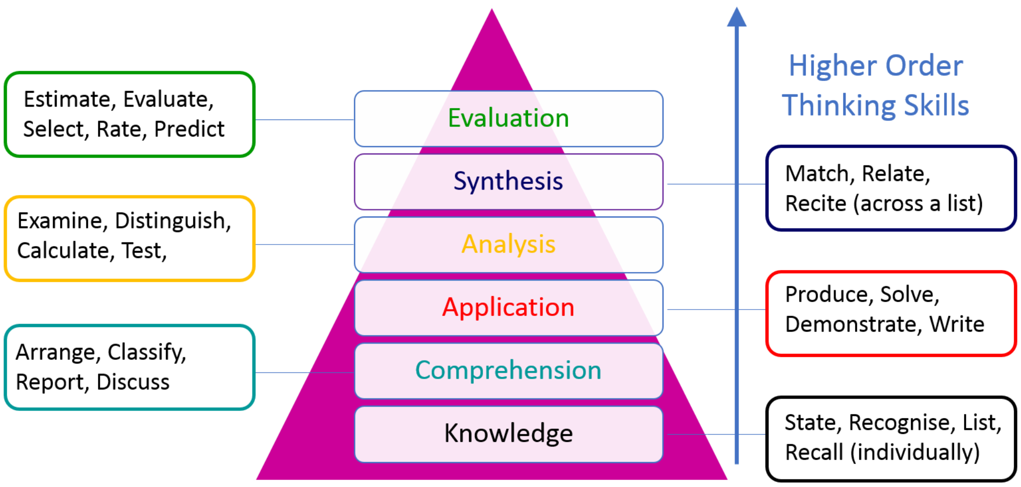

Figure 3.1: *The six cognitive objectives of Bloom's Taxonomy with associated action words for each.*

In the cognitive (or knowledge) domain, Bloom and co-authors categorized commonly used instructions or action words into six cognitive objectives known as higher order thinking skills (HLOs). These cognitive objectives are outlined in Figure 3.1 and are accompanied by commonly used words that are associated with distinct objectives. Each objective is classified in accordance with actions of increasing cognitive value, so that objectives that require more cognitive input appear further up in the classification (Kim, Patel, Uchizono, & Beck, 2012). Because of this, a pyramid or a ladder is typically used to represent the taxonomy, like that illustrated in Figure 3.1.

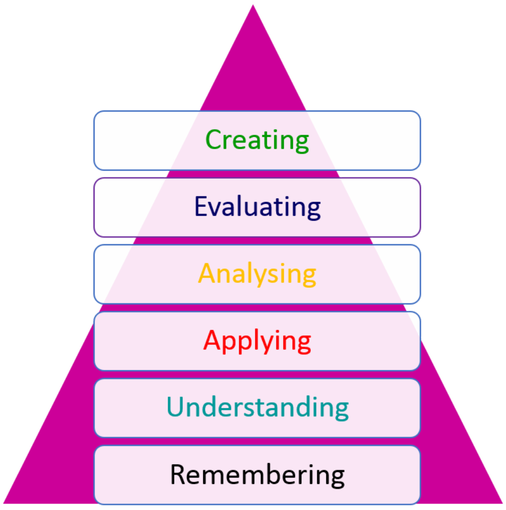

Figure 3.2: *The new interpretation of Bloom's Taxonomy by Anderson and co-workers.*

In the 1990's, Bloom's Taxonomy was revised by Anderson and co-workers with the intention of making the guide more relevant to students and teachers in the 21st century (Anderson *et al*., 2001). The revised taxonomy both renamed and reordered the original objectives according to the order illustrated in Figure 3.2.

Both the original and revised taxonomies have come under criticism for dividing human cognition into six categories and suggesting that learning can be classified linearly. Different learners establish alternative learning pathways so using one model to adapt to all is impossible (Pring, 2008). Despite these arguments, both versions have been used to evaluate cognitive learning, and are regularly used as design guides across all disciplines and levels of education. Examples include Kim and co-workers adaptation of the taxonomy to multiple choice questions for undergraduate pharmacotherapeutics courses or the comparison of Advanced Placement Biology and other biology exams for preparation towards the Medical College Admissions Test (MCAT) (Kim et al., 2012; Zheng, Lawhorn, Lumley, & Freeman, 2008). In Ireland, Bloom's Taxonomy has effectively used by Cullinane and Liston to evaluate two iterations of Leaving Certificate Biology, before and after the last curriculum reform of the subject in 2002 (Cullinane & Liston, 2016).

3.3.3 Designing a Comparative Study for this Project

These studies, as well as those by Yan and Sothayapetch, have reinforced the need for similar comparative work in chemical education (Sothayapetch, 2013; The Organisation for Economic Co-operation and Development, 2016; Yan, 2007). The findings of Cullanine and Liston's study were based on an review of biology exam papers completed using Bloom's original taxonomy (Cullinane & Liston, 2016). In order to make cohesive recommendations across Leaving Certificate science subjects, the original version of the taxonomy will also be used in this work. As the Advanced Placement Chemistry curriculum was updated in 2013, exam papers from 2014-2018 will be assessed. The terminology will be adapted to contexts in chemical education according to the following assignment.

Knowledge-refers to a question or task that requires a student to provide an answer based on knowledge acquired before the examination e.g. state a definition.

Comprehension- A question or task that requires a student to demonstrate more than acquired knowledge. If a student must comment on information provided in a question (e.g. a data set) but must use a relevant term(s) that they previously have learnt.

Application- A question that requires a student to complete an action other than a calculation (e.g. draw a molecule or graph) to demonstrate a higher level of understanding.

Analysis- A question or task that require a data set to be manipulated. Verbs that are commonly used to distinguish this objective are calculate, analyse or distinguish.

Synthesis- refers to a question or task that requires a student to analyse multiple statements or datasets to support or to challenge a statement.

Evaluation- requires a student to judge or assess a range of ideas to arrive at an opinion. Applying this classification can only be done if a student creates a new opinion.

Each programme will be assessed according to the classifications described. The presence of individual objectives throughout a paper will be calculated, and from these results an average objective value will be produced. As the Leaving Certificate offers chemistry at both higher and ordinary level, the programme will be analysed at two levels. Results will therefore be given for three sets of data.

3.3.4 Limitations: data analysis and access to resources

This project will use a combined qualitative and quantitative approach to achieve a more holistic view of both programmes. The study will not solely rely on the classifications resulting from the exam paper analysis but will simultaneously look at other factors such as entry requirements, curriculum design and experimental content. It is hoped that this will generate a more comprehensive set of conclusions and will enable the researcher to assess both programmes as transparently as possible.

The researcher also acknowledges the resource limitation (time, jurisdiction) in completing this study. As a result, research will be conducted as regimentally as possible throughout the year leading up to submission. It is envisaged that this timeline will also mirror the publication of the 2018 exam papers from both programmes (published in late June), so that these can also be incorporated into this study.

3.3.5 Personal Bias

According to the recommendations laid out Bradburn and co-workers, the following guidelines have been advised when conducting an international comparative study.

"An international comparative education study must avoid political, national, religious, racial, gender or ideological bias. It is essential that all nations to be included in a study participate in the study design, and the mechanisms for facilitating such participation should be described in the proposal.

Norman M. Bradburn, p 21

(Board on National Comparative Studies in Education, 1990)

This comparative study focuses on an international programme that is outside of the direct proximity and curriculum expertise of the researcher. This study will require an extensive knowledge of the educational, cultural and political environment surrounding the syllabus design. This study also needs to be cognisant of the effect that religious beliefs have on science education in the United States (Rutledge & Mitchell, 2002). As a graduate of Leaving Certificate Chemistry, and having taught undergraduate students who have also progressed through the Leaving Certificate Chemistry programme, the researcher has also developed a number of personal frustrations over the last decade that may lead to bias in the study (O'Brien, 2016). To counteract for these natural biases, the researcher has identified suitable advisors who will be consulted throughout the duration of this study:

An Advanced Placement Physics teacher with four years high school teaching experience in North America. The teacher offers a perspective on the process of developing an Advanced Placement curriculum and the personal transition to a university environment in Ireland.

A programme coordinator for chemical outreach initiatives based in a third level institution. The coordinator delivers an outreach programme especially aimed at

Leaving Certificate Chemistry students. The coordinator understands the strengths and weaknesses of the Leaving Certificate Chemistry programme

By incorporating the feedback of both advisors into the design and data analysis of this study it is hoped that any bias towards either programme can be overcome.

3.3.6 Ethical considerations of this research

As this study is primarily restricted to desk-based research, it will not require access to minors or sensitive data (e.g. personal records or assessment results). On this basis, informed consent will not be required from schools or parents to complete this research project. This research will be conducted independently and appropriate measures, such as the voluntary recruitment of two advisors, will ensure that this research is conducted as sensitively as possible.

3.4 Conclusion

This chapter outlines both the qualitative and quantitative approach taken in this comparative study. The limitations of the design and personal bias have been described and counteractive steps have been proposed to mitigate both matters.

Having now accounted for the methodological plan of this study, the next chapters will describe the data analysis and findings of this project.

Chapter 4: Results and Discussion

4.1 Introduction

This chapter focuses on a comparison of the structure, curriculum design and content of the Leaving Certificate and Advanced Placement Chemistry programmes. This comparative study will also include the prerequisites for entry into each course as well as their aims and objectives. This will provide an educational context which will allow a subsequent analysis of their curriculum and the associated experimental content to be completed. An analysis of exams papers from the current Leaving Certificate and Advanced Placement Chemistry courses from 2014 to 2018 inclusive will be conducted according to Bloom's Taxonomy.

Part One: Curriculum and Experimental Content Analysis

4.2 Entry Requirements for Programme Admission

The following sections will discuss the prerequisites for entry into the Leaving Certificate and Advanced Placement Chemistry programme.

4.2.1 Junior Certificate Science as a prerequisite to Leaving Certificate Chemistry

Students who elect to take the Leaving Certificate chemistry programme are not required by the Department of Education and Skills in Ireland to study the Junior Certificate science programme as a prerequisite for entry. However, individual secondary schools may require Junior Certificate Science in order to proceed to any Leaving Certificate science subject (NCCA, 2008). Junior Certificate students are typically 12 to 15 years of age. This introductory programme may be taken at either ordinary or higher level for which the content varies according to breadth of topics and depth of detail. The course is based on four strands namely (i) the physical world, (ii) the biological world, (iii) earth and space and (iv) the chemical world (Department of Education, 2015). This ensures that students have a good foundational knowledge of science in each area before they specialise in individual Leaving Certificate science subjects. Practical work accounts for one quarter of the overall mark and is examined at school level by individual Junior Certificate science teachers. The final examination is a 3-hour written paper worth 65% of the final grade and is split equally across all strands of the course. Although there is no final grade requirement from the Junior Certificate programme for entry into any Leaving Certificate science subjects, students are typically advised based on individual subject results as to whether they are better suited to higher or ordinary level at Leaving Certificate level. In addition, students are not required to study Leaving Certificate Mathematics at higher level into be eligible to study Leaving Certificate Chemistry (Department of Education and Skills, 1999, Leaving Certificate Chemistry Syllabus, page 77).

4.2.2 American High School- Science Education Requirements

To be eligible to graduate from high school in the United States, all students are required to complete a set programme of subjects from grade 9 to grade 12. Unlike other international education systems, there is no final assessment at the end of grade 12. Instead, students must pass each subject annually through on-going class assessments to progress from one year to the next. Most North American high schools also require students to complete a standardised test, such as the SAT or the ACT exam during their 11th grade (The College Board, 2018). Students are required to present standardised tests results along with a high school diploma as a minimal entry requirement for university admission.

The SAT exam assesses 4 components; reading, writing and language and math. The test does not include a specific science section on the exam. However, many high schools also require SAT students to complete three additional subject tests of which tests in chemistry, physics and biology subject tests are options. Each SAT subject exam is in multiple choice format and is one hour in duration. For admission into Trinity College Dublin, applicants must have a minimum SAT score of 1290 out of 1600 (Trinity College Dublin, 2018). SAT subject exams are not required from applicants to the university but are encouraged, specifically to demonstrate relevant knowledge for certain degree courses.

The ACT test has five sections including a specific scientific reasoning section where students must answer 40 multiple choice questions in 35 minutes. The scientific reasoning component is designed to test interpretative, analytical, evaluation and problem-solving skills. Each of the five sections on the test has an overall score of 36 except for the writing section which has a score of 12. For admission Trinity College Dublin, applicants must have a minimum composite ACT score of 29 out of 36 (Trinity College Dublin, 2018).

4.2.2.1 Entry requirements for Advanced Placement Chemistry

All high school students must complete the compulsory science programme outlined in Table 4.1. For each of these science subjects, there is a set programme of individual class assessments which is at the discretion of individual high school teachers.

Table 4.1: *The United States high school grade progression and required associated subjects (AP indicates Advanced Placement).*

Grade	Science Subject
7	Earth Science
8	Science (Physical Science and Technology)
9	Biology I
10	Physics I or Chemistry I
11/12	At least one of Environmental Science, AP Environmental Science, Biology II, AP Biology , Chemistry I, AP Chemistry, Physics I or AP Physics

To be considered for admission into the Advanced Placement Chemistry programme, high school students are required to have completed the progression outlined in Table 3.1, electing to take Chemistry 1 as a subject by the end of grade 11. Students will also have completed a standardized test, as previously mentioned before admission into the Advanced Placement Chemistry class. In addition, students must also have completed the Algebra II programme before they can be considered for entry (Khan, 2018). High schools may permit the Algebra II programme to be taken alongside Advanced Placement Chemistry in grade 12 (The College Board, 2017, AP Chemistry Course Overview, page 2).

4.3 School Timetables- Ireland and the United States

Students usually begin between 8.30 and 9.30 am in Ireland and conclude their day no later than 4 pm. Class periods are divided into 35-45-minute intervals and a day is timetabled to allow between 7 and 9 class periods. Practical subjects, such as chemistry, are timetabled to facilitate practical classes by incorporating double class periods of 80 minutes. Leaving Certificate science classes are scheduled for 4 to 5 class periods a week, including one double period.

In American high schools, the school day commences over a similar range of times and the time allotted to a class period is also 35-45 minutes. The frequency of a subject is dependent on the weighting of the class credit and the grade in which a subject is studied.

4.4 Leaving Certificate Chemistry- Introduction to the programme

Leaving Certificate Chemistry is one of six science subject programmes available during senior secondary education in Ireland. The current chemistry curriculum was implemented nationally from 2002 to 2004 (Department of Education and Skills, 1999). The programme is constructed around five syllabus objectives which include knowledge, skill, understanding, competence and attitudes. Each objective intertwines with different aims of the programme. These aims include the development of an appreciation for the scientific method, to develop skills such as observation, analysis, evaluation, communication and problem-solving.

4.4.1 How the programme differentiates between higher and ordinary level

Leaving Certificate Chemistry is taught at both higher and ordinary level and differs between the two both in the range of topics and in the depth of treatment. All topics appearing on the ordinary level syllabus also appear on the higher level programme. Ordinary level chemistry requires students to complete one core section and one of four options (1A, 1B, 2A and 2B), two of which are examined per year. The higher level syllabus requires students to cover both the core and two paired optional topics (either 1A and 1B or 2A and 2B). These students must study all of the content of both topics as well as a greater range of content across the syllabus.

Each topic on both syllabi is divided across four subsections and allocated a recommendation number of class periods in which to cover associated content (Childs, 2009). This layout is illustrated in Table 4.2. The syllabus is designed so that approximately one third of the syllabus maps on to the social and applied aspects so that students put a greater emphasis on the context of the subject in relation to their everyday lives. A full illustration of the content for the Periodic Table and Atomic Structure section of the syllabus is available in A-1.

Table 4.2: *How each topic is presented on the Leaving Certificate Chemistry higher level syllabus*

Periodic Table and Atomic Structure			
Content	**Depth of Treatment**	**Activities**	**Social & Applied Aspects**
1.1 Periodic Table (Time needed: 3 class periods)	Elements. Symbols of elements 1–36.		History of the idea of elements, including the contributions of the Greeks, Boyle, Davy & Moseley.
	The periodic table as a list of elements arranged so as to demonstrate trends in their physical & chemical properties.	Arranging elements in order of relative atomic mass; note differences compared with the modern periodic table.	History of the periodic table, including the contributions of Dobereiner, Newlands, Mendeleev & Moseley. Comparison of Mendeleev's table with the modern periodic table.
	Brief statement of the principal resemblances of elements within each main group, in particular alkali metals, alkaline earth metals, halogens and noble gases.	Demonstration of the reaction with water of lithium, sodium and potassium.	

Currently both levels require each of the following topics to be covered: the periodic table and atomic structure, chemical bonding, stoichiometry and formulas and equations, acids and bases, volumetric analysis, thermochemistry, organic chemistry, rates of reaction, chemical equilibrium, and water chemistry. The programme's options are focussed on industrial chemistry, atmospheric chemistry, materials and the extraction of metals with additional electrochemistry.

4.5 Advanced Placement Chemistry- Introduction

The current Advanced Placement Chemistry curriculum was introduced to the Advanced Placement subject listing in 2013. As with all Advanced Placement subjects, the one-year high school programme is intended to illustrate a higher knowledge of chemistry by students who have an interest in chemistry and/or intend to apply for STEM degrees at university. The programme is not a mandatory science requirement but many universities in North America will accept the programme in exchange for college credits or may even provide an exemption for some first-year chemistry classes (Kennedy, 2014).

The programme is elective. By its nature, it assumes that all students who enrol are focussed on STEM subjects and are typically beyond the level of mandatory high school science programmes. Advanced Placement classes are usually scheduled every day, and for all Advanced Placement science subjects students often have a double period three times per week. For comparative purposes, this rigorous one-year programme is roughly equivalent to the entire contact time required by Leaving Certificate Chemistry over the two-year duration.

The design of the Advanced Placement Chemistry programme is centred around a list of concepts which were introduced in the new 2014 curriculum. These core concepts are referred to as the six *Big Ideas*, which are listed in Table 4.3. These concepts primarily focus on aspects of either general or physical chemistry (i.e. atomic theory and structure, states of matter, kinetics, thermodynamic and bonding) which are further broken down into 26 sub sections known as either *Enduring Understandings* or *Essential Knowledge* statements. An example of one of these statements is “The structure of the periodic table is a consequence of the pattern of electron configuration and the presence of shells (and subshells) of electrons in atoms” (see A-2). This statement follows from *Big Idea 1* (Kennedy, 2014).

Table 4.3: *The six central ideas of the 2014 Advanced Placement Chemistry syllabus*

Big Ideas
1. The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangements of atoms. These atoms retain their identity in chemical reactions
2. Chemical and physical properties of material can be explained by the structure and arrangement of atoms, ions or molecules and the forces between them
3. Changes in matter involve the rearrangement and/or reorganization of atoms and/or transfer of elections.
4. Rates of chemical reactions are determined by details of the molecular collisions
5. The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
6. Any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition sensitive to initial conditions and external perturbations.

The Advanced Placement Chemistry course aims to foster reasoning and inquiry skills in all students by enabling them to connect concepts both within individual topics and across the programme content. The course aims to do this by also including a mandatory list of *Scientific Practices*. These practices are not equivalent to a definitive list of associated course experiments or demonstrations like in other high school science programmes, but rather a list of practical objectives that a student will master during the programme. One example is *Science Practice 1* where students will use representations and models so that they can communicates scientific phenomena and solve scientific problems. This focuses on the student's visualization ability as each of the *Big Ideas* require students to understand concepts that are minuscule in nature (The College Board, 2014).

Once a student accomplishes an understanding of these ideas, it is expected that they will be able to adapt their knowledge and newly acquired skill set to more chemical concepts as they progress through STEM or health science degrees.

4.5.1 Advanced Placement Chemistry curriculum content: remarks and inclusion/omissions

Advanced Placement chemistry students progress through a wider scope of content within a topic than their Leaving Certificate peers. To understand the magnitude of this difference, a comparative content study on one area, rates of reaction, is illustrated in Table 3.4. It is immediately clear that Advanced Placement students explore topics that are well beyond the remit of their Leaving Certificate counterparts. Complex concepts, such as rate laws and orders of reactions, which are covered in the freshman years of university science degrees in Ireland, are included within the programme content. This advanced understanding of the topic is mirrored by other areas within the syllabus e.g. thermodynamics, chemical equilibrium and gases.

Table 4.4: *Rates of Reaction content on the Advanced Placement and Leaving Certificate Chemistry programmes. Common content is highlighted in blue, omitted topics are in orange for clarity.*

Rates of Reaction	
Advanced Placement	**Leaving Certificate**
Rates of Reaction	Rates of Reaction
Factors that Affect Rates	Monitoring the Rate of Reaction (experiment)
Kinetics of a Reaction (experiment)	
Rate Laws	Average and Instantaneous Rates
Rate Constant	Factors Affecting Reaction Rates
Order of Reaction	Concentration of Reactants
Arrhenius Plot	Particle Size
Zero-order to Second-order reactions	Nature of Reactants
Integrated Rate Laws	Catalysts
Collision Theory	Pollution Caused by Car Engines
Collision Frequency and Orientation	Activation Energy and Collison Theory
Transition State Theory	Theories of Catalysis
Reaction Profile	
Potential Energy Diagrams	
Activation Energy	
Catalysts	
Enzymes	
Reaction Mechanisms	
Elementary Reactions	

4.5.2 Disadvantages of the Advanced Placement Chemistry programme

The function of a senior high school curriculum is to build on the knowledge and skills acquired throughout foundation years of second level education. Students then go on to establish specific subject knowledge in third level education which is in line with their chosen subject speciality. Second level or high school education acts as a middle ground for the two educational levels and tries to find a balance between general groundwork and specific facts and theories in a subject. This is commonly referred to in education as the "depth versus breadth" argument (Schwartz, 2008).

In the case of Advanced Placement Chemistry, this is not necessarily the case. The syllabus is designed to explore topics in depth rather than spanning the breadth of chemistry disciplines, like other international high school chemistry programmes. A consequence of this approach is the exclusion of organic chemistry from the Advanced Placement Chemistry syllabus which many consider to be one of the fundamental branches of chemistry (American Chemical Society, 2015). It is my understanding that it is an option rather than a mandatory topic often covered between the Advanced Placement exams in May and the end of the high school year in June. The inclusion of any organic chemistry in the course is at the discretion of individual teachers (The College Board, 2017).

Table 4.5: *Comparison of organic chemistry content on the Leaving Certificate, International Baccalaureate and Cambridge A-Level Chemistry programmes and recommended teaching hours. Similar sub-topics are highlighted.*

Organic Chemistry		
Leaving Certificate	**International Baccalaureate**	**Cambridge A Level**
7.1 Tetrahedral Carbon	10.1 Fundamentals of Organic Chemistry * includes nitrogen compounds	14. Organic Chemistry Introduction
7.2 Planar Carbon	10.2 Functional Group Chemistry	15. Hydrocarbons
7.3 Organic Chemistry Reaction Types	20.1 Types of Organic Reactions	16.Halogen Derivatives
7.4 Organic Natural Products- Extraction Techniques	20.2 Synthetic routes	17. Hydroxy Compounds
7.5 Chromatography and Instrumentation in Organic Chemistry	20.3 Stereoisomerism	18. Carbonyl Compounds
	(Please note that analytical techniques are covered under the optional topic biochemistry-proteins)	19. Carboxylic Acids and Derivatives 20. Nitrogen Compounds 21. Polymerisation 22. Analytical Techniques 23 Organic Synthesis
Recommended 28.4 hours of class time	Recommended 23 hours of class time	No specific recommendation for this topic

To further understand the importance of including organic chemistry as a second level chemistry curriculum subject, Table 4.5 illustrates how it is typically covered by three other international high school chemistry programmes, including Leaving Certificate Chemistry. All three programmes are accepted for admission into university. Groups of cells are coloured to reflect similarities between topics (blue, grey etc). Table 4.5 also includes how many hours of class time are recommended by individual programme syllabi to cover this chemistry subtopic.

From this comparison, there is significant overlap between organic chemistry concepts covered in all three syllabi. Graduates of each programme listed in Table 4.5 will have acquired a basic knowledge of the topic upon admission into third level STEM programmes. For Advanced Placement Chemistry graduates, this knowledge deficient will be a considerable disadvantage in the primary years of European university scientific degrees as it is commonly incorporated into the curriculum of the first and second year, regardless of the resulting science specialisation (e.g. pharmacy, genetics, astrophysics etc).

4.6 Laboratory Practicals

4.6.1 Leaving Certificate Chemistry experimental design and requirements

The current Leaving Certificate Chemistry curriculum consists of 28 mandatory experiments at higher level of which a subset of 20 are on the ordinary level curriculum. Students must complete all mandatory experiments and maintain a record of their practical work for the duration of the course. Demonstrations are also referenced which should be completed by the class teacher where indicated on page 7 of the syllabus (Department of Education and Skills, 1999). Students engage in practical classes during the allocated double period in their timetable every week. It is not mandatory to conduct an experimental class in this period, it may also be used for theoretical work, depending on the scheduling requirements of the class.

4.6.1.1 Positive aspects of the Leaving Certificate practical unit

Through a review of the practical syllabus, the majority of the 28 mandatory student experiments can be classified as either analytical chemistry (approximately 40%) or organic chemistry both of which focus on building general dexterity and the development of a student's technique range. Examples include establishing specific concentration solutions, acid-base titrations and various separation techniques. The prominence of both analytical and organic experiments in the curriculum can easily be justified given that the pharmaceutical industry accounts for a large proportion of both the Irish workforce and international exports (Burke, 2017).

The organic chemistry component of the Leaving Certificate programme is a good illustration of the importance placed on Higher Order Thinking skills. This section includes multiple experiments which enable students to conduct a systematic study of functional groups using the same parent hydrocarbon chain (ethane through to ethanoic acid). Students are encouraged to make connections across a range of experiments over the duration of the topic while evaluating the outcomes of individual experiments as they are conducted.

4.6.1.2 Negative aspects of the Leaving Certificate Practical Curriculum

In 2012, the National Council for Curriculum and Assessment (NCCA) published a report on Senior Cycle Science specifically addressing the current number of mandatory experiments on the Leaving Certificate Chemistry curriculum as being too high. This report recommended that a senior cycle science programme should contain no more than 18 experiments (NCCA, 2012). It also recommended that any alternative or amendments to existing practical content should focus on reducing the mechanisms that enable students to be rewarded for rote-learning and should incorporate more opportunities for students to show Higher Order Thinking and problem -solving skills (Madhuri, 2012).

According to Copraidy's study, teachers should have the chemical knowledge, ability, skills and attitude to apply science in a better way (Copraidy, 2015). Instating a teacher without the adequate training in a subject can also directly affect the confidence of a student (Watson, 2010). It is well documented how difficult it is to ensure adequately qualified teachers are allocated to teach their chosen subject in Ireland (O'Brien, 2017; Woulfe, 2010). Instead of taking steps to minimise the probability of this happening, the format of many secondary school subject curriculum encourages this behaviour and Leaving Certificate Chemistry is no exception.

Table 4.6: *Sample of a typical layout of a mandatory experiment in a recommended Leaving Certificate Chemistry book.*

Mandatory Experiment Number:	
Introduction Including relevant balanced equations	
Chemicals needed	**Equipment needed**
Procedure Including ✓ Reminder to wear safety glasses ✓ Directions to copy and complete a table with specific results required ✓ Step-by-step instructions on the procedure and what calculations should be completed	**Experimental Diagram** Including an illustration of ✓ End point of the experiment ✓ Blank table of results (to be copied and completed by the student)

As shown in Table 2.6, mandatory experiments are presented in a layout that is like a food recipe book. This style has many benefits, providing the knowledge that a student needs in a clear and comprehensive manner which leaves little room for interpretative variation. However, this format also encourages rote-learning in many students. Furthermore, teachers are enabled to successfully complete the experimental curriculum without fully testing their ability or skills. This enables both the students and teachers to complete the experiments without demonstrating a high degree of understanding in the topic. This prescribed mechanism of teaching experimental procedures ultimately affects the student experience or at least contributing to the misconception that chemistry is one of the harder Leaving Certificate science subjects. This must lead to a reduction in the number of students electing to take STEM subjects, something that is against the national STEM strategy of the country (O'Brien, 2017).

4.6.2 Advanced Placement Chemistry- Experimental Design and Requirements

Although the design of an Advanced Placement subject timetable is at the discretion of individual high schools, Advanced Placement Chemistry is typically scheduled for 4.5 hours of class time per week with individual classes lasting for approximately 45 minutes. Through conversations with Advanced Placement science teachers, high schools typically schedule two or three double periods per week to facilitate experimental class-time.

In order to gain Advanced Placement Chemistry accreditation, subject teachers are required to demonstrate that they have included at least 16 of the 26 approved Advanced Placement Chemistry experiments in their programme design. The experimental format is at the individual teacher's discretion and should be based on encouraging discovery rather than specific instructional inquiry (see Table 4.7).

These experiments should follow the guidelines provided in Appendix C of the Advanced Placement Chemistry course handbook and specifically address topics such as communication and group collaboration (The College Board, 2017). All practical tasks should reinforce the importance of skills such as scientific inquiry, reasoning and critical thinking. The format designed for each experiment should permit students to plan, direct and incorporate a range of scientific practises e.g. experimental design, data collection and the opportunity to apply quantitative skills.

Table 4.7:*The College Board's Advanced Placement Chemistry laboratory manual guidelines.*

Advanced Placement Chemistry Practical Guidelines	
Title Should be descriptive e.g. "pH Titration Lab not "Experiment 5"	**Data Tables** Students will need to create any data tables or charts necessary for data collection in the lab.
Date of Experiment	**Data** Students are not to record data on separate lab sheets. They need to label all data clearly and always include proper units of measurement. Students should format appropriately or credit any device they choose to help organize this section.
Purpose of Experiment	**Calculations and Graphs** Students should show how calculations are carried out. Graphs need to be titled, axes need to be labelled, and units need to be shown on the axis. To receive credit, graphs must be at least ½ page in size.
Procedure Outline Students must use bulleted statements or outline procedure format to make it easy to read. For a guided inquiry lab, they may be required to write a full procedure that they have develop.	**Conclusions** Students will usually be given direction as to what to write, but it is expected that all conclusions will be well thought out and well written.
Pre Laboratory Questions	**Post Laboratory Error Analysis**

The College Board also requires that 6 experiments be based on guided inquiry. An example of this is through the experiment entitled "How Long Will That Marble Statue Last?". This topic requires students to answer factors that ultimately the effect of a rate of chemical reactions between calcium carbonate and hydrochloric acid (Cacciatore, 2014). This aligns with *Big Idea 4* (chemical kinetics and rates of reactions) and introduces concepts such as surface area, concentration of reactants and the effect of temperature. It requires students to select suitable materials for their investigation, plan the experimental procedure and complete data collection. In comparison, a traditional experiment on this topic would have required the students to follow a prescribed experimental procedure on kinetics. In contrast, an open-ended research question would have required the students to explore the topic of kinetics (Cobern, 2010).

Other examples of experimental topics on the curriculum include:

- Identification of white substances.
- Liquid chromatography.
- Analysis of silver in an alloy.
- Gravimetric analysis of a metal carbonate.

As illustrated by these examples, the Advanced Placement Chemistry experimental programme is ultimately designed to focus more on the scientific process rather than requiring students to complete a prescribed list of techniques.

There is one obvious omission from the Advanced Placement Chemistry experiment programme. Only one of the 26 experiments, the synthesis, isolation and purification of an ester" is based on organic chemistry. Given that a teacher may choose 16 out of the given experimental list, combined with the lack of organic chemistry topics in the written curriculum, it is possible for an Advanced Placement student to progress through the programme without any practical exposure to the topic. Other high school chemistry curricula, including the Leaving Certificate programme, place a distinct emphasis on fundamental organic chemistry theory and practices.

Part 2: Review of Examination Papers According to Bloom's Taxonomy

4.7 Methods of Assessment

Both the Leaving Certificate and Advancement Placement programmes conclude with an assessment that takes place during a national exam period held in the summer of the concluding year. The results from these assessments are produced so that students may use them on their college transcripts for third-level applications.

4.7.1 Leaving Certificate Chemistry- Assessment Format

The Leaving Certificate Chemistry exam is 3 hours in duration. Each student must answer two questions from Section A (the experimental section) and six questions from Section B of the paper. Each question is worth 50 marks and there are 10 questions in total. Question four consists of 11 short questions, of which the student must answer 8. Question 10 and 11 both require students to answer 2 of 3 parts. Question 11 focuses on the optional content of the curriculum.

Currently, Leaving Certificate Chemistry has no practical exam, but students are required to complete a laboratory notebook throughout the duration of the programme and this must be made available on request to an inspector from the State Examinations Commission. In addition, to complete Section A successfully, memorisation of the 28 mandatory experiments is required. In this section, students are typically asked to provide further details on the design, expected outcomes and calculations on the selected experiments.

Students are permitted to use the "*Formulae and Tables*" booklet but a copy must be obtained from the superintendent on the day of the exam. In addition, students are given a number of numerical values or scientific constants on the cover of the examination paper. These include relative atomic masses, Avogadro's constant, molar volume and the universal gas constant. Students are also permitted to use a non-programmable calculator and have access to graph paper during the course of the examination (State Examinations Commission, 2016).

4.7.2 Advanced Placement Chemistry- Assessment Format

The Advanced Placement Chemistry exam is 3 hours and 15 minutes long and consists of 2 sections, each of which account for 50% percent of the final score. Section 1 is a multiple choice (MCQ) section which consists of 60 conceptual and estimation questions which must be answered in the 90 minutes allocated for the section. This section was reformatted during the redesign of the curriculum in 2013 and is now intended to assess the presence of both conceptual skills (how scientific themes are understood or demonstrated) and higher order cognitive skills (the ability to link concepts in unfamiliar situations) (Domyancich, 2014). As a result, the format of these questions often necessitates students to complete a number of steps in order to arrive at a conclusion, reducing the possibility of simply guessing the correct answer. This format may understandably prevent the assessment of the highest order objectives (e.g. evaluate and synthesis). Consequently, the paper's second half (called the free response section) contains 3 long questions (each worth 10 marks) and 4 short questions (each worth 4 marks) and is designed to assess both quantitative and qualitative components of the curriculum (Price, 2014). All questions in both sections are compulsory. The overall range of questions types (MCQ, short and long questions) contained throughout the exam enables all six objectives to be assessed.

A periodic table, a table of symbols, constants and equations are provided during both sections of the exam. A calculator may be used during the second section but not in the first half of the paper (The College Board, 2014).

4.7.3 Review of Leaving Certificate and Advanced Placement Chemistry Exam Papers

As discussed in Chapter 2, Bloom's Taxonomy was selected as an appropriate classification system for both sets of papers. To conduct the study, the presence of each of Bloom's six cognitive objectives was measured throughout each paper for the last five years. This period was specifically chosen to limit the study to exam papers published since the new Advanced Placement Chemistry curriculum was introduced in 2013 (Kennedy, 2014). Although the Leaving Certificate Chemistry curriculum is currently under review, recent exam papers are believed to reflect some of the changes that are likely to be implemented in a new curriculum design (Hyland, 2014)

All exam papers used in this study were either sourced from the State Examination Commission exam paper online archive (Leaving Certificate Chemistry) or the College Board's Advanced Placement Chemistry Exam Practice webpage unless otherwise stated (State Examinations Commission, 2018; The College Board, 2018).

4.7.3.1 Question Classification

The content of each exam paper in both programmes was individually reviewed so that each question component was assigned using one of the six objectives of Bloom's Taxonomy. As Leaving Certificate Chemistry is offered at higher and ordinary level, both sets of exam papers were included in the analysis. Advanced Placement Chemistry is currently only offered at one level, hence analysis of a single set of papers was conducted.

The classification was completed according to the following guidelines

- **Knowledge**- refers to a question or task that requires a student to answer based on knowledge acquired before the examination.
- **Comprehension**- A question or task that requires a student to demonstrate more than acquired knowledge, or to comment on a data set provided using a term(s) that he/she must know before the exam.

- **Application**- Questions or tasks that require a student to interpret a dataset without a calculation and so demonstrate a higher level of skill. Examples including draw a molecule or graph
- **Analysis**- Questions or tasks that require a data set to be manipulated to arrive at an answer or opinion are classified. Common verbs include calculate, analyse or distinguish.
- **Synthesis**- refers to a question or task that requires that student to analyse multiple statements or datasets to support or challenge a statement.
- **Evaluation**- requires a student to judge or assess a range of ideas to arrive at an opinion. Applying this classification can only be done if a student creates a new point of view.

Once this classification was completed, the sum of each objective was recorded per paper and the overall presence of each objective was calculated by percentage. An average of these results was also included so that the content of each objective assessed could be compared across the Leaving Certificate and Advanced Placement programmes.

4.7.3.2 Leaving Certificate Chemistry Higher and Ordinary Level Exam Papers (2014-2018)

The results of the quantitative analysis of both sets of Leaving Certificate papers are presented in Figure 4.1 and Figure 4.2 respectively. According to Bloom's Taxonomy, the combined knowledge and comprehension objectives are worth 65% of the total objectives at higher level. At ordinary level, this percentage is significantly increased (80%). Opportunities to test the higher objectives of the taxonomy were limited throughout all five years across both papers and when higher level objectives were present, the paper architecture had limited scope beyond the application or analysis objectives.

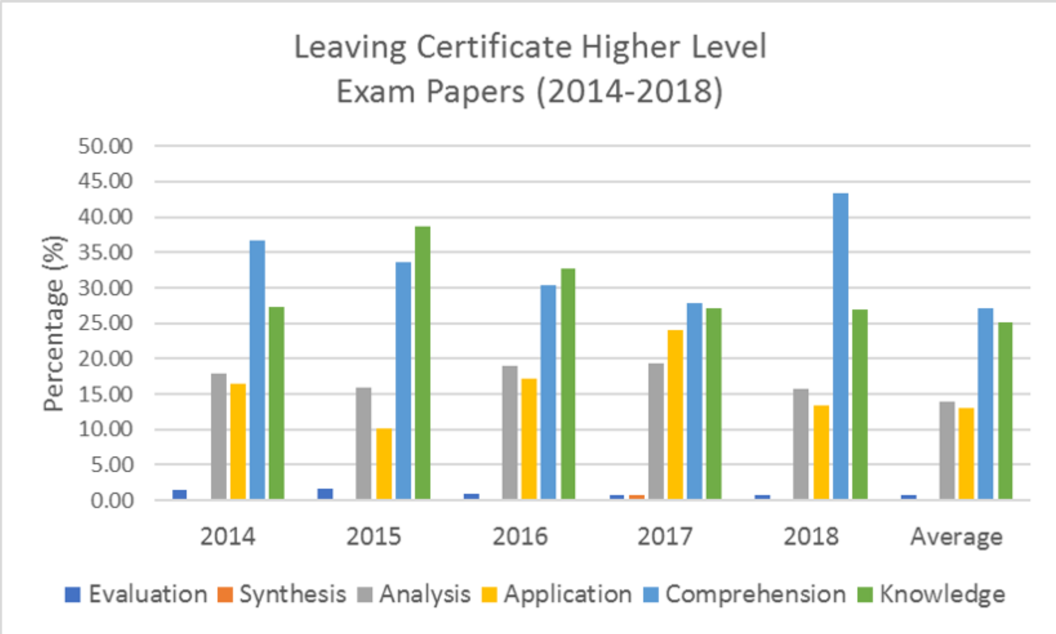

Figure 4.1: *Frequency of each objective in Leaving Certificate Higher Level Chemistry exam papers (2014-2018) and the overall average result.*

Higher order objectives, when observed, were commonly achieved through calculation-based questions or by instructing the student to balance an equation. There was a noticeable lack of evidence throughout all five papers that questions were designed to test a student's ability to evaluate a result or predict an outcome. The omission of these questions show that the programme is not enabling the student to display a more sophisticated understanding of the topic. It also prevents the development of enquiry based learning and critical thinking skills, both of which we require in the next generation of scientists. This result mirrors the findings concluded by Cullinane and Liston in their study of Leaving Certificate Biology papers from 1999 to 2008 which indicates that this finding is not just restricted to one Leaving Certificate subject (Cullinane & Liston, 2016).

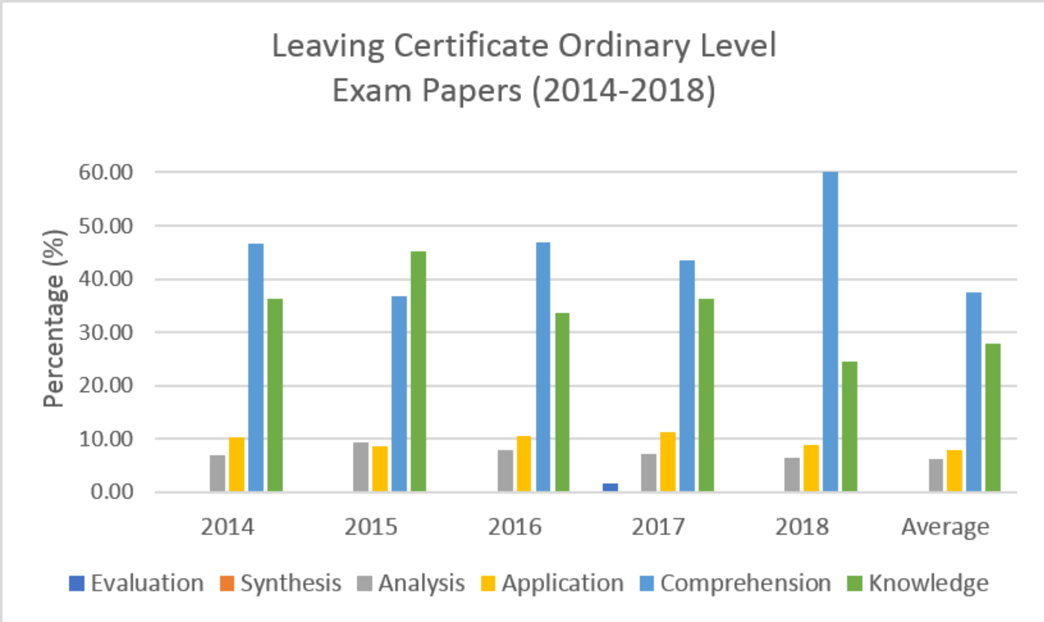

Figure 4.2: *Frequency of each objective in Leaving Certificate Ordinary Level Chemistry exam papers (2014-2018) and the overall average result.*

Closed or convergent questions are frequently observed throughout both sets of exam papers. These require students to provide a single word or a short sentence to correctly answer a question (Tofade, 2013). The closed question format favours students who have a high capacity to memorise definitions and applications and ultimately illustrates the significant value placed on rote-learning by the Leaving Certificate programme.

All questions are designed using a restricted list of verbs (e.g. state, list, define, predict) yet each term has no specific value or mark associated with it. Instead the same verb may be used in the same context but can be worth a range of marks. A specific example of this is in the 2016 exam paper. In question 2 part (f) the student is asked what colour is observed when a sodium salt (NaCl) is placed in the centre of a Bunsen flame (yellow) and is awarded 6 marks. In question 3 part (a) of the same paper, the student is asked "*What is a catalyst?"* (a substance that alters the rate of a reaction without being consumed) and is only awarded 5 marks if answering correctly. Although in the second example, a student is required to provide a longer answer, the answer is worth one less mark than in the first example.

Where students can choose to answer one of multiple parts, the exam paper format allows them to avoid calculations or the minority of questions that require an evaluation or an opinion. To illustrate this point, Question 11 on the 2017 higher and ordinary level exam paper was analysed according to the marks awarded for each of the six learning objectives. The analysis results are shown in Figure 3.3. Question 11 has three overall parts (A, B and C) of which two must be attempted and worth 25 marks each at both levels. Part C contains two subparts C (a) or C (b), and if chosen, the student must answer either C(a) or C (b). As illustrated by Figure 4.3 (i), students who elect to answer part A and C (b) at higher level require lower level objectives than students who elect to answer part B and C (a). Similarly, students who choose to answer part A and C (b) on the ordinary level paper use lower cognitive objectives than those who choose to answer part B and C (a). This shows that the structure of each question and the mark awarded for each part varies significantly and enables students to attain high marks for unequal amounts of effort.

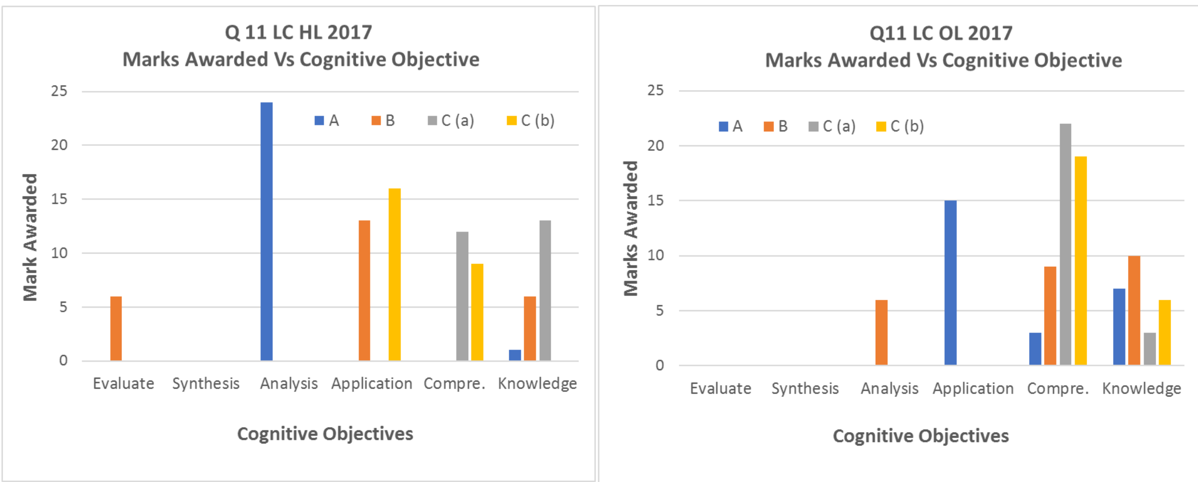

Figure 4.3:*The marks awarded per cognitive objective for Question 11 on the (i) higher level and (ii) ordinary level exam papers in 2017.*

By examining the corresponding marking scheme for each paper, it is also evident that students have limited flexibility in the range of possible answers that they can provide to a given question. Question 3 (c) on the 2015 ordinary level paper illustrates how only specifically worded answers are acceptable to receive marks for a question.

Question 3(c): *Describe with the aid of a labelled diagram how the concentration of dissolved solids could have been measured.*

Answer (from marking scheme): *filter // known volume // through filter paper // previously weighed / of known mass // wash filter paper with distilled water // dry / place in oven, etc // reweigh // find difference in masses (9 marks)*

This exam solution format may allow examiners to increase their average marking efficiency per exam script but does not encourage students to research material outside of that presented in their course textbooks.

4.7.3.3 Advanced Placement Chemistry Exam Papers (2014-2018)

A similar quantitative analysis was conducted for the Advanced Placement Chemistry exam papers over the same range of years. Equal marks are given for the two sections of the paper and one mark is awarded for all correct answers given by the student, regardless of the instruction. There is no choice on either section of the exam, all questions are mandatory. Topics that are perceived by the student to be more challenging cannot be avoided.

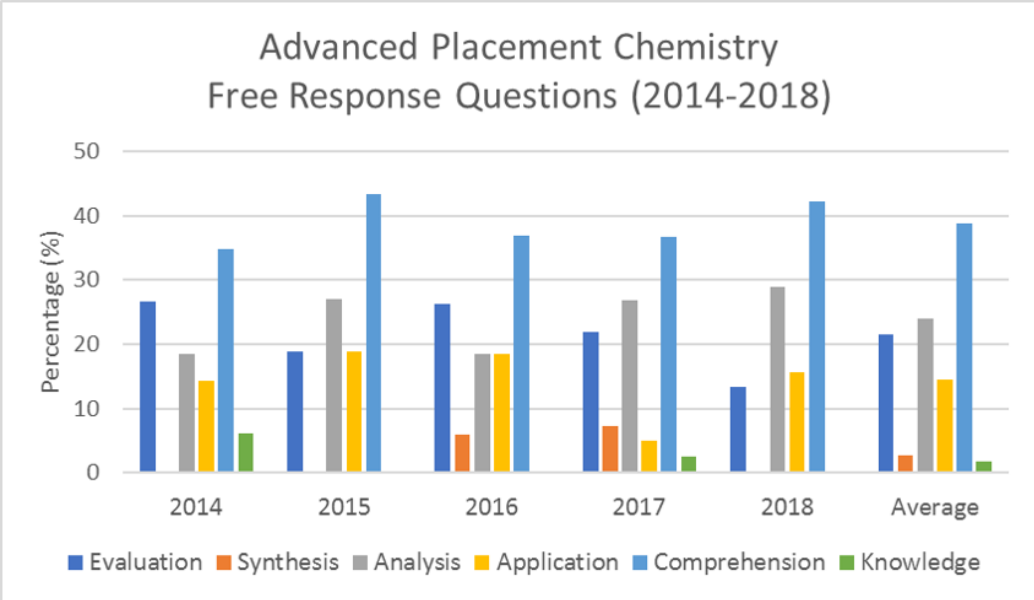

Figure 4.4: *Frequency of each objective in the free response section of the Advanced Placement Chemistry exam papers (2014-2018) and the corresponding overall average result of each objective.*

Figure 4.4 shows the results of the analysis of the free response section of each paper. Emphasis is primarily placed on three of the six cognitive objectives in Bloom's Taxonomy e.g. evaluation, analysis and comprehension. The comprehension objective is always the highest of these three objectives and on average accounts for 40% of the questions across the papers studied. This value concurs with both of values recorded in the comparative analysis of the Leaving Certificate higher (35%) and ordinary level (45%) papers. However, a noticeable difference is observed in the contribution of the knowledge objective which typically accounts for less than 5% of the objectives on a free response question. There is an apparent progression of cognitive objectives in the exam design which is vastly different from what was observed in the Leaving Certificate paper analysis.

In the free response section, every question incorporates a request for students to justify or evaluate previously attempted parts (The College Board, 2018). In contrast to a typical Leaving Certificate Chemistry marking scheme, each justification is not required to be the approved answer provided in the marking guidelines. This open-ended approach reduces the possibility of rote-learning yet simultaneously encourages students to interpret a question in their own way.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3$ (*aq*)	0.500	5.00
NaOCl (*aq*)	0.500	5.00
NaOH (*aq*)	0.500	5.00

Question 1 (c): Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

NaOCl is the limiting reactant. Given that equal numbers of moles of each reactant were present initially, it follows from the coefficients of the reactants in the balanced equation that NaOCl will be depleted first.	1 point is earned for identifying the limiting reactant <u>and</u> providing a valid justification.

Figure 4.5: *Question 1 (c) and the accompanying excerpt from the 2018 Advanced Placement Chemistry Free Response Section marking guidelines.*

An example of this can be seen from Question 1 (c) in the 2018 paper. According to the scoring guidelines, a mark is given for correctly identifying NaOCl as the limiting reagent. An additional mark is also given for correctly justifying NaOCl as the limiting reagent, yet only a sample solution is provided. Students are encouraged to provide other solutions if appropriate to the question.

4.7.3.4 Advanced Placement Chemistry- Section 1, Multiple Choice Questions (MCQs)

Although the College Board annually releases the latest free response section through the Advanced Placement Chemistry website, the MCQ paper is never officially released into the public domain. This is to minimise the chances of prospective examinees predicting potential questions from year to year. As a result, the classification of the MCQ exam in this study required identifying alternative sources of the exam that were deemed to be a fair representation of the exam standard itself. These sources include:

- A sample test provided by the College Board on the Advanced Placement Chemistry website (The College Board, 2018, Advanced Placement Chemistry Exam Practice).
- An unofficial copy of the 2016 Advanced Placement Chemistry Section 1 MCQ exam.
- A sample MCQ exam (referred to as AP Sample 2016 in Figure 3.4) which has be provided in the appendix (see A-1).
- Two practise tests from *Barron's AP Chemistry* a popular revision book for students registered to take the Advanced Placement Chemistry exam, jointly written by Prof Neil D. Jespersen, (St. John's University, Queen's New York) and Pamela K. Kerrigan, (College of Mount Saint Vincent, Bronx, New York). Both tests are available on pages 543 and 583 of the 8th edition (Jespersen & Kerrigan, 2016).

Although this selection provided a more cohesive image of the variety of resources typically used by students in preparation for the exam, there was a notable difference in the measured percentage of each objective (see Figure 4.6). The sample tests provided by the College Board administrators had a better range of the cognitive objectives throughout the exam. It is also worth noting that both of Barron's practice tests had the combined highest percentage of the comprehension and knowledge objectives, as well as a large variation in the tallied sum of these objectives (55% and 72.5% respectively). This may lead to a false sense of security amongst Advanced Placement Chemistry students who rely on this book as a study aid to prepare for the exam.

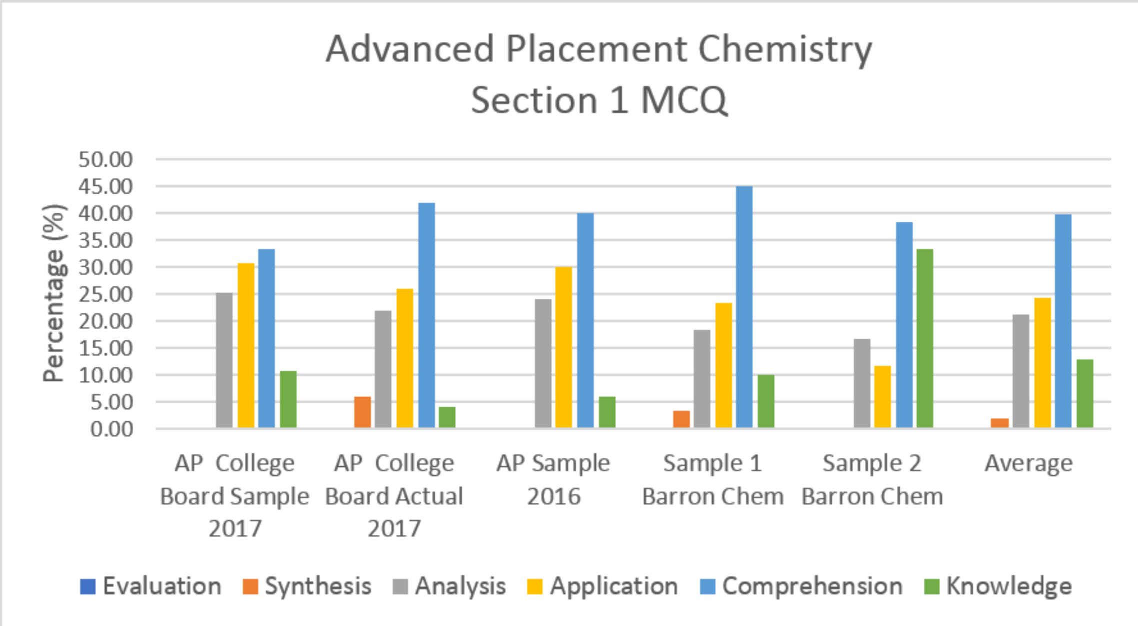

Figure 4.6: *Frequency of each objective in all Advanced Placement Chemistry MCQ exams and the overall average result from across the exam paper sources.*

The format of a MCQ, by its nature, does not easily incorporate the evaluation and synthesis objectives into the MCQ question design. As a result, there is naturally a higher percentage of comprehension and application-based questions presented. According to Domyancich, the format of all redesigned multiple-choice questions deliberately assesses more advanced learning outcomes than the exam papers associated with the former Advanced Placement Chemistry curriculum (Domyancich, 2014). This is achieved by incorporating context dependent questions. Context dependent questions typically include a visual representation (such as a table or graph) and requires a student to display problem-solving skills as well as some degree of evaluation (Haladyna, 2010). For the Advanced Placement Chemistry MCQ exam, they must agree with one of the reasons associated with the image in order to arrive at the correct solution. There is a noticeable increase in context dependent items evident throughout the analysed papers, an example of which can be seen in Figure 4.7.

Consider the dissolution of calcium chloride, $CaCl_2$, in water as shown in the reaction below:

$$CaCl_2(s) \rightarrow Ca^{2+}(aq) + 2Cl^{-}(aq)$$

A student uses a polystyrene cup calorimeter to determine the enthalpy of solution of calcium chloride and obtains the following data:

Mass of calcium chloride	5.02 g
Volume of water	99.8 mL
Initial Temperature of Water	19.3°C
Final Temperature of Water	27.1°C

Based on this data, is the dissolution of calcium chloride endothermic or exothermic?

(A) Endothermic because the water becomes warmer and therefore must be absorbing energy.

(B) Endothermic because the breaking of the ionic bonds in calcium chloride and the hydrogen bonds in water require an input of energy.

(C) Exothermic because the water becomes warmer as a result of the attractive forces between the ions and water molecules.

(D) Exothermic because the dissolution is spontaneous and therefore thermodynamically favored.

Figure 4.7: *A sample context dependent question from an Advanced Placement Chemistry MCQ.*

4.7.4 Overall Comparison of Exam Papers

In order to establish the final recommendations from this study, the average results were analysed from all three sets of papers, the results of which are shown in Figure 4.8. This final analysis was limited to the free response section of the Advanced Placement Chemistry exam so that similar exam question formats from both programmes could be compared i.e. the short and long questions. It is clear from Figure 4.8 that both levels of Leaving Certificate Chemistry incorporate minimal exposure to higher learning objectives. It is also evident that Advanced Placement Chemistry free response questions incorporate a greater distribution of the six learning objectives, with the smallest contribution resulting from the knowledge objective. The most worrying observation from the comparison is that a Leaving Certificate ordinary level student can complete a typical exam and receive more than 80% of the marks based solely on knowledge and cognitive object. Less than 15% of the exam is designed to test any other objective, thereby justifying the public criticisms on rote learning and memorisation (O'Brien, 2016).

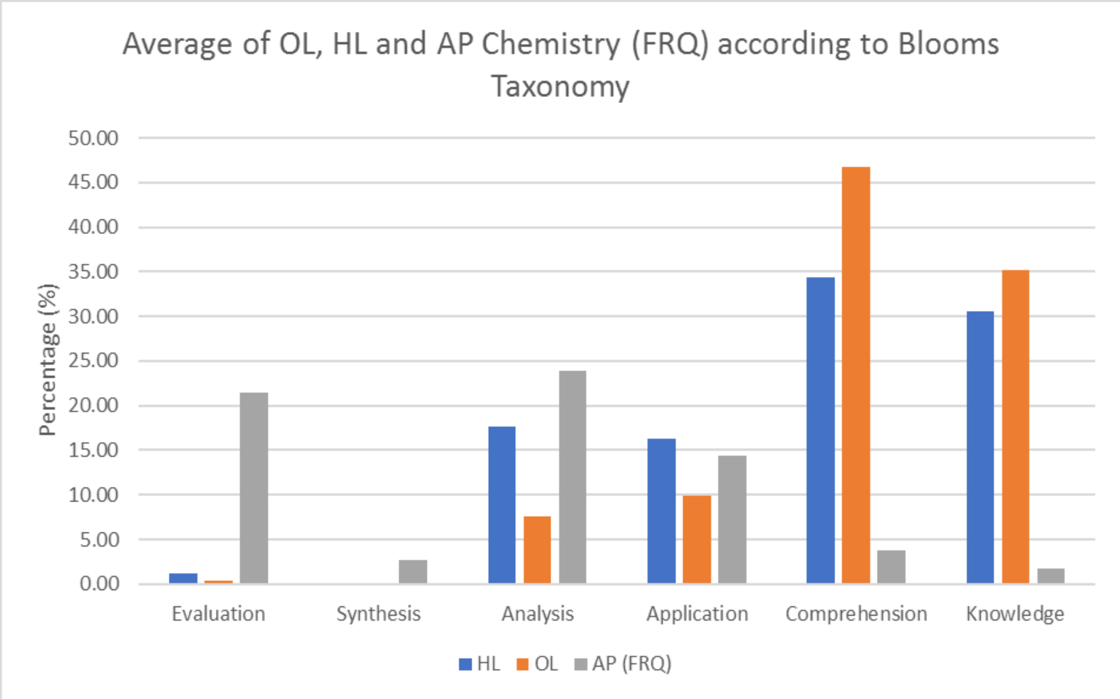

Figure 4.8: *A comparison of the average percentage of each of the six objectives in Leaving Certificate higher (HL) and ordinary (OL) level versus the free response section of the Advanced Placement exams (2014-2018)*

4.8 Conclusions

Both programmes aspire to assess the same qualities in students i.e. their general scientific abilities and their understanding of basic chemistry. Although neither programme requires students to complete a formal practical assessment, both aim to place an importance on the practical laboratory element of chemical education. If a student is required to demonstrate their ability to make an apple tart under time constraints (Leaving Certificate Home Economics) why are the next generation of chemists not required to demonstrate their practical capabilities under similar constraints?

The exclusion of organic chemistry from the Advanced Placement Chemistry programme is worrying. Although the programme's exam is intelligently designed to assess the six cognitive objectives in this study, Advanced Placement Chemistry students who proceed to science degree in university are usually expected to have a basic level of organic chemistry before admission. By formatting the programme to align with the six *Big Ideas*, the specialised approach of the curriculum may be beyond the scope of a high school student.

This study has also shown that the current Leaving Certificate programme, at both levels, is not an accurate assessment of a student's ability to proceed to a third level science degree. A redesigned Leaving Certificate Chemistry curriculum must incorporate mechanisms to assess the higher order thinking skills so that both third level educators and those who progress through the programme can have a greater faith in those that accomplish a H1 grade.

Chapter 5: General Discussion and Conclusion

5.1 Introduction

The aim of this chapter is to summarize the findings from this comparative study so that recommendations can be made on curriculum and assessment for future research. These recommendations will be described according to the order that this study adopted, namely prerequisites for enrolment in the programmes, syllabus content and practical assessment, final examinations and admission into third level courses. Finally, this chapter will include a brief discussion about the implications of the new Leaving Certificate Chemistry curriculum and will suggest possible avenues for future work should this study be continued.

5.2 General Discussion

This work set out to conduct a comparative study between two high school chemistry programmes by assessing their curriculum content, experimental design and resulting examinations. The aims of both programmes are similar despite the diversity in a student's pathways before progressing through their educational journeys. One of these aims is to ultimately prepare their students for third level chemical education. By enabling them to develop the basic scientific competency for further related studies at third level, the programmes endeavour to maintain a student's enthusiasm for scientific learning. Based on this comparative study, it can be concluded that neither programme fully realise these aims in the current format of their curriculum and assessments.

To contextualise the similarities and differences between both programmes, each research questions will be now stated at the beginning of the following sections and the corresponding results of the research question will be given.

5.2.1 Comments on Programme Enrolment

Research Area	Associated Research Question
Programme requirements	Are the entry requirements of both programmes the same and how it science education in second level education perceived?

A student can graduate from Irish secondary education without having completed Junior Certificate science, it remains at the discretion of individual secondary schools whether it is a mandatory part of the Junior Certificate curriculum. It is also not compulsory to choosing a Leaving Certificate science subject despite the importance placed on science knowledge in our economy today. The approach of the American high school education system, although different, ensures that all graduates complete a minimum of five years of science education. This multidisciplinary approach ensures that a minimum level of basic scientific learning is acquired by the country's population. By electing to complete an Advanced Placement science subject, students can personalise their final years of high school education in accordance with their interests and strengths.

5.2.2 Comments on Design and Content of the Programmes

Research Area	**Associated Research Question**
Curriculum design	How do both chemistry programmes differ in content, subject matter and structure? How is practical work incorporated into each curriculum and how is it assessed?

The Leaving Certificate Chemistry programme is very specific and so is accompanied by a prescriptive syllabus that leaves little room for variation in interpretation or misunderstanding. The syllabus requires teachers to attribute timeslots to different aspects of the course, in the same way that instructions accompany a piece of furniture to be assembled. This approach can be perceived both positively and negatively in terms of learning and development. Although it does not promote educational processes such as scaffolding or contextual learning, it does ensure that the Leaving Certificate Chemistry cohort is progressing through the curriculum content in an unvarying manner. The content outline, combined with one single recommended textbook, ensures a uniform standard is maintained by all, and the final examination is an adequate reflection on the abilities of the cohort of students.

The Advanced Placement Chemistry programme offers an alternative perspective to students on chemical education. Although the overall themes and topics of the programme are designed by the College Board, it is left to registered teachers to decide and interpret how content is presented by Advanced Placement schools (Price, 2014). Teachers are permitted to set individualised lesson plans or experiments that correspond to the framework of the course but are encouraged to design specific content according to their personal strengths or resources available. This creative approach also instils an enhanced level of trust in the programme's approved teachers, which I believe should be considered in the proposed redesign of the Leaving Certificate science curriculum.

North American Universities typically accept Advanced Placement subjects either in lieu of specific course requirements, or in exchange for partial credit in the first year of a degree. This practice is not commonly reciprocated by European universities. The Advanced Chemistry programme is primarily a general and physical chemistry curriculum. Some of the subtopics and their associated terminology are well beyond the scope of even higher level Leaving Certificate Chemistry (e.g. Graham's Law of Effusion and the integrated rate laws). However, Leaving Certificate Chemistry focuses on a greater breadth in the selection of topics offered, and the exposure of its students to global applications of chemistry e.g. through its inclusion of industrial and atmospheric chemistry. This content misalignment between the Advanced Placement and Leaving Certificate Chemistry course is greater than that observed between Leaving Certificate Chemistry and other international chemistry programmes. As a result, teaching these cohorts must present challenges in third level multicultural science classrooms.

Although Advanced Placement Chemistry explores six of the central chemistry ideas in greater detail than the Irish curriculum, the exclusion of organic chemistry is the most concerning compromise of this specialisation. To fully appreciate the relevance of organic chemistry to everyday lives (soaps, detergent, cosmetics, food, medicine and fuels), students need to be exposed to necessary applications. Because of this compromise, the Advanced Placement curriculum cannot truly reflect the importance of chemistry to its students.

Both programmes facilitate the inclusion of practical work by timetabling weekly double class periods. However, the Leaving Certificate programme promotes rote-learning by requiring students to complete the programmes mandatory experiments like a recipe book. Yet aspects of the programme are to be commended, especially the inclusion of the organic chemistry functional group comparison in the experiment list. The experimental list also includes a greater range of techniques than the Advanced Placement programme due to the programme content spanning a greater range than that of Advanced Placement chemistry.

The Advanced Placement programme is designed to allow for a greater amount of guided research than the it's Irish counterpart. The programme does this by giving the students a topic and its associated parameters but specifically allows students to investigate the theme in their own way. It also allows individual Advanced Placement teachers to interpret the specific design of each experiment. Students are required to complete a template to accompany each completed experiment, but this template is not as prescribed as the one accompanying the Leaving Certificate syllabus.

5.2.3 Comments on the Assessment Format and Grading Criteria

Examination style and associated importance	How do examination structures differ in question style and range of material covered? Do both programmes successfully adhere to Bloom's Taxonomy by incorporating all six cognitive objectives into their assessment? How do both contribute to entry into undergraduate science programmes?

There are aspects of both programme's final assessment architecture that undoubtedly appeal to all educators. The structure of the Leaving Certificate Chemistry paper allows students to select topics according to their own personal strengths and interests. The span of topics assessed in the exam are also a true reflection of the course content and the current design deliberately includes real world applications. In doing this, however, the Leaving Certificate also offers students too much choice, making it a challenge to correct in a uniform manner. The annual marking scheme, like the conclusions drawn in this study's curriculum review, is too prescriptive and encourages students to learn only the "correct" answers in preparation for the exam. It also highlights the inconsistencies that exist across questions. An awarded grade can be earned without completing comparable levels of difficulty within the same paper. This makes it problematic for a third level institution to identify the students with a high aptitude for the subject, from those who have successfully memorised the required answers to sit the exam. By reducing the considerable choice that students have and assessing a uniform list of cognitive objectives throughout each question, the review time for each answer booklet would be decreased and a higher proportion of higher order objectives could be assessed.

The results of the exam paper analysis conducted in Chapter 4 reiterate many of the findings of Cullinane and Liston in their review of Leaving Certificate biology (Cullinane, 2016). There is clear reliance placed on questions that can be answered with a basic knowledge of the subject, particularly at ordinary level. In this way, the programme does not differentiate high aptitude students from their peers.

The Advanced Placement exam includes a range of questions that require students to have a comprehensive knowledge of the subject, while simultaneously testing the range of cognitive objectives covered by Bloom's Taxonomy. The programme's marking guidelines also allow students to answer a question creatively whilst simultaneously enabling them to receive credit in a consist manner. Unlike the Leaving Certificate, the Advanced Placement exam requires students to answer each question on the paper and in doing so, does not account for the individual strengths of a student. In this way, both programmes mirror each other's strengths and weaknesses in their chosen examination design.

Both programmes conclude with a single high stakes assessment, the results of which are used to obtain admission into third level education. It is well documented that a single exam may not be an adequate reflection of a student's academic performance in a chosen subject (Hernandez, 2012; Polesl, Rice, & Dulfer, 2014). In Ireland, the recent reform of the Junior Cycle to a continuous assessment model means that alternative assessment pathways are currently being considered in the context of Irish secondary schools. Although individual subjects are assessed internally by grade in North American high schools, Advanced Placement subjects are designed to highlight enhanced student aptitude which the programme scores through a final summative exam. To adequately reflect the spectrum of learning within the subject, the results of this research project strongly highlights the need for diversification within the syllabi and the inclusion of a practical assessment. This would allow students to receive credit for the effort that they put into mandatory experiments while simultaneously enforcing the importance of the development of techniques and skills that are required to begin a third level science degree (Bennett, 2001).

Table 5.1 compares the grade distribution for both programmes from their 2017 annual exam results. The College Board scores all Advanced Placement assessments on a five-point scale, five being the maximum score a student can attain. From Table 4.1, it can be deduced that the Advanced Placement score distribution is very much aligned with the bell curve model. More than one quarter of students received an overall score of 3, and almost two thirds of students received a score of less than three. Based on these results and the limited number of bands used to grade the exam, it can be established that the Advanced Placement Chemistry scores are not graded using standard deviation, which many believe is a much more accurate judge of performance (Aviles, 2010; Chan, 2014). According to the College Board *"In general, an AP grade of 3 or higher indicates sufficient mastery of course content to grant a student exemption from a college course, credit, or both"* (Sadler, 2007). This statement, combined with the 2017 exam results and the conclusions of this research study, indicate that the level of the programme is above that of a typical high school course.

Table 5.1: *Comparison of the 2017 Chemistry exam grade distribution for both the Advanced Placement and Leaving Certificate Chemistry programme. The total number of students refers to the total number who sat the final examination.*

2017 Leaving Certificate Higher Level Grades + Marks	H1 (100)	H2 (88)	H3 (77)	H4 (66)	H5 (56)	H6 (46)	H7 (37)	H8 (0)	Total No. of Students
Chemistry (%)	11.3	17.7	17.3	14.9	12.95	11.1	7.7	6.9	8162

2017 Advanced Placement Grades (%)	5 (100-80)	4 (79-60)	3 (59-40)	2 (39-20)	1 (19-0)	Total No. of Students
Chemistry (%)	10.1	16.2	26.1	26.2	21.4	158,931

As discussed in Chapter 2, the Leaving Certificate programme adopts an eight-point scale for marking both the higher (H1-H8) and ordinary (O1-O8) exam papers which was introduced in 2017. According to the report published by the Irish Universities Association and the Institutes of Technology Ireland, the intention of this scoring system is to allow students to achieve marginal gains and to encourage greater engagement with the each Leaving Certificate subject (Irish Universities Association and the Institutes of Technology Ireland, 2015). The adoption of this new scale was also an effort to reduce the frequency of rote-learning and to encourage innovation when attempting the paper. Yet Table 4.1 illustrates that almost half of higher level chemistry students received H3 (77 marks) or higher in the 2017 exam. This observation supports the need for a redesign of the curriculum not just the grading system to collaboratively combat the success of rote-learning within the exam itself.

From these results, it can be concluded that results from the Advanced Placement programme are a greater indicate of the overall aptitude of a student and are therefore a better reflection of student merit for entry into undergraduate science degrees.

5.3 Other Challenges for Advanced Placement Graduates

To further understand the challenges that Advancement Placement graduates face, informal conversations were scheduled with both an Advanced Placement teacher and alumni of the programme. From these discussions it became evident that there is some confusion in Ireland around the equivalency of Advanced Placement subjects for admission into national university programmes. Based on these conversations, it appears the programme duration (one year) versus Leaving Certificate cycle (two years) seems to be a issue for university admissions teams in Ireland who process high school transcripts. As this research has illustrated, students who undertake Advanced Placement Chemistry typically have a distinct aptitude for the chemical sciences. The syllabus content is more advanced than higher level Leaving Certificate Chemistry, going beyond those ideas explored in second level education here. The number of contact hours in the Advanced Placement course is frequently equivalent to or slightly above the total prescribed contact hours for Leaving Certificate Chemistry (Department of Education and Skills, 1999). Pending the attainment of the necessary ACT or SAT scores, students who choose Advanced Placement Chemistry should qualify here for entry into science subject dependent courses. However, knowing that graduates of Advanced Placement Chemistry are unlikely to have sufficient background knowledge in organic chemistry, this study also recommends that they are required to participate in preliminary chemistry coursework or dedicated organic chemistry tutorial support for the first year of third level science courses.

5.4 Going Forward: Leaving Certificate Science Syllabi Reform

The current Leaving Certificate Chemistry syllabus was first published in 2002. In 2011 it was announced that the chemistry, biology and physic syllabi were each to undergo a curriculum redesign by the NCCA (Cullinane & Liston, 2016). This redesign was primarily intended to include modern scientific developments that are omitted from the current syllabus, and their associated skills and techniques.

In 2014, the Hyland report, was presented at the annual Irish Science Teachers' Association (ISTA) conference, Ireland's professional body for science teachers. The report compared three Leaving Certificate science programmes with similar high school courses in Scotland and Australia. It also examined the proposed new features of a prospective curriculum design (Hyland, 2014). The report was requested by ISTA after the association had expressed concerns about the proposed content of the new science syllabi, specifically with regards to the depth of each topic within the new curricula (Donnelly, 2014). According to ISTA, the proposed syllabi for all three subjects did not measure up to the reviewed examples of international best practise (Donnelly, 2014).

Although this researcher could not access the proposed syllabi, from reading the Hyland report, it is believed each science subject will now require the completion of two assessments, a written assessment (worth 70%) and a practical assessment (worth 30% of the final mark). Although little detail was given as to their prospective content, it is expected that both will be externally assessed at separate intervals of the programme. Students will be required to answer three main question types in the written assessment; short answer questions, open-ended questions and extended response questions which is aligned with the format of the Advanced Placement programme analysed by this study. This proposed assessment format will enable the student to showcase a greater range of the skills that have been acquired within the programme. This proposal also agrees with the recommendation of this comparative study. The new content is expected to cover five units, each with a list of associated sub-topics and associated learning outcomes.

The report also states how each of the proposed units in the draft curriculum lack detailed descriptions for suggested activities, depth of treatment or social and applied issues, all of which were previously incorporated into the existing chemistry curriculum.

Further NCCA Recommendations for the design of a new Leaving Certificate Chemistry curriculum

In the NCCA's 2012 report, ISTA recommended that new science curriculums should include more emphasis on the development of dexterity and manipulation skills rather than stressing the importance of open-ended research (NCCA, 2012). This recommendation is extremely controversial as open-ended research in a curriculum undoubtedly provides increased opportunities for inquiry and critical thinking skills, the presence of which is a considerable factor in pursuing a STEM degree or career (Thiry, Laursen, & Hunter, 2011). A compromise to this may be the incorporation of guided inquiry. According to a study completed by Cheung, guided inquiry reduces the occurrence of many common issues that teachers have with open-ended research i.e. shortage of class time, useful instructional materials and the challenge of open-ended research when teaching large groups (Cheung, 2007). If the ISTA's recommendation is to be implemented, then more opportunities for guided inquiry must be integrated into a new Leaving Certificate Chemistry curriculum. This would ensure that students can develop the necessary skills and techniques that are required for enrolment in a third-level science course.

5.5 The Implications and Validity of this Study

This research project centres around a comparative study of senior second level chemical education in Ireland and the United States. To my knowledge, there is no such pedagogical study reported in chemical education by the literature, although studies of complimentary scientific subjects and levels exist. Irish third-level institutions have become increasingly financially reliant on educational internationalisation, so establishing best practice and benchmarking national education against other international second level programmes is undoubtedly within our interest. Given the significant importance that is currently placed on science education in the global landscape, it is surprising that more comparative studies in this area have not been conducted to date. In this respect, the results and recommendations of this work are internationally valid and important.

5.5.1 Limitations of this study

This has been primarily a desk-based research project and as such, the comparative study was conducted in a clinical manner. Textbooks were reviewed, papers were read, and the prescribed analysis was completed. This design was deliberate and was primarily to allow me to maintain a full-time job. Although this role is based in a university, it did not permit me the freedom to travel to schools in Ireland or the United States to conduct comprehensive research on the student and teacher experience. These factors are extremely important considerations in designing a curriculum and should also be assessed if this study is continued.

This project also involved a programme that was not taught nationally. This provided geographical limitations and reduced many of my interactions with the programme to informal conversation and emails. To date, I have sat in on an Advanced Placement Chemistry lesson, so have some sense of how the programme is taught day to day. However, this was a single lesson, conducted by a teacher and a set classroom of students. This is not a full representation of how the subject is taught, never mind representing the Advanced Placement programme itself.

5.6 Future Work

This study has highlighted the need to extend this research to other international high school chemical education programmes so that best practice across peer programmes may be established. Although both the International Baccalaureate and the Cambridge A-Level courses were referred to in the context of their overlap in organic chemistry, a complete review of the programmes was not completed during the timeframe of this study. The Hyland Report has included references to both the Scottish and Australian counterparts of the Leaving Certificate and highlighted aspects of their programmes design (Hyland, 2014). The report does not include a comprehensive review of the examination papers under the same criteria as those chosen for this work. The results of the proposed study would potentially be very informative in establishing a more complete understanding of global chemical education.

To extend this comparative study, an investigation into the social context and the teaching atmosphere that exists around both programmes needs to be understood. Other factors such as the requirements for teacher's participation in continuous professional development (CPD) coursework or even the access of students to STEM outreach activities could be analysed (Supovitz, 2010; Prendergast, 2018). An important aspect could involve designing focus groups or surveys to further understand the student's perception of both programmes (content, resources, examination style etc) similar to the work completed by Yan in her comparison of biology teaching in Northern Ireland and Beijing (Yan, 2007).These factors would give a more holistic view of second level chemical education in both countries.

Although this project was initially proposed to fulfil the research requirements of a Master's in Education, the results of this study suggest that a wide spread analysis now needs to be completed on all Leaving Certificate subjects, which is beyond the remit and expertise required for this project.

This comparative study has focussed on the curriculum content and examination requirements of both programmes. It is therefore sensible that the next steps of this project now focus on how successful each assessment is in achieving the programme specific objectives. According to the literature, one of the preferred methods of doing this is to explore the variation in student's answers according to Bloom's Taxonomy. This method is known as the Rasch Model and is explained in Appendix A.4)

By applying the Rasch Model to this study (see A-4), a comprehensive review of the examination system could be conducted and the precise topics of perceived difficulty identified (Childs & Sheehan, 2009). If this study is extended to include other international programmes, it would be useful to understand if commonalties exist across programmes, despite the different cultural backgrounds and pedological approaches adopted.

Final Conclusions

This study has proved rewarding, both in terms of deepening my understanding of the design and format of Irish second level chemistry education, as well as my knowledge of high school education internationally. This experience has also encouraged me to identify other methods of best practise in other chemical education programmes and to identify steps that could be incorporated into the starting months of Irish undergraduate science programmes to compensate for the differences between international second level chemistry programmes. An example of this is a possible preliminary organic chemistry programme for students matriculating from the Advancement Placement Chemistry programmes, or the timetabling of additional organic chemistry tutorials for the first-year class. These simple suggestions could vastly improve the educational experience off international students undertaking science programmes in Ireland.

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Appendices

Appendix A-1

Extract from Leaving Certificate Higher Level Chemistry Syllabus

The full syllabus can be accessed at

www.curriculumonline.ie/getmedia/7bdd3def-f492-432f-886f-35fc56bd3544/SCSEC09_Chemistry_syllabus_Eng.pdf

Appendix A-2

Extract from Advanced Placement Chemistry Course Guidelines and sample syllabus

Full documentation can be accessed at www.media.collegeboard.com/digitalServices/pdf/ap/ap-chemistry-course-and-exam-description.pdf and

www.apcentral.collegeboard.org/pdf/ap-chemistry-sample-syllabus-1-id-1029708v1.pdf

Appendix A-3

Sample Advanced Placement Multiple Choice Test

Appendix A-4

Explanation of the Rasch Model

The Rasch Model

The Rasch Model was established by George Rasch in 1960 and has been developed as a quantitative method to model how effective an assessment is by measuring the variation of student responses (Arsad et al., 2013).The method has already successfully been used at multiple educational levels, from the study conducted by Liu *et al* to investigate the early mathematical achievements of pre-school children, through to Edwards and Alcock's measure of undergraduate student performance (Clements, Sarama, & Liu, 2008; Edwards & Alcock, 2010).In chemical education, the Rasch Model has been also been utilized by Sevian and Fulmer to assess a range of skills in undergraduate chemical laboratory work such as critical thinking and communication skills and engagement in science (Sevian & Fulmer, 2012).

In order to fully understand the model design, a simplified explanation of the Rasch Model is presented below. To utilise the model effectively, the user must first design a question with two possible outcomes. A point is awarded if the answer is deemed to be correct. A value of zero is awarded for an incorrect answer. The overall calculation is the value of the probability $P_i(\Theta)$ of a student (n) in scoring either 1 or 0 from correctly answering a question (typically termed the item, represented as (*i*) in the equation). The ability of a student is Θ_n and the difficulty of the questions is referred to as δ_i

$$P_i(\theta) = \frac{\exp(\theta_n - \delta_i)}{1 + \exp(\theta_n - \delta_i)}$$

If there are more than two possible responses to a question, this model is further expanded to account for multiple potential answers.