Examining the cognitive demand of high-stake Physics and Chemistry examinations in Ireland

Damienne Letmon

B.Sc., H. Dip.Ed., M.Sc.

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Supervised by Dr Eilish McLoughlin, Dr Odilla E. Finlayson

Declaration Page

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and that I have exercised reasonable care to ensure that the work is original and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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List of Abbreviations

BERA	British Examination Research Association
C1	Chemistry syllabus 1
C2	Chemistry syllabus 2
C3	Chemistry syllabus 3
CBAs	Class-Based Assessments
Dept. Ed	Department of Education (1921-1997, 2020-present)
DES	Department of Education & Science (1997-2010)
DES	Department of Education & Skills (2010-2020)
DOK	Depth-of-Knowledge
eISB	electronic Irish Statute Book
HL	Higher- level
IAEA	International Association for the Evaluation of Education Achievement
ILSAs	International Large-Scale Assessments
INES	International Indicators of Education Systems
LC	Leaving Certificate Examination
LCVP	Leaving Certificate Vocational Programme
OBT	Original Bloom's Taxonomy
OECD	Organisation for Economic Co-operation and development
OL	Ordinary- level
P1	Physics syllabus 1
P2	Physics syllabus 2
P3	Physics syllabus 3
PISA	Programme for International Student Assessment
RBT	Revised Bloom's Taxonomy
SEC	State Examinations Commission
TIMSS	Trends in International Mathematics and Science Study
TIMSSAdvanced	Trends in International Mathematics and Science Study(Advanced)
NSW	New South Wales
Sth. Africa	South Africa

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Abstract

Examining the cognitive demand of high-stake Physics and Chemistry examinations in Ireland.

Damienne Letmon

The high-stakes public examinations which mark the end of upper secondary education have been and still are a common feature of most education systems. These high-stake curriculum-based assessments, irrespective of the form of such assessments, are based on a specifically drawn- up programme or syllabi approved by the relevant educational bodies. Literature has shown that as well as providing a framework within which to assess the alignment of the examinations with the associated curricula, Bloom's revised taxonomy can facilitate the comparison of the cognitive skills of high-stakes examinations of different education systems.

Between 1966 and 2016, three different syllabi in physics and chemistry were implemented at the upper secondary level in Irish Schools. This thesis focused on the cognitive demands of the Leaving Certificate examinations in physics and chemistry during this period. Using Bloom's taxonomy as the framework, a two-study approach was adopted. The first study focused on the cognitive demands of the questions as presented in the physics and chemistry Leaving Certificate examinations. Using a defined list of action-verbs associated with Bloom's revised taxonomy as the analytic tool, the second study compared the cognitive demands of the 2016 high-stakes written examinations in six countries (England, Ireland, the Netherlands, New South Wales, South Africa and Scotland). The examination year 2016 was selected as the syllabi and examination system of these six countries had not changed in the two previous years, with similar topics being examined. This study included a comparison of cognitive demands across comparable topics in these examinations.

Findings from these two studies are discussed within the context of developing and promoting the use of questions which assess higher cognitive demands of *analyse*, *evaluate* and *create* in these high-stakes examinations at the end of upper second-level education.

Chapter 1 Introduction

1.1. Introduction

Since the 1960s, there has been a growing realisation internationally that education, in particular science education, needed to be adapted to accommodate the varying demands and abilities of the students while at the same time addressing the ever-evolving role of science education in the economy of the countries. The high-stakes public examinations which mark the end of upper secondary education have been and still are a common feature of most education systems. These high-stake assessments, irrespective of their forms, are based on specifically drawn-up programmes or syllabi approved by the relevant national educational bodies.

1.2 Personal perspective

Between 1966 and 2016, three different syllabi in physics and chemistry were implemented in Irish upper second-level schools. I find myself in a unique position of having taught all three syllabi in physics and chemistry in Irish schools. My first awareness of a syllabus was when the Principal of the school I was teaching handed me the Department of Education's annual book of syllabi (An Roinn Oideachais, 1971) and tasked me with introducing physics into the school's programme. As I read the syllabus, I was struck by how much it resembled the first-year physics course I followed at university. However, this resemblance faded as the syllabi were revised over the years. My recollection of these revised syllabi was that, while there was more and more content to teach each time, there appeared to be less depth or substance in the subsequent revision.

The introduction of a 'point system' in 1977, whereby grades achieved in the Leaving Certificate (LC) examinations were assigned points (Mac Aogáin, 2005), which then, in turn, determined entry or not to third-level institutions, did influence how and what was taught, with students continually asking, "Is this on the exam?'. Thus, at the senior level, 'teaching to the exam' determined the teaching strategies (Klein, 2016). Initially, I disagreed, but when, from 2001 onwards, the State Examinations Commission (SEC) published both the marking schemes and Chief Examiners' reports on the Leaving Certificate physics and chemistry examinations (State Examinations Commission, n.d), I was inclined to agree. Anecdotally, by forensically analysing the examination questions and marking schemes, it appeared that knowing all definitions and statements of laws, knowing (but not necessarily carrying out) all the mandatory experiments was sufficient to obtain at least 55- 60% of the total marks. Media criticism of the Leaving Certificate examinations continually portrayed it as an examination that promoted rote learning (Looney, 2006; O'Donoghue, Glesson and McCormack, 2017; McCormack, Gleeson and O'Donoghue, 2020).

1.3 Thesis focus

This thesis focuses on the cognitive demands of the Irish Leaving Certificate examinations in physics and chemistry from 1966-2016. Using the Revised Bloom's Taxonomy as the framework, a two-study approach was adopted. The first study focused on the cognitive demands of the Irish Leaving Certification examinations from 1966 to 2016. The second study compared the cognitive demands of the 2016 high-stakes physics and chemistry examinations in six countries (England, Ireland, the Netherlands, New South Wales, Scotland and South Africa.

In 1966, free access to second-level education for all in Ireland was introduced. By 2016, three syllabi in physics and chemistry had been implemented. Despite the importance placed on the role of science in the State's economy (Department of Education, 1965; Government of Ireland, 2006), research showed that just three studies focused on the cognitive demands of these subjects.

In 1970, Madaus and Macnamara published the first analysis of the Irish Leaving Certificate examinations (Madaus and Macnamara, 1970). Their study centred solely on the 1967 Leaving Certificate examination. The authors used Bloom's Taxonomy of Educational Objectives (Bloom *et al.*, 1956) to analyse nine subjects, Irish, English, Latin, French, History, Geography, Mathematics, Physics, and Chemistry. Their findings for higher-level physics questions showed a very high percentage (76%) of questions within the knowledge category. In comparison, the percentage of the ordinary-level physics questions was higher (90%) for the same category – a category the authors judged "required of the student nothing more than that he reproduce in the examination what he had learned in roughly the same form as he had learned it" (Madaus and Macnamara, 1970, pp. 96–97); there were very few questions in the comprehension and application categories; in chemistry, the percentages for questions in the knowledge category were somewhat lower, at 69% (higher-level) and 83% (ordinary level). In addition, the chemistry analysis showed there were questions in the other categories of *comprehension*, *application*, and *analysis* but no questions within the *synthesis* and *evaluation* categories (Madaus and Macnamara, 1970, pp. 102–103).

It was nearly forty years before another study of Leaving Certificate physics and chemistry examinations was carried out. In 2009 McCrudden and Finlayson reported on their analysis of chemistry examination papers for 2000-2008 (McCrudden and Finlayson, 2009). This analysis was also based on Bloom's taxonomy through action-verbs to determine the cognitive demand levels. The findings showed that the greatest percentage of marks were allocated to the cognitive demands of *knowledge* and *understand*, with no marks allocated to synthesis or evaluation. Burns et al. (Burns et al., 2018) based their finding on the analysis of twenty-three Leaving Certificate examinations subjects, including physics and chemistry, for 2005-2010. They reported that the cognitive demand *remember* was the dominant cognitive demand in the physics and chemistry papers; similar to the findings reported by Madaus and Macnamara and McCrudden and Finlayson for chemistry, the categories of *remember* and *understand* were the dominant cognitive demand for chemistry. Another study, although focusing on Biology, reached the same conclusion – the examinations were more a test of memory reliance rather than an assessment of cognitive demands of *analys*e and *evaluate* (Cullinane and Liston, 2016)

1.4 Rationale of this research

As the time lapse between the first study (1970) and the other two studies (2009, 2018) was between 40 and 50 years, it was impossible to establish a trend which merited monitoring or conclude the results were coincidental.

At the 1996 British Examination Research Association (BERA) Conference, Patrick presented four reasons why comparing Public Examination standards over extended periods, i.e. twenty years or more, was valuable (Patrick, 1996). Firstly, comparisons carried out over short time spans (typically between four and five years) are not as comprehensive as those carried out over longer spans of twenty years or more. Secondly, extended-period comparisons can highlight areas that merit closer monitoring. Thirdly, some trends are more discernible over a long-time span, and fourthly, such spans can provide "insights into what is happening to the curriculum and to the means by which it is assessed" (Patrick, 1996, p. 8).

Such a longitudinal historical analysis of the cognitive demands of physics and chemistry can provide opportunities to learn from past successes and failures, to understand the present in terms of the past, and plan for the future rather than repeating the same mistakes – to misquote Santayana slightly, 'those who ignore the past are doomed to repeat it'. This was the basis for the first research question,

> *What were the cognitive demands of the higher-level physics and chemistry examination questions in the high-stakes Leaving Certificate Examination in Ireland (from 1966-2016)*

Ireland participates in international education assessments such as the OECD's Programme for International Student Assessment (PISA)[1] and the IEA's Trends in International Mathematics and Science Study (TIMSS)[2]. However, the assessment metrics are internationally agreed upon rather than on the participating countries' syllabi.
The second research question centres on an international dimension -

- *Were there similar ranges of cognitive demands in selected comparable high-stakes written physics and chemistry examinations in other countries, as in the Irish Leaving Certificate examinations in these subjects?*

The introduction of this international dimension facilitates an investigation into the possible adaption of practices and question styles from other countries to enhance the LC physics and chemistry examinations.
This research is timely. Firstly, it is the first longitudinal historical analysis of the cognitive dimensions of the higher-level Irish Leaving Certificate physics and chemistry examinations. The findings will provide a baseline. The review of the LC physics and chemistry syllabi has been ongoing since 2009. Recent consultative documents[3][4] for both subjects indicate a change of focus from subject content to learning outcomes (formerly specifications). It is worth noting that the language change from 'subject content' to 'learning outcomes' was implemented in 2016 for lower second-level science and first examined in 2019. To date (2023), there is no published review of the impact of the change in emphasis and the possible consequences for the physical sciences at the upper second-level.
Secondly, it is the first cross-country comparison of the Irish Leaving Certificate physics and chemistry examination with other countries. Although based on one year's examination paper, the findings will provide evidence of examination questions emphasising the cognitive demands of *apply*, *analyse* and *evaluate*. As part of the Senior Cycle review, National Council for Curriculum and Assessment (NCCA) researched upper-level secondary education in several other countries (O'Donnell, 2018). The scope of the research was broad, focusing on structures, organisation, curriculum and assessment. The granular comparisons of the international physics and chemistry examinations will add another valuable dimension to this review.

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[1] https://www.oecd.org/pisa/
[2] https://www.iea.nl/studies/iea/timss/
[3] https://ncca.ie/en/senior-cycle/curriculum-developments/physics/ .
[4] https://ncca.ie/en/senior-cycle/curriculum-developments/chemistry/

1.5 Outline of thesis

Chapter One introduces the rationale and contextual background for this thesis. Chapter Two presents an overview of the development of the Irish second-level education system post-1960 in the context of a selection of other European countries. Two contrasting images of Ireland within a European context are presented in Section 2.2. Sections 2.3 and 2.4 focus on the Leaving Certificate physics and chemistry syllabi and how the content of these syllabi was assessed in the Leaving Certificate examinations between 1966 and 2016.

Chapter Three briefly overviews two key inputs from Piaget and Flavell to cognitive development. Section 3.3 gives an overview of several models of assessment. Section 3.4 considers several studies which focused on the applications of models to assess the cognitive content of high-stakes examinations. The focus of Section 3.5 is on previous studies of the assessment of Leaving Certificate examinations in physics and chemistry.

Chapter Four details how Bloom's taxonomy was used as the analytic tool in the thesis. Section 4.2 explains the compilation of action verbs. Section 4.2.1 discusses how cognitive levels are defined via the action verbs used in the Irish examinations, while Section 4.2.2 details the compilation of action verbs used in the international examinations. Section 4.3 and Section 4.4 explain the coding and analytical processes applied to the analysis of the Irish and the international examinations, respectively.

Chapter Five presents the results of applying Bloom's taxonomy to the Leaving Certificate examinations in higher-level physics and chemistry from 1966 to 2016. Section 5.2 and Section 5.3 examine and compare the distribution of cognitive demands in the physics and chemistry examinations based on the three revised syllabi. Section 5.4 discusses the trends in the cognitive demands of the physics and chemistry examinations.

Chapter Six presents the results of the investigation of the cognitive demands of the high-stake examinations in physics and chemistry of six countries- England, Ireland, the Netherlands, New South Wales (NSW), Scotland, and South Africa. Section 6.2 details the selection process adopted in selecting the six countries; details of the examination papers chosen in each country are also included. The analysis of the 2016 physics and chemistry examination papers is detailed in Section 6.3 and Section 6.4, respectively. The overall findings from these analyses are discussed in Section 6.5.

Chapter Seven presents and discusses recommendations for enhancing the Leaving Certificate examinations in physics and chemistry. The limitations of the study are identified, and several possible themes for further studies are presented in this chapter.

Chapter 2 Review of developments in the Physical Sciences education in Europe and Ireland

2.1 Introduction

In 1923, when the newly formed Irish State was seeking to formulate an educational system, the government had, as its aim, an all-inclusive education addressing both utilitarian and cultural values. It was not until 1966, with the introduction of free access to second-level education for all in Ireland, that the second-level education system in Ireland could be considered comparable to European educational systems. A common feature of most international education systems in 1966 was the examinations marking the end of upper second-level education. In many countries, these examinations provide the gateway to further education and entry to university education and hence can be called 'high-stakes examinations'.

This Chapter outlines key events that influenced educational developments in Europe, and Ireland, between 1966-2016. Section 2.1 briefly presents some influences on the development of education internationally. Section 2.2 compares the Irish upper second-level programme to six European countries (Denmark, Finland, the Netherlands, Norway and Sweden) considered to share many educational similarities with Ireland. This comparison centred on the programmes offered in two time periods, in the 1960s and the 2010s. Section 2.3 details the Irish upper-second-level education system during the same period. Section 2.4 traces the changes in the upper second-level physics and chemistry high-stakes examination programmes, called the Leaving Certificate examination (LC) in Ireland from 1966 to 2016.

2.2 External Influences on Educational Developments in the 1960s

Being one of the founder members of the Organisation for Economic Co-operation and Development (OECD) in 1960 enabled Ireland to move from its protectionist-isolationist position to becoming more open and receptive to external influences (Fleming and Harford, 2014). Ireland was one of the first countries to participate in the OECD's *Educational Investment and Planning Programme* in 1962-1965 (Papadopoulos, 1994, pp. 36–54; Resnik, 2006). In *Targets for Education in Europe,* Ireland was included in 'the northern countries' of Denmark, Iceland, Norway, Sweden and the United Kingdom (Svennilson, 1962). With the exceptions of Iceland and the United Kingdom, there were many similarities between these countries (also referred to as Nordic countries) and Ireland – their agrarian-based economies were on the cusp of moving to a technological/industrial basis; all had a centralised second level education system with curricula and standards established by education ministries. The further sections of this chapter will focus on developments in the Nordic countries and the Netherlands in comparison to Ireland.

2.3 Upper second-level education in Europe in the 1960s and 2010s

Thanks to the US-lead financial aided *European Recovery Programme* –sometimes referred to as the Marshall Plan – Europe was slowly recovering from the ravages of World War 2 (Meenan, 1948; Elvin, 1961; Svennilson, 1962; OECD, 1965; Gass *et al.*, 1967; Whelan, 2008). As the countries were rebuilding, so was the growing realisation of the interdependence of economies and an educated workforce, particularly a scientifically literate one. The 1950s and 1960s were eras of the expansion of technical knowledge and expertise, e.g. communications were being revolutionised due to the invention of the transistor in 1948; Crick and Watson were unravelling the intricacies of DNA in 1952/53; the Soviet Union launched the first satellite in 1957; Yuri Gagarin was the first man into space in 1961; and the first transatlantic television signal was transmitted in 1962.
In September 1961, the Organisation for Economic Co-operation and Development (OECD) was established to promote policies that would improve people's economic and social well-being worldwide. In October (1961) it held its first conference – *Education and Economic Growth* –in Washington, U.S.A. A more expansive view of education for economic growth evolved from that conference – weighting the function of education versus the needs of society, reviewing pedagogies to suit changing situations and demands, the quality of training (of teachers and the trainers) and the importance and usefulness of educational statistics as planning tools. There was also an acknowledgement that governments needed to formulate science policies rather than regard science as a cultural entity (OECD, 1965; Psacharopoulos, 1994; World Bank, 1995; Barro, 2001; Blöndal, Field and Girouard, 2002).

2.3.1 Upper second-level education in the 1960s

During the 1960s, education at all levels assumed a more significant role due in a large way to the emphasis placed by the OECD on education for all, with science education being the pathway to economic stability and prosperity (Blöndal, Field and Girouard, 2002; Bürgi, 2016). Table 2.1, based on data from the UNESCO World Survey of Education (1961), shows that for the six countries considered in this chapter (Denmark, Finland, Ireland, the Netherlands, Norway and Sweden), upper secondary education was the gatekeeper to university education. It shows a utilitarian approach to upper secondary education being considered one of the critical drivers for economic growth.

Table 2.1 Rationale of upper second-level education in the 1960s (UNESCO, 1961)

Country	***The rationale of upper second-level in the 1960s***
Denmark	*Three years of upper secondary leading to Studentereksamen (STX)– a qualification required to enter university*
Finland	*Senior secondary – mainly prepared students for study at university level-basic principle of Finnish education -all must have equal access to high-quality education and training.*
Ireland	*Testified to the completion of a good secondary education and to the fitness of students to enter a course at university-level or an educational institution of similar standing*
the Netherlands	*Gymnasium governed by Higher Education Act and was to serve as preparation for university education.*
Norway	*Gymnasier – was to prepare students for entry to universities and similar institutes.*
Sweden	*Gymnasieskola – provided secondary education beyond the level of lower secondary and prepared students for entrance to universities and other institutes of higher education.*

Data from World Survey of Education, Vol.3, Secondary Education (1961)

Across the European countries of Denmark, Finland, Ireland, the Netherlands, and Norway, having completed their lower second-level education, students had to choose between (i) an academic/general education path or (ii) a vocationally orientated education path to continue their education at upper second-level. Consequently, students were required to decide on their future career options when they selected their upper second-level path. All programmes followed in the academic and vocational paths were distinct and did not allow for transfer from one system to another (UNESCO, 1961; Garrouste, 2010). Table 2.2 outlines the differences between both paths. The exception to this system was Sweden which adopted a comprehensive education system in 1962. Another exception was Ireland, where the duration of the upper second-level system was a two-year programme, while in the other five countries, students completed a three-year programme.

Table 2.3 lists the specialist subjects/programmes available within the academic path in the six countries. For example, a Danish student entering the upper secondary – general path could choose the Mathematics & Science programme along with the four core subjects, Religious Knowledge, Danish, French and History(UNESCO, 1961, p. 415).

Table 2.2 Upper second-level programme for the six countries in the 1960s.

	Upper Second level – General/Academic			**Upper Second level - Vocational**		
Country	Year 1	Year 2	·ar 3	Year 1	Year 2	Year 3
Denmark	General Upper Secondary Education (STX)	Higher Preparatory Examination (HF)		Home Economics schools	Commercial schools	Technical schools
Finland	Upper Secondary General Education			Vocational Education and Training		
Ireland	Leaving Certificate (LC) Programme			Vocational education	Technical education	
the Netherlands	General Secondary Education			Secondary vocational training	Domestic Science and Technical training	Training as an infant-school teacher
Norway	Upper Secondary schools			Vocational schools		
Sweden	Comprehensive system including both academic and vocational programmes					

Table 2.3 List of subjects/programmes available at the upper second-level in the 1960s

Country	***Subjects/programmes available – one to be selected***
Denmark	*(i) Classical studies, (ii) Modern Languages, (iii)* ***Mathematics & Sciences***
Finland	*(i) Finnish language & Literature, (ii) Foreign Languages, (iii)* ***Mathematics, Physics, Chemistry****, (iv)* ***Natural Science*** *& Geography*
Ireland	*Irish + Mathematics and four other subjects from a list of other subjects as supplied– which included* ***Physics, Chemistry, Combination Physics-Chemistry, General Science, Botany, Physiology-hygiene, Agricultural Science, Domestic Science***
the Netherlands	*(i) Classics to include Latin and/Greek, (ii)* ***Sciences***
Norway	***(i) Sciences,*** *(ii) Modern Languages, (iii) Latin and /Greek, (iv)* ***Natural Sciences, (****v) Norse*
Sweden	*(i) Classical studies, (ii)* ***General Science,*** *(iii) General Studies*

In contrast, the choice of subjects for Irish students was restricted to studying a total of 6 subjects, two of which were mandatory – Irish and Mathematics – and the remaining four subjects from a range of 23 subjects. The list of 23 subjects appeared rather generous, but in reality, choices were determined by the entry requirements of the Irish Universities (An Roinn Oideachais, 1961, 1968).

2.3.2 Upper second-level education in the 2010s

By the turn of the century, a more holistic view of the rationale for upper secondary education had evolved, as encapsulated in the European Commission report on *Science Education for Responsible Citizenship* (Hazelkorn *et al.*, 2015). Table 2.4 is drawn from research carried out by NCCA showing this emphasis (O'Donnell, 2018)

Table 2.4 Rationale of upper second-level education in the 2010s

Country	***Rationale of upper second-level in the 2010s***
Denmark	*Enhancement of students' knowledge, proficiency, and skills, providing flexibility between different programmes, leading to better preparation for higher education*
Finland	*Promote the development of students as balanced members of society as well as providing knowledge and skills for maintaining a work-life balance.*
Ireland	*To prepare students to be active citizens and to progress to further education.*
the Netherlands	*To contribute to students' social development by equipping them with the knowledge and skills needed as well as providing pathways to further education*
Norway	*To facilitate students in attaining qualification, be it academic or vocational or both, by providing programmes which contain vocational and academic courses.*
Sweden	*To provide a foundation for work and further studies and enable active participation in society.*

Data from Upper Secondary Education in Nine Jurisdictions (2018)

Reforms and restructuring of the upper second-level structures in all six countries led to increased subject choices for students, particularly science subjects, as highlighted in bold text (Table 2.5). Four countries, Denmark, Finland, Norway and Sweden, included a science subject in the obligatory core element of the programme. Denmark and the Netherlands had programmes which led to students sitting formal end-of-upper second-level-education examinations- referred to as STX, HTX and HHX examinations in Denmark, and in the Netherlands as VMO and HAVO (Table 2.5). Ireland retained the Leaving Certificate examination format with an additional elective module, the Leaving Certificate Vocational Programme (LCVP). It comprises two-linked modules, *Preparation for the World of Work* and *Enterprise Education* (NCCA, 2015), to add a vocational dimension to the Leaving Certificate programme.

Table 2.5 List of subjects/programmes available at the upper second-level in the 2010s

Country	Programme	Core/Obligatory	Elective
Denmark	**Higher General examination programme (**STX-programme**)**	Danish, English, 2nd Foreign language, history, physical ed. Classical studies, **physics**, an artistic subject, maths, **a natural science subject,** social science + two (biology, **chemistry,** and geography)	Depending on the choice of specialised study programme – 2 of the following electives: English, **a natural science subject**, social science, and **astronomy.**
	Higher Technical examination programme (HTX-programme)	Danish, Technical science, English, **physics, chemistry**, maths, biology, technology, biology, communications/IT, social science and history of technology.	Depending on the choice of specialised study programme – philosophy, technology, innovation, history of ideas, business economics, psychology, statistics, physical education
	Higher Commercial examination programme (HHX programme**).**	no science components	
Finland	**General Upper Secondary**	47- 51 compulsory courses – covering languages, maths, **environment & natural sciences (physics, chemistry, biology, geography),** religion/ethics, philosophy, psychology, history, social studies, Arts, Physical Ed., Music, Visual Arts, Health Education, Educational and vocational guidance	28-24 – specialisation courses available – these are electives relating to compulsory courses of the same subject, i.e. within the course of Environmental & natural science – for example, there are **seven specialisation courses in physics – (Heat, Waves, laws of Motion, Rotation & Gravitation, Electricity, Electromagnetism, Matter & Radiation),**
Ireland	**Leaving Certificate Programme (**LC**)**	Irish + 4 other subjects from a list of 31 subjects	English, Latin, French German, Italian, Spanish, Japanese, Arabic, Russian, History, Geography, Applied Maths, **Physics, Chemistry, Physics-Chemistry, Agricultural Science**, **Biology,** Agricultural Economics, Construction Studies, Accounting, Business, Economics, Technology, Religious Studies, Design & Communications, Art, Classical Studies, Home Economics S & S, Mathematics, LCVP Link-modules
the Netherlands	**Pre-university Education (**VMO**)**	Latin & Ancient Greek; Dutch language & Literature; English language & Literature; Arithmetic, Civics, Cultural & Artistic education; Physical Education**.**	Culture & Society; Economics & Society; Nature & Health (Maths., Biology, **Chemistry**); Nature & technology (Maths., **Physics, Chemistry**)
	Senior General Secondary Education (HAVO)	Dutch language & Literature; English language & Literature; Arithmetic, Civics, Cultural & Artistic education; Physical Education**.**	Culture & Society; Economics & Society; Nature & Health (Maths., Biology, **Chemistry**); Nature & Technology (Maths., **Physics, Chemistry**)
Norway	**General Studies Programme**	Norwegian, Maths., **Natural Science**, English, Social science, Geography, History, Religion & Ethics, Physical Education	One of 4 specialising programmes- Languages, **Natural Sciences & Maths**., Social Science; Economics
Sweden	**Higher education preparatory programme**	English, History, Physical Ed. & Health, Maths., **Science Studies,** Religion, Social Studies, Swedish.	Business Management & Economics; Arts; Humanities; **Natural Sciences**; Social Science; Technology

In Finland, Norway and Sweden, the upper second-level education comprised two components – compulsory courses and specializations/electives related to the compulsory courses. For example, in Finland, if physics formed part of the compulsory component, then the specialization component also required selecting a number of specialisation courses in Physics related topics, i.e., Heat, Waves, Laws of Motion, Rotation & Gravitation, Electricity, Electromagnetism, Matter & Radiation. In Norway and Sweden, Natural Sciences/Science studies were included in the core subjects, irrespective of the chosen electives.

In summary, with education at all levels being regarded as one of the critical drivers for economic growth and development, *second-level education was always considered the gateway to third-level education. Initially, curriculum programmes at the second-level were utilitarian, with a strict boundary between the academic and vocational content. While still viewed as the gateway to third-level education, second-level education presented more holistic elements by the turn of the century. Although some countries still provided opportunities for students to specialise in specific areas, i.e., sciences and languages, other countries provided a greater range of core subjects to include aspects of science studies.*

2.4 Second-level education systems in Ireland 1960-2016

2.4.1 Irish education at the beginning of the 1960s

In the 1960s, there were two separate second-level education systems in operation in Ireland, the vocational system and the secondary school system (Figure 2.1), both of which, albeit under the remit of the Department of Education, addressed distinct needs, followed different curricula and provided separate certificated assessments (O'Raifeartaigh, 1967; Heraty, Morley and McCarthy, 2000; Clarke, 2010).

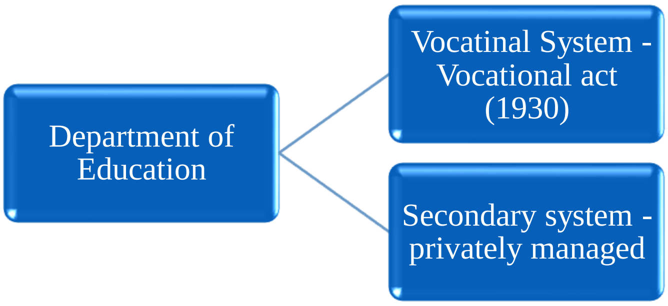

Figure 2.1 Irish education system in the early 1960s

The State established and funded the Vocation system as laid out in the Vocational Act of 1930 (Minister for Education, 1930). The Vocational system offered continuing education either through whole-time day courses or evening courses, as well as providing technical education for various trades and apprenticeships. As the vocational schools were locally based, rural communities benefited greatly. This was especially true for girls, where training in secretarial skills greatly enhanced their employment prospects. The availability of night courses enabled many to continue working during the day, continue their education, and even strengthen their education in particular trades. Those who did not wish to continue in education after they had attained the compulsory school leaving age of 14/15 years could sit the certificate examination on the condition of completing the two years of whole-time day-continuation education course, more generally referred to as the Group or Day Certificate.

The introduction of an Irish comprehensive school system in 1963 led to further changes, one of which was the gradual phasing out of the Group Certificate and introduction of the State Intermediate Examination, taken after the end of 3 years of compulsory lower second-*level education (Dáil Eireann, 1987). Other changes included expanding the range of subjects offered by the Vocational schools and the availability of Leaving Certificate programmes to these schools.*

The term 'secondary schools' referred to those privately managed schools generally by religious organisations, predominately of the Catholic religion, or private individuals. Most of these secondary schools had existed for many years before the foundation of the Irish State in 1922. While attendance at these schools was voluntary, access to these schools depended on success in any entrance examination set by a school as well as being able to pay the tuition fees. In its first annual report, the Department of Education described the secondary school system as being

> *Largely a private one in which schools…retained their full autonomy in all matters of appointment and internal organisation. The State at present inspects these schools regularly and exercises a certain amount of supervision through its powers to make grants as a result of these inspections, but it neither founds Secondary Schools nor finances the building of them,…nor exercises any power of veto over the appointment or dismissal of such teachers or management of the schools.*
>
> (An Roinn Oideachais, 1926, p. 8)

Although written in 1926, these comments equally applied to secondary schools in the 1960s. In sharp contrast to the vocational school programme, the secondary school programme or curriculum, based on subject syllabi prescribed by the Department of Education, was set out in the annual publication *Rules and Programmes for Secondary*

Schools. The secondary school programme was distinctly classical-academic in content as befitted a programme which aimed at preparing students to enter professional areas such as civil service, finance, and academia *(Bonel-Elliott, 1994; Clarke, 2010; Fleming and Harford, 2014)*. Based on the syllabi, the assessment was in the form of two external examinations – the Intermediate Certificate at the end of the first three years of secondary school and the Leaving Certificate at the end of the subsequent two years. The Examinations branch within the Department of Education was solely responsible for setting, administrating, correcting and issuing results of these two examinations.

In 1962, the then Minister of Education, Dr Patrick Hillary, in cooperation with the Organisation for Economic Co-operation and Development (OECD), commissioned the *Investment in Education* survey (Murray, 2012; Elliott, 2015). At the same time, he tasked an internal Department of Education committee to study the Irish education system and advise on changes needed (Bonel-Elliott, 1996). Bonel-Elliot believed that the report from this internal committee referred to as the Duggan report, contributed significantly to one of the critical reforms of second-level education: the idea of a comprehensive education system. Bonel-Elliot noted that the Duggan report was confidential and difficult to verify. However, on May 20th, 1963, Dr Hillary held a press conference detailing his vision of a comprehensive education system. Dr Hillary said that such a system

> *would provide for children of age between 12-13 to about 15-16 a three-year course during which observations and tests would show with fair probability in which direction, academic or technical, each pupil's bent would eventually lie. At the end of the three years in the comprehensive section, the pupil would take the Intermediate Certificate Examination, which in any case, it may be necessary to amend in several ways. If he [the pupil] passed that Examination, he could, if he so wished, proceed to the secondary or technical course in accordance with his previous showing at the Comprehensive school and at the Intermediate Examination.*
>
> (Irish Times Reporter, 1963; An Roinn Oideachais, 1965, pp. 67–68).

Unlike the secondary system, access to comprehensive schools would not depend on pupils sitting an entrance examination or having financial means to pay for tuition. Moreover, the curricula offered were to reflect a suitable combination of the Group Certificate and the Intermediate examination (McKernan, 1984; Clarke, 2010). One of the consequences of this announcement was extending the vocational two-year continuation education course to a three-year one, thus allowing its students to set the State Intermediate Certificate examination (Dáil Eireann, 1987). By 1966 three comprehensive schools had been established.

The *Investment in Education Survey* report was published in 1965 (Department of Education, 1965b, 1965a). It forensically analysed all aspects of the Irish education system through the cold lenses of statistical data (Fitzgerald, 1965; Cannon, 1966; O'Sullivan, 1992; Hyland, 2014; Loxley, Seery and Walsh, 2014). Despite the scale of its investigation, it made just one formal recommendation concerning the reorganisation of the Department of Education itself (Department of Education, 1965b, pp. 350–355). Underlining the significance of education in the country's economic development, the report stated that the Department needed to move from purely administrative to active educational development. The Department should consist of two separate yet interdependent units – the administrative and educational development units. The latter unit would be responsible for long-term planning while ensuring that the Department's policymakers (in the administrative unit) were fully informed of the 'effectiveness of the education system in attaining defined objectives' ((Department of Education, 1965b, p. 388).

The report also highlighted some issues and problems which emerged from the survey. Commenting on the multiplicity of second-level schools in any area, i.e. separate boys' secondary schools, separate girls' secondary schools alongside a vocational school, all competing with each other to maintain numbers and facilities, the Report suggested that local conditions might indicate that a better use would be to maximum facilities through sharing rather than all schools offering the same facilities and that secondary schools be afforded the option of accepting some form of State financial support to enable them to extend tuition to lower second-level students at the same standard fee as that of vocational schools. Interestingly, introducing free access for all students to second-level education in 1966 paved the way to remedy many of the issues raised in the Report. The multiplicity of second-level schools mentioned above was addressed through the amalgamation of schools to form community schools. Those secondary schools run by religious orders who took part in the free education system still retained their private ownership and were referred to as voluntary secondary schools. Accordingly, by 1969 the second-level education system comprised voluntary, vocational and community-comprehensive schools, all with their own ethos, management structure, and different ownership status. Nonetheless, all followed the curriculum the Department of Education specified and had access to the state examinations.

2.4.2 Irish education in the 2010s

As mentioned previously, the only recommendation from the *Report on Investment in Education Survey* in 1965 centred on establishing an educational development unit within the Department of Education. Such a unit, named the National Curriculum and Assessment Council (NCCA), was in place from 1987 onwards but only became a statutory body of the Department of Education with the enactment of Part VII (Schools) of the *Education Act 1998* (Minister for Education and Science, 1998). Through consultation with stakeholders – parent organisations, educators and industry – the NCCA advises the Minister of Education and Skills on the development of the curriculum for early childhood education as well as primary and post-primary education. It also supports the implementation of changes and the ongoing assessment of what is taught and how learning is assessed in each subject area (NCCA, 2002).

Part VIII (The Inspectorate) of the *Education Act (1998)* lead to the establishment of the State Examinations Commission (SEC) (Minister for Education and Science, 1998). In 2003, the SEC replaced the Department of Education Examinations Branch. As a non-departmental public body under the aegis of the Department of Education (https://www.examinations.ie/), the SEC was now responsible for all aspects of the second-level State examinations: the Junior Cycle Certificate (marking the end of compulsory education) and the LC (making the end of formal upper second level education). It is responsible for the development, assessment, accreditation and certification of the second-level examinations. Each year, the SEC publishes the examination papers, associated marking schemes, the Chief Examiner's reports for selected subjects; the manual used for drafters of the exam questions; examination statistics and an SEC Annual Report (SEC, 2020), thus making the process of assessment and certification visible to all.

One of the many issues which emerged from the *Report on Investment in Education* centred on the qualifications of teachers (Chapter 16 of the Report). To address this, the *Teaching Council* was established as the professional standards body for teaching professionals at primary and post-primary levels and within specific areas of third-level education (Minister for Education and Science, 2006). The Teaching Council sets the standards for the teaching profession by

- maintaining a register of teachers who meet the Council's requirements.
- regulating the criteria for entry to teaching
- establishing a Code of Professional Conduct for all teachers
- investigating complaints concerning fitness to teach of registered teachers.

- It also advises the Minister of Education and Skills on both initial teacher education and teachers' continuing professional development.

(Teaching Council, 2019)

In summary, the second-level educational system in Ireland is now comprised of mainly community schools, comprehensive schools, voluntary secondary schools, and Education & Training Boards (formally vocational schools); all follow the same programme cycle of a three-year junior cycle, culminating in the State Examination Junior Certificate and then the three- year senior cycle programme culminating in the Leaving Certificate examination. Even as all these schools follow the same national programmes and the Department of Education provides the finance required, the ethos, funding and administration structures of these schools vary; the community and comprehensive schools are managed by Boards of Management which are representative of local interests, but the budget is negotiated annually with the Department of Education; the voluntary secondary schools are privately owned with being each school managed by trustees via Board of Management, funding is in the form of annual per capita grants for students from the Department of Education; schools under the auspices of the Education & Training Boards are funded from a central budget allocated to the Board that distribute funds to their schools. There is a separation between the body that sets out curricula and assessment (NCCA) and the body that conducts the examination process (SEC). All teachers must be registered with the Teaching Council to ensure appropriate qualifications for all teachers. The Department of Education oversees all the activities of the schools irrespective of the management style of the schools.

2.5 Leaving Certificate Sciences in Ireland 1966-2016

2.5.1 Leaving Certificate sciences update 1966-2016

In the early 1960s, the LC programme offered 25 subjects in total – Irish, English, Greek, Latin, French, German, Italian, Spanish, Hebrew, History, Geography, Mathematics, Applied Mathematics, Music, **Physics, Chemistry, General Science, Botany, Physiology & Hygiene, Physics-Chemistry(joint), Agricultural Science,** Art, Commerce, Domestic Science and Drawing. However, this did not mean that every school was obliged to offer all subjects. The subjects in bold were considered science subjects in the Department of Education's reports (An Roinn Oideachais, 1961). Two of the 25 subjects listed above were mandatory for all schools, namely Irish and Mathematics. To be awarded the Leaving Certificate, a student must pass at least six subjects, including the two mandatory subjects.

The Department of Education set out the syllabus/curriculum for each subject (and, more recently, in conjunction with the NCCA).

Focusing on the science subjects, the Leaving Certificate examinations in these subjects consisted solely of a written examination based on the relevant syllabi. Typically, the examination paper contained ten to twelve questions in which students self-selected any six questions to answer in 2½ hours (later extended to 3 hours in 1979). The examination papers were set at two levels – higher or higher level and ordinary or pass level - which, again, the students could self-select on the day of the examination. To be awarded a higher / honours grade, a student needed to obtain at least 60 % of the marks on the higher-level paper; a 40% mark was sufficient for awarding an ordinary/pass grade, irrespective of the level of the examination paper.

The percentage of LC students who sat examinations in a science subject from 1964 to 1974 is shown in Figure 2.2. This data relates the percentage of students who sat a science subject to the total number of students who sat the Leaving Certificate Examination. Of the seven science subjects offered, *Physiology & Hygiene* was the most popular ranging from 20% to 28%. The least popular science subject was *General Science* decreasing in popularity during this time from 5% to 1%. This subject was a combination of botany, chemistry, physics and physiology.

The subject, Agricultural Science, was introduced into the curriculum in 1943 "*with a view to giving a stimulus to agricultural education ...with courses designed to suit the requirements of pupils who are likely to become farmers...and is primarily intended for schools with farms attached.*" (An Roinn Oideachais, 1944, p. 24)

The low percentage of students sitting the Agricultural Science examinations reflected the regional uptake of the subject. Physics and chemistry saw increased uptake of 21 % in the 1969 LC examination, coinciding with the introduction of free second-level education in 1967.

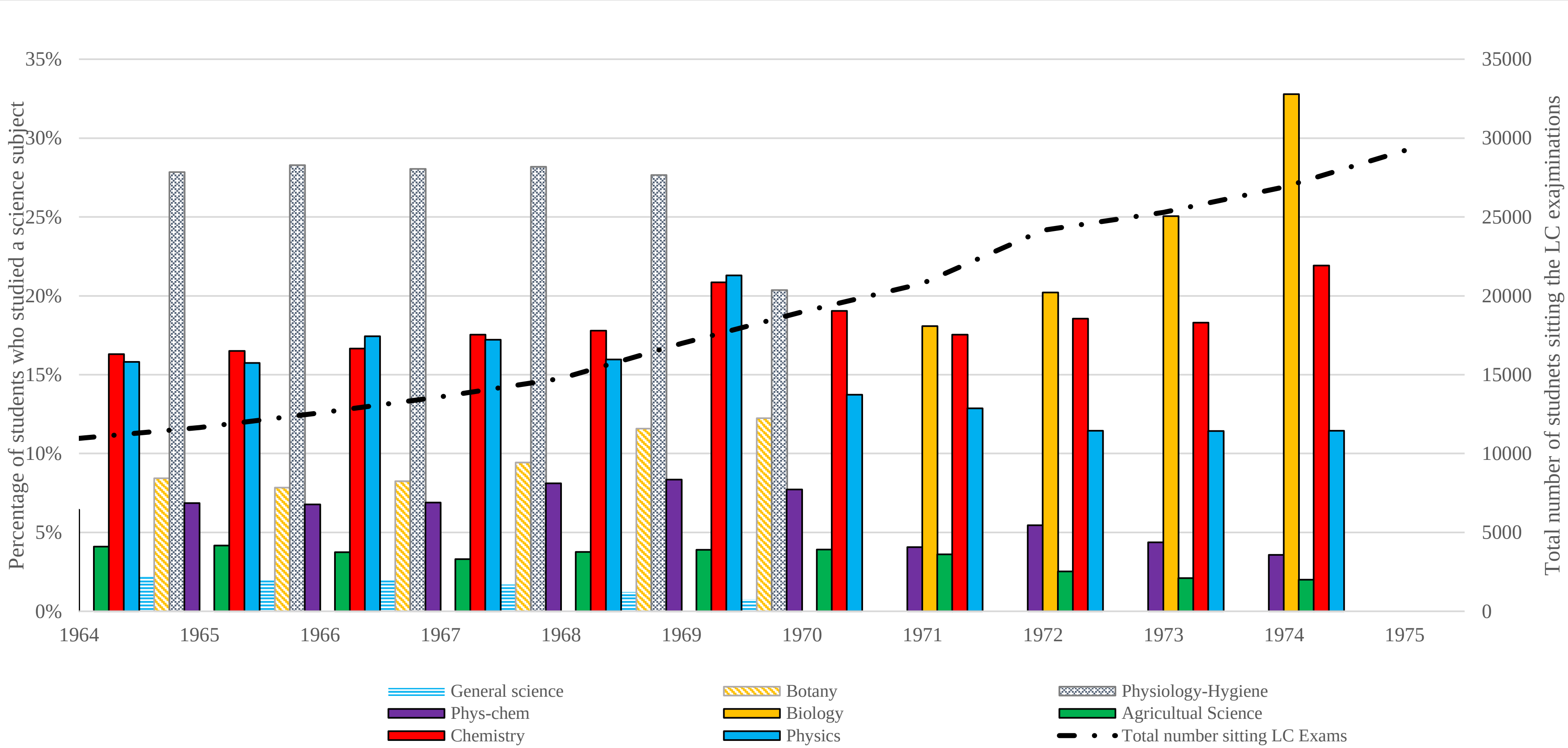

Figure 2.2 Percentage of Students who sat a science subject between 1964-1974

The introduction of comprehensive schools and free access for all to a second-level education led to a radical restructuring of the second-level curriculum at both lower and upper levels. In the early 1960s, lower second-level science consisted of six alternative syllabi as follows; two experimental courses called Syllabus A and Syllabus B and a demonstration non-experimental course, Syllabus E; all three were available for boys and girls; two experimental courses, Syllabus C and Syllabus D for girls only; an experimental course in Agricultural Science. Note: Syllabus E was designed for schools which did not have a laboratory and for those schools which could not timetable science for more than 90 minutes per week (An Roinn Oideachais, 1961, p. 60). By the end of the 1960s, these syllabi subsumed into two – Syllabus A and Syllabus B until 1992, when there was just one syllabus, Science, with separate examination papers at higher and ordinary level standards. However, the science syllabus and examination format at the lower second-level remained largely unchanged between 1974 and 2015. The format consisted solely of a series of short questions for each section, i.e. physics, chemistry, and biology, to be answered in a proforma booklet. As mentioned previously, eight subjects were listed as LC science subjects – physics, chemistry, Physics-Chemistry, Agricultural Science, General Science, Botany, Physiology & Hygiene and Domestic Science. The subject, General Science, was discontinued, and the last examination was held in 1970. The subject, Domestic Science, was replaced by two subjects, Home Economics (Scientific & Social) and Home Economics (General), neither of which is now considered a science subject (as there is no laboratory-based component). Elements of Botany, and Physiology & Hygiene were subsumed to form the new subject Biology, which was first examined in 1971. Concerns that Biology, replacing the most popular of the sciences, physiology-hygiene, would significantly impact the uptake of the remaining sciences did not materialise, as shown in Figure 2.3. While the number of students sitting the Leaving Certificate Biology examinations and Agricultural has steadily increased, overall, the percentage of students sitting Physics and Chemistry, on average, remains at 15±5%.

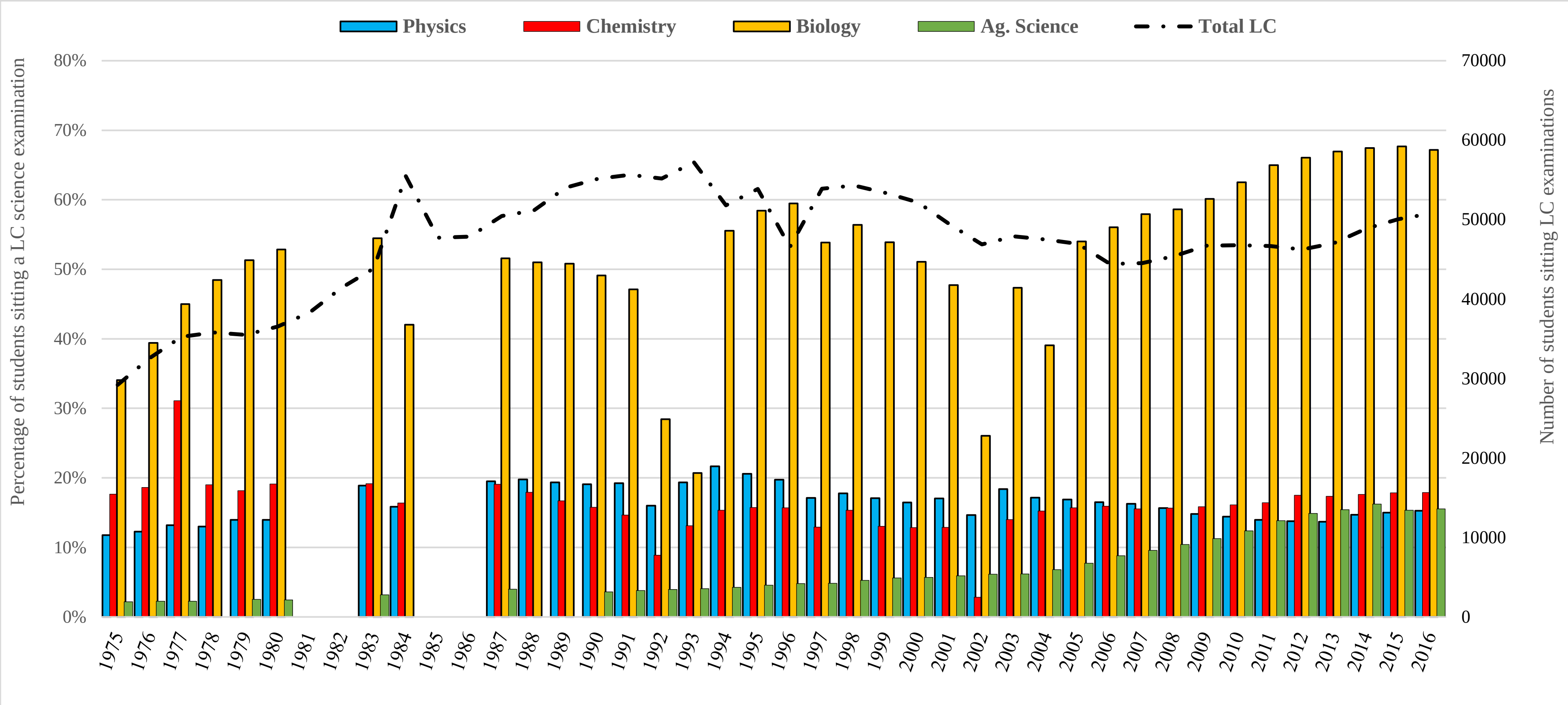

Figure 2.3 Percentage of students who sat a science subject between 1975-2016

Note: The Department of Education did not publish the Leaving Certificate results for the 1981 examinations- stating the intention to publish them in the 1981/1982 Statistical Report ((An Roinn Oideachais, 1981, p. 60). Furthermore, the Statistical Reports published for 1981/1982, 1984/1985, and 1985/1986 did not contain any Leaving Certificate results.

Between 1964 and 2016, three syllabi were examined in physics and chemistry. The following section discusses the changes in the syllabi during this period.

2.5.2 Leaving Certificate physics syllabi 1966-2016

Between 1966 and 2016, the LC physics examinations were based on three syllabi- the first syllabus (P1) first examination was in 1964, and the last examination was in 1985; the second one (P2) was first examined in 1986, and the last examined in 2001; and the third one (P3) first examined in 2002 and currently is still in force (2022). The following sections explore the relationship between the syllabi and the questions of the relevant examination papers.

- **Syllabus P1: 1966 -1985**

In its annual report for the school year 1961-1962, the Department of Education, writing about science at the secondary level, noted that the new LC syllabi in physics and chemistry, introduced in 1962, had been 'modernised' and from 1964 onwards the LC examinations would be based on them. [Note Syllabus P1 comprised of two syllabi - Pa from 1966-1970 and Pb from 1971-1985] The syllabus, Pa, was succinct, consisting of the customary itemised list of topics. The extract in Table 2.6 illustrates this terseness.

*Table 2.6 Example of the itemised list for **Light** in syllabus Pa*

Syllabus for Light, Ordinary and Higher Leaving Certificate Physics (P1)	
Light	Laws of reflection and refraction. Velocity, the formation of images by mirrors and lenses. Simple telescope. Dispersion by prism, formation of spectra.

.

In its Annual Report for 1961-1962, the Department of Education highlighted its proposed in-services for these subjects.

> *As an aid to the interpretation of the new syllabuses, the Department is strengthening and extending its provisions of refresher courses. It proposed to organise six such refresher courses in 1963 – three in physics and three in chemistry in Dublin, Cork and Galway.* (An Roinn Oideachais, 1962)

In its 1963 annual report, the Department of Education's inspectors expressed satisfaction that the *transition from the old to the new (modernised physics courses) has worked smoothly* (An Roinn Oideachais, 1963, p. 66). None of the listed topics on Pa was identified as applying to higher or ordinary levels. Consequently, all students followed a common course. Subsequently, on the day of the exams, having read both the ordinary and higher levels examination papers, the students were then permitted to decide which level of examination paper to answer. The sample questions in Figure 2.4, based on the topics listed above, are from the 1968 LC examination. Question 4 was at the ordinary-level, and question 3 was at the higher-level. There was no indication of how the 66 marks allocated to each question were divided between the various parts, nor, for example, how much detail was required to 'explain what is meant…' in question 4 and 'write a concise note …' in question 3. The only data material available was the *Mathematics Tables* (Anon, n.d.) which had limited physics-related formulae on page 41 under the heading *Applied Mathematics.*

1968: Ordinary Level, question 4	**1968: Higher-level, question 3**
Explain what is meant by (i) the transverse nature of light waves, (ii) the interference of light waves, and (iii) the wavelength of monochromatic light. In Young's experiment, the parallel slits, 0.4mm apart, are illuminated by monochromatic light. If the fringe-width of the interference fringe, formed on a screen 40 cm. from the slits, is 0.6mm. Calculate the wavelength of the light. (66 marks)	Write a concise note on the nature of light. Show how (i) refraction of light and the laws associated with it and (ii) interference of light may be explained in terms of the wave theory. How may the wavelength of monochromatic light be measured? (66 marks)

Figure 2.4 Comparison of ordinary and higher-level questions on the 1968 LC physics examination

Nonetheless, to carry out the calculation in question 4, the student needed to know/ remember the equation associated with this experiment, that is

$$\lambda = \frac{dx}{nD}$$

Furthermore, assuming n = 1, then the required wavelength, λ, = (slits width, d,)(fringe width, x)/ (distance of the screen from slits, D). It would be difficult for the student answering the last section of question 3 not to include this equation.

The 1969 edition of *Rules and Programmes* (An Roinn Oideachais, 1970) contained a revised Pb with the physics content arranged according to traditional divisions of **mechanics,**

heat, geometrical optics, nature of light, wave-motion, electrostatics, magnetism, electricity, atomic physics. A list of topics for each division was clarified and expanded. An asterisk identified all higher-level sections. Figure 2.5 shows how the topics within Mechanics were clarified - the underlined portions being previously in Pa.

Mechanics:

1: Displacement. Vectors and scalars. Addition and resolution of vectors. Velocity and acceleration. Parallelogram law. Proof and simple use of equations of motion, including vertical motion under gravity. Horizontal projection.

2: Newton's laws. Force. Mass. Weight. Conservation of momentum.
The three laws and their meaning. Force as a rate of change of momentum and the special case of Force = mass x acceleration; Proof of conservation of momentum from second and third laws. Simple applications to acceleration and braking of vehicles of constant mass. Momentum changes as practicable means of causing changes in velocity in space. Weight as a force. (See also work in connection with Heat – as a form of energy)

3: Force as a vector. Moments. Gravitation.

Uniform circular motion. Centripetal force. Parallelogram of forces; simple problems. Moment as a turning force; proof that one moment can only be balanced by another. *Proof of formula and use of formula $F = \frac{mv2}{r} = mr\omega^2$ etc., and, therefore, centripetal force. Simple examples. Newton's law of gravitation; the relationship between G and g. Determination of g, with appropriate theory. *One method for determination of G, with appropriate theory. *Circular satellite orbits: relationship between period, mass of the central body and radial orbit. *Simple problems

Figure 2.5 Clarification of the underlined topics listed for Mechanics in Pb

- ***Overview of examination papers based on Pa/Pb***

The introduction to the Pb syllabus stressed that 'there should be plentiful use of experiment and demonstration' ((An Roinn Oideachais, 1970, p. 141). Embedded within the sections were examples of such experiments and demonstrations, such as

- the experiment to show Brownian movement,
- the method of determining focal lengths of mirrors and lenses,
- determination of magnetic dipole moment,
- variation of current with the potential difference in metallic conductors, electrolytes, diodes etc., treated experimentally (ps.141-148).

The format of the higher-level and ordinary-level LC physics examinations reflected this revised syllabus. There were ten questions on the LC examination, six of which were to be answered. Typically, the first question contained sixteen short questions, such as from the 1972 higher-level examination (Figure 2.6).

1. Answer eleven of the following sixteen items (a), (b), (c) …etc. Each item carries six marks. Keep your answers short

(a) Which has the greater momentum: a body of mass 2kg moving with a velocity of 5 metres per second or a body of mass 3kg moving with a velocity of 4 metres per second?

(b) A rocket of mass 20,000kg is at rest on the ground. What force is is required to make the rocket move off with a vertical acceleration equal to ½ g? (Take g=9.8 m s^{-2} = 980 cm c^{-2}).

(c) In a constant volume gas thermometer, the pressure of the gas is 74 units at 0°C and 102 units at 100°C. What would the thermometer read in °C when the pressure of the gas is 81 units?

(j) Figure 2 shows a lamp L which is lighting, an a.c. source and a solenoid C. | what may be observed when a bar of soft iron is place inside C and why?

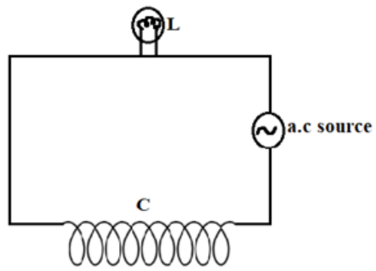

Figure 2

(o) Complete the nuclear reaction: ${}_{13}\mathbf{Al}^{27} + {}_{2}\mathbf{He}^{4} \rightarrow {}_{15}\mathbf{P}^{30} +$

Figure 2.6 Sample of short questions from the 1972 higher-level examination paper

The last question on the paper was always a set of four short questions, of which two were to be answered, such as from the 1980 higher-level examination paper (figure 2.7)

10. Answer any two of the following.

(a) Define the ampere. Describe an experiment to check the accuracy of an ammeter without using another ammeter
(b) Describe a method, giving the relevant theory, of measuring the wavelength of monochromatic light using Young's slits or a diffraction grating.
(c) Explain the terms, amplitude, frequency, fundamental, harmonic in relation to wave motion. With regard to sound, describe how each of the above may be demonstrated experimentally.
(d) Describe the structure of a photoelectric cell. Explain how the effect of varying the intensity or the wavelength of the light incident on a photoelectric cell may be investigated in the laboratory.

Figure 2.7 Example of question 10 from the 1980 higher-level examination paper

On the ordinary level paper, there was always a question which centered on explaining the basic principles involved, for example, from 1984, Question 5 (Figure 2.8)

5. Explain the basic physical principles involved in any *four* of the following

(a) The water at the bottom of a waterfall is slightly warmer than at the top.
(b) A bicycle fitted with a dynamo produces less light as it slows down.
(c) A concave mirror is sometimes used by a dentist as a magnifying mirror.
(d) The timekeeper of a race watches for the flash of the starting gun.
(e) A thick copper strip, with one end buried in the earth is often attached to the outside of a tall building.

Figure 2.8 Question on basic principles from the 1984 OL physics examination

Again, on the ordinary level, there was always a question on laboratory-based experiments, for example, from the 1978 examination (Figure 2.9)

7. Describe how you would perform any two of the following experiments in the laboratory:

(a) To check the accuracy of an ammeter by electrolysis
(b) To measure the specific heat capacity of a liquid
(c) To measure the wavelength of one of the lines in the mercury spectrum
(d) To compare the electromotive force (e.m.f.) of two cells.

Figure 2.9 Question on experiments - 1978 OL physics

The remaining questions were based on one of the traditional physics divisions of mechanics, light, electricity, and atomic physics. The structure of the higher-level paper was somewhat less predictable. Even though the number of questions on an examination paper varied between ten and eleven, six were to be answered. The first and last questions followed the same pattern as the ordinary- level. The remaining questions were based on the topics. The unpredictability lay in how many questions there were per topic. For example, one year, two questions might focus on light, with no question on heat; another year, every question, irrespective of the topic, ended with a calculation; some years, most questions included describing one of the laboratory-based experiments. Whilst the emphasis of the ordinary level paper was on the understanding of the practical applications of physics, the focus of the higher-level paper tended towards the theoretical - deriving formulae, explaining theories associated with experiments, for example, from 1976 examination paper –Question 6 (a)

Describe an experiment to measure the internal resistance of a cell and give the theory associated with the experiment.

Alternatively, *discuss the Compton effect and conservation laws*. As mentioned, no data sheets were available for students answering these papers, so they were wholly dependent on their information retention ability.

- **Syllabus P2: 1986-2001**

The 1984 edition of *Rules and Programme* presented P2 as a revised syllabus rather than a new one to be examined for the first time in 1986 (An Roinn Oideachais, 1984). Comparing the Pb syllabus and P2 indicated the revision nature, with much of Pb content retained, while new topics replaced those omitted. To emphasise the experimental nature of physics, each topic included several specific experiments considered 'essential for a proper understanding of the syllabus content'. Moreover, the syllabus stated

> *a candidate will not be admitted to the Leaving Certificate examination in this subject in any case where the Department considers that an adequate course of laboratory work has not been followed by such candidate. For this purpose, records of practical work done must be kept and made available for inspection.*
>
> (An Roinn Oideachais, 1984, p. 221)

However, while the experiments were stated, they were not mandatory. It was the teachers decided on the experimental methods. In total, 28 experiments were identified across the six topics as in Table 2.7 (those marked with an asterisk for higher-level only).

Table 2.7 Number of experiments listed in P2.

Mechanics	Heat	Sound	Light	Electricity	Semiconductors
7	5	2	5	3 + *3	3

- ***Overview of examination papers based on P2.***

The extended P2 syllabus was reflected in the number of questions per paper – i.e. thirteen. Accordingly, the number of pages in the examination papers also increased from six to eight. (Examination papers based on Pb were two to three pages long). However, the number of questions to be answered remained at six. For the first time, marks were allocated to all question parts. The LC paper now consisted of three sections, A, B and C. Section A was compulsory, consisting of one set of multi-choice questions and three sets of short answer questions which focussed on the factual recall of knowledge, for example,

- State Archimedes' principle;
- What is meant by a thermometric property?;
- The temperature 373K on the Kelvin scale is equivalent to ….on the Celsius scale?

Section B focused on three of the listed experiments. For those who had carried out and correctly recorded the results of these experiments, the questions were focused on recalling what they had done. The nature of the questions asked reflected the type of recorded entries found in a laboratory journal, for instance, question 7, 1992 OL (Figure 2.10) shown below. Questions on the higher-level paper followed the same pattern.

> A coil of wire, a calorimeter and other apparatus were used by a student in an experiment to verify Joule's Law.
> (i) Draw a labelled circuit diagram for this experiment (18)
> (ii) State the measurements which the student would have made in the experiment (9)
> (iii) State how the measurements would be used to verify Joule's law (12)

Figure 2.10 Question 7, 1992 OL

Questions in Section C covered all aspects of the syllabus. Most of the questions began with a short recall question which tended to set the rest of the question in context – e.g.

- ' State the laws of refraction',
- ' what is meant by an ideal gas',
- ' give two properties of…'.

At least five questions asked the student to 'describe an experiment to show/measure/verify…' with each of these experiments from the listed experiments. Anecdotally knowing all definitions, laws, principles, and the listed experiments, it was possible for a student to obtain a high-grade mark of ~ 60%+. One challenging aspect of the examination was the problems or calculations, particularly those based on mechanics and electricity. Students were expected to remember the formulas required for calculations as no data sheet was available. Accordingly, students still were very much dependent on having good information retention ability.

- **Syllabus P3: 2000-current**

The current syllabus P3 was introduced in 2000 and first examined in 2002. The syllabi and accompanying *Guidelines for Teachers-Physics* were issued in separate booklets (NCCA, 1998; Department of Education & Science/NCCA, 1999b). In the preamble to the revised 2000 physics syllabus, it is stated that " all the LC science syllabi are designed to incorporate

- science for the inquiring mind, or pure science to include principles, procedures and concepts of the subjects as well as its cultural and historical aspects

- science for action or the applications of science and its interface with technology

- science, which is concerned with political, social and economic issues of concern to citizens."

(Department of Education & Science/NCCA, 1998)

For the first time, the assessment objectives were stated in the physics syllabus document :

> *The syllabus will be assessed under the heading knowledge, understanding, skills and competence. All material within the syllabus is examinable. It should be noted that STS [Science and Technology in Society] is examinable. Students will be expected to have a knowledge of general applications but will not be required to have a detailed knowledge of specific applications. Practical work is an integral part of the study of physics; it will initially be assessed through the medium of the written examination paper*.

(Department of Education & Science/NCCA, 1999b, p. 4)

Table 2.8 is a selection from a long list of the physics syllabus objectives against which the LC physics examinations were assessed (Department of Education & Science/NCCA, 1998c, p. 6,24)

Knowledge – students should know
▪ Basic physical principles, terminology, facts and methods
▪ How physics is fundamental to many technological developments
Understanding- students should understand
▪ how physical problems can be solved
▪ how the scientific method contributes to physics
Skills- students should be able to
▪ plan and design experiments
▪ apply physical principles to solving problems
Competence- students should be able to
▪ report on experimental procedures and results concisely, accurately,
▪ explain the science underlying familiar facts, observations and phenomena

Figure 2.11Sample of physics syllabus objectives

The syllabus content was presented with the traditional classifications of topics in physics – *mechanics, temperature, light, sound, electricity, and modern physics* -with the addition of two option sections, *Particle physics* and *Applied Electricity*. The syllabus was presented in four columns under the headings: Contents, Depth of Treatment, Activities, Science and Technology in Society(STS). According to the P3 syllabus, the column titled Activities

> *describes how the syllabus objectives are to be achieved as the content is studied. The activities column provides a pedagogical approach to the syllabus by outlining the relevant demonstrations and by indicating where problem-solving is required.*
>
> (Department of Education and Science, 1999a, p. 2)

The fourth column, STS, was:

> *To place the concepts, principles and theories of physics within the relevant contexts by (a) referring to the application of physics and (b) solving problems set in the everyday world. It is important to include personal, medical, biological and social examples of physics as well as mechanical or technical examples so that the place of physics in the everyday world can be appreciated* (p.2)

A cursory comparison of the content of P2 and P3 highlighted the similarity between both. As mentioned earlier, P2 listed twenty-eight named experiments by highlighting the experimental nature of physics. Most of these experiments were retained in P3 but now were listed as mandatory.

Table 2.9 is a copy of the syllabus structure for the topic – *Vibrations and Sound*, showing the document's design and the illustrative content. The text in bold italics indicates for higher-level examination only. The three mandatory experiments for this topic are listed at the end of the topic. All other topics followed the same structure.

Table 2.8 Syllabus content for Vibrations and Sound (LC physics syllabus p.31)

Vibrations and Sound

Content	Depth of Treatment	Activities	STS
1. Wave nature of sound	Reflection, refraction, diffraction, Speed of sound in various media	Demonstration of interference, e.g. two loudspeakers and a signal generator Demonstration that sound requires a medium	Acoustics. Reduction of noise using destructive interference. Noise pollution.
2. Characteristics of notes	Amplitude and loudness, frequency and pitch, quality and overtones. Frequency limits of audibility.		
3. Resonance	Natural frequency. Fundamental frequency. Definition of resonance and examples	Demonstration using tuning forks or suitable methods	Vocal cords (folds),
4. Vibrations in strings and pipes.	Stationary waves in strings and pipes. Relationship between frequency and length. ***Harmonics in strings and pipes.*** $\boldsymbol{f = {}^{1}/_{2l}\sqrt{\frac{T}{\mu}}}$ ***for a stretched string***	***Appropriate calculations.***	String section and woodwind section in orchestras
5. Sound Intensity levels.	***Sound intensity: definition and unit.*** Threshold of hearing and frequency response of ear. Sound intensity level is measured in decibels. ***Doubling the sound intensity increases the sound intensity level by 3 dB.*** The dB (A) is used because it is adapted for the ear's frequency response.	Use of sound-level meter	Examples of sound intensity level. Hearing impairment. Ear protection in industry, etc

Mandatory Experiments
1. Measurement of the speed of sound in air
2. Investigation of the variation of the fundamental frequency of a stretched string with length
3. *Investigation of the variation of the fundamental frequency of a stretched string with tension*

- ***Overview of examination papers based on P3.***

The examination paper consisted of two sections, Section A focuses solely on the mandatory experiments and Section B on theory and practical knowledge. The number of questions per paper was reduced from thirteen to twelve. On the other hand, the number of questions to answer increased from six to eight – three from Section A and five from Section B. Moreover, each question now comprises six to nine question-parts, resulting in an examination paper of ten to twelve pages. Section A's questions, based on the mandatory experiments, focused on the details of carrying out the experiment and manipulating the data. These were straightforward to those who had carried out the mandatory experiments and therefore acted as an encouragement to teachers to carry out the experimental work. Figure 2.11 illustrates a question, from 2009 HL, based on the mandatory experiment – *Measurement of the focal length of a converging lens*.

2. A student was asked to measure the focal length of a converging lens. The student measured the image distance v for each of three different object distances u. The student recorded the following data.

u/cm	20.0	30.0	40.0
v/cm	65.2	33.3	25.1

Describe how the image distance was measured. (12)

Give two precautions that should be taken when measuring the image distance. (6)

Use all of the data to calculate the focal length of the converging lens. (15)

What difficulty would arise if the student placed the object 10 cm from the lens? (7)

Figure 2.12 Example of question focusing on a mandatory experiment

Section B questions were quite long on the ordinary and higher-level papers due to the numerous question-part per question, which accounted for the many pages. Questions relating to the mandatory experiments were generally not asked in this section; however, demonstrations could be asked: for example:

- Describe an experiment to demonstrate the photoelectric effect: outline Cockcroft and Walton's classical experiment:
- Describe how an electric field pattern may be demonstrated in the laboratory.

The inclusion of STS in the examination paper largely depended on the topic of the question. Various questions on mechanics were based on Global Positioning Systems (2015HL), the

International Space Station (2013HL), and children's toys (2011HL). In 2011, the *Formulae and Tables* booklet replaced the *Mathematics Tables* for all state examinations. This booklet contained several pages of relevant formulae for physics calculations, thus reducing the necessity to memorise relevant formula/e.

2.5.3 Leaving Certificate chemistry syllabi 1966-2016

The introduction of the chemistry syllabi during this period followed the same pattern as that of physics, the first syllabus (C1) examined from 1964 to 1984, the second one (C2) from 1985 to 2001 and the current syllabus (C3) was introduced in 2002 (2022). Generally, the chemistry syllabi's layout, structure and supporting documentation mirrored the physics syllabi; for example, C1 consisted of Ca (1964-1970) and Cb (1971-1985). Similar to physics, Ca was composed of the customary list of topics without accompanying explanation or guidance; the refresher courses for teachers were available for Chemistry as well as Physics teachers; the 1969 edition of *Rules and Programmes for Secondary Schools* published a detailed guide to depth of coverage in a revised CI; and the presentation of P3 and C3 were each accompanied with *Guidelines for Teachers.*

- **Syllabus C1: 1966-1984**

Syllabus C1 consisted of Ca and Cb syllabi. Rather than placing the syllabus content within the traditional divisions of chemistry, for example, organic chemistry, inorganic chemistry, and physical chemistry, Ca was presented as a list of 20 items with numbers 1-10 for ordinary-level and 1-20 for higher-level. The selection of the content of Ca, as in Figure 2.12, shows a lack of detail with no indication as to the depth of content required.

Pass level (ordinary level**)**

1: Properties of gases, liquids and solids; elements, compounds and mixtures.

2: Structure of simple molecules; covalent, electrovalent and metallic bonds; crystal structure as exemplified by the sodium chloride lattice; electronegativity.

5. Determination of equivalent, atomic and molecular weight. Vapour density. Simple volumetric and gravimetric analysis. Formulae and equations.

8. Study of the chemistry of methane, ethylene, acetylene, ethyl alcohol, acetaldehyde, acetic acid, benzene, and nitrobenzene.

Honours level (higher level)

As for the Leaving Certificate Ordinary Course and in addition: -

12. The shape of simple symmetrical molecules (organic and inorganic; tetrahedral, planar and linear), reference to orbitals and hybridisation.

14. Study the chemistry of methyl alcohol, ethylene (polymerisation of), chloroform, diethyl ether, glycerol, formaldehyde, formic acid, lactic acid (optical isomerism), fumaric and maleic acids (geometrical isomerism), ethyl acetate, acetone, glucose, cane sugar, aniline. 16. Law of Mass Action and electrolyte solutions. Strong and weak acids, hydrolysis of salts; pH and indicators 18. The study of the following reactions as examples of reaction mechanisms: chlorine and hydrogen, chlorine and methane, bromine and ethylene, sodium hydroxide and ethyl bromide. Catalysis

Figure 2.13 Excerpt of Ca syllabus 1964-1970

The questions asked on the examination paper reflected the items listed. Both questions in Figure 2.13 illustrate how Ca was reflected at both levels of the LC paper. Question 1 at ordinary-level was based on items 1 and 2 (see Figure 2.11), assessing the basic understanding of sodium chloride's terms and structure. Question 1 at higher-level was based on item 12 (see Figure 2.11) above. The final part of the question encompassed an understanding of the roles played by bond types and electron pair repulsion theory in determining the shapes of the molecules listed in the question.

1969: Ordinary Level, question 1	**1969: Higher-level, question 1**
State clearly what you understand by (i) elements, (ii) compounds, (iii) mixtures Classify each of the following under the above headings:- (a) sodium, (b) ammonia, (c) air, (d) methane, (d) mercury, (f) carbon dioxide, (g) sodium chloride. Describe briefly the structure of a sodium chloride crystal. (66 marks)	State clearly what you understand by (a) a linear molecule, (ii) a planar molecule, (iii) a tetrahedral molecule, and classify each of the following as linear, planar or tetrahedral: Cl_2, H_2O, CO_2, NH_3, CH_4, C_2H_4. Justify your classification and comment on the bonds in each molecule (66 marks)

Figure 2.14 Comparison of ordinary and higher-level questions on the 1969 LC chemistry examination.

The 1969 edition of *Rules and Programme* contained a revised Cb, which bore little resemblance to Ca. The original twenty items were reduced to fifteen. Previously listed at the higher-level, some items were now included at the ordinary level. The higher-level content was underlined. In addition, each reorganised item was accompanied by an explanatory note. Figure 2.14 is a sample of the restructuring for item 12 in Cb.

Ca (higher level)	***Cb with higher level underlined***	***Explanatory note***

12. The shape of simple symmetrical molecules (organic and inorganic; tetrahedral, planar and linear), reference to orbitals and hybridisation.	4. Structure and shapes of simple molecules of both organic and inorganic compounds (planar, tetrahedral and linear): interpretation in terms of bonds from hybrid orbitals.	Ordinary course students to use electron pair repulsion theory. Suggested example BeH_3, BF_3, CH_4, NH_3, H_2S, H_2O. For higher course students, hybrid orbital interpretation: BeH_2, BF_3, CH_4, C_2H_4, C_2H_2

Figure 2.15 Treatment of the same topic in Ca and Cb

In a departure from its usual practice of not recommending either background books or specific textbooks, the syllabus included a reference list of fifty chemistry textbooks 'to be read in conjunction with the syllabus' (An Roinn Oideachais, 1984, p. 150). Included in this list were numerous books suitable as background reading for teachers themselves, including Irish publications *Leaving Certificate Chemistry* by the Christian Brothers (The Christian Brothers, n.d.) and *Chemical Analysis* by W. Broderick (Broderick, 1966), Somerfield (publishers Folens). The first book placed experiments within the relevant topics. The second one focused on the skills and techniques to be followed when carrying out specific experiments. The *Practical Chemistry for Today*, published in the late 1970s, focused exclusively on ninety experiments (Henly, 1979). Interestingly, Cb did not identify any specific experiments leaving teachers dependent on the in-service courses provided by the Department of Education and Irish-produced textbooks for guidance and analysing previous examination papers, although based on Ca.

- ***Overview of examination papers based on Ca/Cb***

Typically, the examination papers based on Ca consisted of ten questions, of which six were to be answered within two and a half hours. Question one comprised fourteen short questions ranging across the whole syllabus. Each of the remaining nine was based on one topic and, irrespective of the levels, was long, quite detailed, yet wide-ranging, with each question containing several parts, as illustrated in Figure 2.15.

Question 9. OL chemistry 1970

(i) Use a labelled diagram to illustrate the preparation of carbon dioxide. Give an account of the principal properties of carbon dioxide.

(ii) If 20 c.c. of sodium carbonate solution required 22 c.c. of normal hydrochloric acid to neutralise it, find the concentration of the sodium carbonate solution in terms of (i) normality, (ii) grams of anhydrous sodium carbonate per litre. Describe how you would carry out this titration and mention the indicator you would use. (67 marks)
Question 9. HL chemistry 1970 (a) What is (i) heat of formation, (ii) heat of combustion, (iii) heat of neutralisation? Find the heat of formation of sulfur trioxide given $S + O_2 = SO_2 + 71$ kcal $2SO_2 + O_2 = 2SO_3 + 46.7$ kcal Describe how you would measure the heat of neutralisation of a strong acid and a strong base. (b) Write a short account of catalysis. In your answer, refer to homogeneous catalysis, heterogeneous catalysis and autocatalysis. (67 marks)

Figure 2.16 Questions based on the Ca chemistry syllabus

The highlighted terms in Figure 2.15 above are examples of some action-verb or question cues used. Other examples of question cues used were

- *Describe fully/briefly…*
- *Describe and discuss…*
- *Discuss the use and importance of/ some expectations …*
- *Write a concise note…*
- *Suggest an explanation of /for/a reason…*
- *Calculate/Determine the value of/Estimate…*
- *Explain with evidence…*

The examination papers based on Cb were equally as long as previous papers, with six of the ten questions to be answered. Interestingly, in 1979 the examination time was increased to three hours, and the paper's length was now four pages, yet the number of questions to answer was still six out of ten. Notably, from 1974 onwards, the number of question parts per question gradually increased. At the same time, many of the question cues listed above were no longer used. Instead, question cues were now more precise; for example,

- *define*,
- *state* (a law/ principle /chemical term),
- *explain what is meant by* (a chemical term, e.g. metallic bond),
- *name/write /identify* (chemical formula).

By 1984 (the last examination based on Cb), the number of question parts per question, irrespective of the topic, ranged from five to ten, requiring short answers. Figure 2.16, question 3 typifies this style of questioning.

Question 3 HL Chemistry 1984

The general gas equation for an ideal gas is given as $PV = nRT$

(i) What do you understand by an ideal gas?
(ii) Write equations for two of the gas laws on which the general gas equation is based.
(iii) Explain the meaning of the terms R and n in the equation.
(iv) Express n in terms of actual mass(m) and the relative molecular mass (M) of the gas
(v) Suggest two reasons why real gases differ from ideal behaviour. Under what conditions of temperature and pressure would a real gas come nearest to being ideal?
(vi) 0.3 g of a gas occupied 168 cm^3 at 300K and a pressure of 1.0×10^5 Nm^{-2}.
Calculate the relative molecular mass (molecular weight) of the gas. (R=8.4 Nm $mol^{-1}K^{-1}$)
(v) The gas in (vi) is an organic compound containing nitrogen and is soluble in water giving a solution of a pH greater than 7. Suggest a possible structure for a molecule of the gas and name the gas you have chosen. **Total marks 66**

Figure 2.17 Typical style of question based on Cb

Syllabus C2. 1985-2001

As in the case of P2, an essential change in C2 was the inclusion of listed experiments. The preamble of C2 contained the same warning regarding laboratory work that records of the work completed were to be maintained. By highlighting that laboratory work was intrinsic to the syllabus, it was recommended that about 40% of teaching time should be devoted to practical work with a number of related experiments to be carried out by the students (An Roinn Oideachais, 1984, pp. 213–214). For the Department of Education, the

> *fostering of critical analytical scientific attitudes and an awareness of the importance, potential and limitations of chemistry are among the objectives of the course* (page 213).

Figure 2.17 is the complete list of objectives as presented by the C2 syllabus by the Department (pp.213-214).

1. Knowledge
▪ Chemical terminology ▪ Specified facts ▪ Scientific method and thought ▪Scientific theory and its limitations ▪ knowledge of everyday applications (including uses and abuses of resources)
2. Experimental/Manipulative Skills
▪To work safely and cooperatively in a laboratory and to follow instructions given by the teacher ▪ Skill in using apparatus to make measurements ▪ Skill in recording all observations accurately
3. Comprehension and Application
▪To understand and translate scientific information in verbal, graphic and mathematical form ▪To apply known laws and principles to data and to solve problems in familiar and unfamiliar situations ▪To appreciate advances in chemistry and their influence on our lives

4. Evaluation
▪To check that hypotheses are consistent with experimental results ▪ To identify important issues and misconceptions and to analyse them critically ▪ To evaluate experimental data
5. Expression
▪To organise ideas and statements and write clearly about scientific work and theories ▪To report experimental procedures and results in a concise and comprehensive manner

Figure 2.18 Objectives of the C2 course

The content of C2 was presented as fourteen topics, as shown in Table 2.10. Each topic was further divided into sub-sections within which the higher-level material was underlined.

Table 2.9 Division of Chemistry Syllabus - C2.

1. Introduction to atomic structure	8. Carbon and Hydrogen
2. Kinetic/Particulate Nature of Matter	9. Chemical Equilibrium
3. Stoichiometry, Formulae and Equations	10. Hydrogen, Oxygen and Water
4. Periodic Table and Atomic Structure	11. Chemistry of Non-Metals, Nitrogen and Sulphur
5. Thermochemistry	12. Electrochemistry
6. Rates of Chemical Reaction	13. Chemistry of Some representative Metals
7. Crystal Structures and Shapes of Molecules	14. Reactions of Some Organic Compounds containing Oxygen

Each of the above fourteen topics was prefaced with an overview of that topic which served as a link to the objectives. The sample overview in Figure 2.18 of the *Kinetic/Particular Nature of Matter* topic illustrates this approach. The syllabus included 'notes' serving as clarification. By way of emphasising the importance of experimental work, practical work was denoted by [*italics*] and was included where it was considered to complement theory.

Kinetic/Particulate Nature of Matter	
Pupils should appreciate that matter is particulate in nature and should be aware of the minute size of particles and have an idea of their motion in solids, liquids and gases. An increase in temperature results, ultimately, in a change of state.	
	Notes
Diffusion [*e.g. bromine in air, ammonia and hydrogen chloride, potassium manganate(V11) in water*] Graham's Law. Size of particles [*oil film experiment*] Brownian movement [*use of smoke cells*]. Kinetic theory of gases. Combining volumes [*e.g.* $2NO + O_2 \rightarrow 2NO_2$, *gas syringe of eudiometer*] Avogadro's Law. Avogadro constant. The mole. Dalton's Law of partial pressures.	The bases of the kinetic theory may be stated as postulates. Derivatives of gas laws from kinetic theory are not required.
Equation of state for an ideal gas. Molar volume	$PV = nRT$
Relative molecular mass (Mr) of a volatile material [*e.g. any suitable experimental method in its original or modified form*]	P in Nm^{-2}, V in m^3. T in K R in JK^{-1} mol^{-1}. J = 1 Nm

Figure 2.19 Example of inclusion of experiment (practical work) in C2.

- ***Overview of examination papers based on C2.***

The LC examination paper, consisting of ten questions, was spread over five to eight pages and included labelled diagrams of apparatus, data tables and detailed chemical reactions. The format set for the C1 examinations was continued, i.e. six of the ten questions to be answered. However, all question parts were now allocated marks. Question one retained the format from previous examinations but was now compulsory. Questions two and three were explicitly based on the listed experiments, and students had to answer at least one. With the emphasis in C2 on the experimental nature of chemistry, experimental data was an integral part of the remaining questions.

- **Syllabus C3:2002-current**

Syllabus C3 was introduced in the same year as P3 resulting in physics and chemistry being examined for the first time in 2002. Like physics, the syllabus content and accompanying *Guidelines for Teachers-Chemistry* were published as separate booklets (Department of Education & Science/NCCA, 1998c, 1998c). Two of the aims of the revised chemistry syllabus were

- To encourage an appreciation of the scientific, social, economic, environmental and technological aspects of chemistry and an understanding of the historical development of chemistry

- To illustrate generally how humanity has benefited from the study and practice of chemistry.

(Department of Education & Science/NCCA, 1998c, p. 2)

The assessment statement was the same as that for physics - to be based on the course's objectives. The list of objectives (Figure 2.19) closely resembled those of C2 (Figure 2.17), albeit reconfigured and extended.

Knowledge – students should have knowledge of
▪ basic chemical terminology, facts, principles and methods ▪ scientific theories and their limitations
Understanding- students should understand
▪ how chemistry relates to everyday life ▪ how chemical problems can be solved
Skills- students should be able to
▪ select and manipulate suitable apparatus to perform specific tasks ▪ interpret experimental data and assess the accuracy of results
Competence- students should be able to

Figure 2.20 A selection of the	▪ translate scientific information in graphical and mathematical form ▪ perform simple chemical calculations

learning objectives to be assessed

Again, the syllabus layout was similar to physics, with the first three columns labelled ‘Content’, ‘Depth of Treatment’, and ‘Activities’, with the fourth one titled ‘’Social & Applied Aspects (SAA). Higher-level content was highlighted in bold italic text. According to the *Guidelines for Teachers*, the inclusion of the SAA component was intended to ‘capture students’ imagination and encourage them to explore chemical concepts from a broader viewpoint’. Moreover, it was ‘to constitute 30% of the syllabus. The *Guidelines for Teachers* listed several references that teachers would find helpful in supporting their inclusion of SSA in their teaching (Department of Education & Science/NCCA, 1999d, pp. 11–29). The number of mandatory experiments was twenty-nine, listed under the relevant topics as shown in this extract from the syllabus (Figure 2.20).

Chemical Equilibrium			
Content	Depth of Treatment	Activities	Social and Applied Aspects
8.1 Chemical Equilibrium	Reversible reaction-dynamic equilibrium. At equilibrium, the rate of the forward reaction equals the rate of the reverse reaction. Equilibrium Law and constant (K_c only)		
8.2 Le Châtelier’s Principle	Le Châtelier’s principle. Effect (if any) on equilibrium position of concentration, pressure, temperature and catalyst.	Mandatory experiment 8.1	Calculations involving equilibrium constants (K_c)
Mandatory Experiments			
8.1 Simple experiments to illustrate Le Châtelier’s principle:			
(i) $CoCl_4^{2-} + 6H_2O \rightleftharpoons (H_2O)_6^{2+} + 4Cl^-$		(To demonstrate the effect of both temperature changes and concentration changes on an equilibrium mixture)	
(ii) $Cr_2O_7^{2-} + H_2O \rightleftharpoons 2CrO_4^{2-} + 2H^+$		To demonstrate the effects of concentration changes on an equilibrium mixture	
(iii) $Fe^{3+} + CNS^- \rightleftharpoons Fe(CNS)^{2+}$			

Figure 2.21 Extract from the 2000 syllabus for HL chemistry

- ***Overview of examination papers based on C3.***

The examination questions reflected the syllabus' changes. The number of questions increased to eleven, as did the number of questions to be answered, from six to eight. The paper was divided into two sections – Section A focused on three mandatory experiments, and Section B addressed the theoretical and practical applications of the syllabus content. At least two of the eight questions had to be answered from Section A. The question cues used were similar to those from previous Cb questions. Each Section A question was extremely long, with at least twelve parts to answer. The examination questions based on C3 were far longer than those based on C2.

2.6 Conclusion

This Chapter has presented an overview of the development of the Irish second-level educational system post-1960 in the context of a selection of other European countries. Section 2.2 presented two contrasting images of Ireland within a European context. In the 1960s, second-level education had assumed a more significant role due mainly to the emphasis placed on education for all by the OECD, with science education regarded as essential to economic growth. Upper second-level education, particularly science education, was seen as one of the critical drivers for economic growth. Comparing the upper second-level programmes of Denmark, Finland, Ireland, the Netherlands, Norway and Sweden regarding the sciences showed a significant difference between Ireland and the remaining five. In Ireland, the physical sciences were included in a list of subjects from which students selected between five to seven for their final end-of-upper second-level education examination.

In contrast, the other five countries had between three and five programmes, each focusing on a specific area, i.e. Modern Languages, Natural Sciences. A second comparison, between the same group, in 2010 showed a very different picture. There was no change in Ireland; students still selected between five and seven subjects from a list. Consequently, it was and still is quite possible for an Irish student to complete second–level education without any input from the sciences. On the other hand, all five other countries had very different programmes. All five countries' programmes comprised two components – a compulsory one and an elective one. In the compulsory components of these countries, one or more of the sciences was included. Consequently, all students experienced aspects of the sciences at the upper second-level education. During this period, the Physics and Chemistry syllabi changed to reflect the changing emphasis of these subjects. Generally, the syllabi became more detailed and descriptive, focusing more on mandatory activities (experimental work). The STS column in Physics and SSA column in the chemistry syllabi were included to encourage teachers to incorporate applied aspects into their courses.

Section 2.4 focused on the Leaving Certificate physics and chemistry syllabi and how they were reflected in the Leaving Certificate examinations. Between 1966 and 2016, the physics and chemistry syllabi were revised three times. The physics content was always presented within the traditional mechanics, heat, light, and electricity divisions. Because these divisions were maintained across the syllabi, it was possible to trace if those changes in content resulted from the clarification or deletion of existing material and the inclusion of experiments as part of the written examination. In contrast, the chemistry content was presented differently in each syllabus, from an itemised list of 20 topics for the first syllabus to a clarified list of 14 for the second syllabus to a defined list of eleven topics for the third syllabus. Overall, the format of the examinations remained unchanged. Students still had to choose ten to eleven questions to answer six to eight.

While the physics and chemistry syllabi have changed over the years, there have been changes in the layout and question type to accommodate these changes, e.g. questions relating to experimental work and including STS/SSA questions. As the high-stakes examinations are based on the syllabi, several questions arise – how had these syllabi changes impacted the cognitive demands of the examination papers? How did the cognitive demands of the examinations in Ireland relate to the cognitive demands of similar examinations in other countries? These questions will be directly addressed in Chapters Five and Six.

Chapter 3 Assessment models

3.1 Introduction

The launching of the first artificial satellite Sputnik, in 1957, by the Soviet Union created a crisis for the Americans, which started scrutiny of their education structures. As a result, the American education system moved from a norm-referenced one to a standard- or outcomes-based one emphasising testing. The U.S.'s *No Child Left Behind* (NCLH) legislation in 2001 led to educational financial resources being dependent on State-mandated testing. Consequently, there was an imperative for state education authorities to ensure alignment between state standards and the assessment process (Fulmer, 2011; Gamson et al., 2015; Polikoff and Porter, 2014). This alignment between state standards and assessment practices was, and still is, an area that generated much debate (Martone and Sireci, 2009). If the assessment practices did not support the objectives/aims of the syllabus, then there was a severe mismatch – and in highly competitive assessments, the assessment may well drive the learning rather than the syllabus (Berliner, 2011; Klein, Esther Dominique, 2016). Therefore, models or taxonomies were developed to determine the assessment's alignment or cognitive demands. Bloom's taxonomy was one such taxonomy, discussed more fully in Section 3.3.

While directly relevant to the development of the taxonomies, it is helpful as a background to outline 'how students learn,' i.e. the theory of constructivism and cognitive development (Section 3.2). This section is not intended to review learning theories or their application but a brief overview of two critical inputs – from Piaget and Flavell. Section 3.3 presents an overview of several models developed. Section 3.4 considers several studies which focused on applying models to assess the cognitive content of high-stakes examinations. The focus of Section 3.5 is on the model used in previous studies of the assessment of Leaving Certificate examinations in physics and chemistry. The final Section 3.6 explains the selection process for the assessment model used.

3.2 Cognitive development

Behaviourism, one of two major cognitive learning theories of the twentieth century, can be said to have its roots in the works of two British philosophers, Thomas Hobbes (1588-1679) and Joseph Locke (1632-1704). They both subscribed to the view that knowledge was based on experience. According to the Spanish philosopher Julián Marías, Hobbes considered '*that knowledge was based on experience, and his concern was to instruct men for practical purposes'* while Locke believed that *'the origin of knowledge was experience…that a* *person's mind at birth was a tabula rasa, like a clean slate on which nothing had been written'* (Marías, Applebaum and Strowbridge, 1966, pp. 250–255). This philosophy found a home in behaviourism as proposed by B. J. Skinner (1904-1990), who promoted programme learning in which the teacher decided on what knowledge should be acquired and how it would be transmitted to the students. The teacher arranged all relevant terms, facts, and principles in sequential steps, resulting in positive learning if correctly followed by the student (Biehler and Snowman, 1986).

Constructivism, the second major learning theory of the twentieth century, could be said to have had its foundations in the philosophical writings of Descartes (1588-1679). Descartes considered ideas to be pivotal to understanding the world. In *Discourse on Method*, he wrote

> *I decided to arrange my thoughts in order, beginning with things the simplest and easiest to know so that I may then ascent little by little, as it were, step by step, to the knowledge of the more complex.* (Smith, 1958, p. 107)

In the 1960s-1970s, presented as a teaching/learning method, constructivism used ideas and concepts students had constructed about scientific phenomena as the basis for teaching about the nature of science. Proposing *a discovery learning* approach, Bruner (1915-2016) envisaged teachers presenting students with problems to be solved independently or through small group discussions. For Bruner, this approach aimed to facilitate the development of problem-solving skills and promoted the growth of self-confidence. Consequently, it encouraged the transference of these skills to other ostensibly less related areas (Biehler and Snowman, 1986). Generally considered the father of constructivism, Piaget (1896 -1980) is widely credited with linking cognitive development to learning theory. While administering Binet-Simon tests[5], he became as interested in the incorrect as the correct answers (Shayer, 2008). Comparing the answering pattern of the different age groups, he observed that young children consistently made the same mistakes in specific questions, whereas the older age groups did not. Piaget hypothesised that young children's cognitive processes were quite different from those of older children and adults. (Biehler and Snowman, 1986; Chalmers and McGonigle, 2003). Through extensive clinical interviewing and observations of children, he formulated his four age-related stages of cognitive development, each building on what went before (Figure 3.1).

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[5] Precursor of the Standford-Binet Intellignece Scale (IQ tests) used to measure intelligence and cognitive abilities of persons 2-85 years.

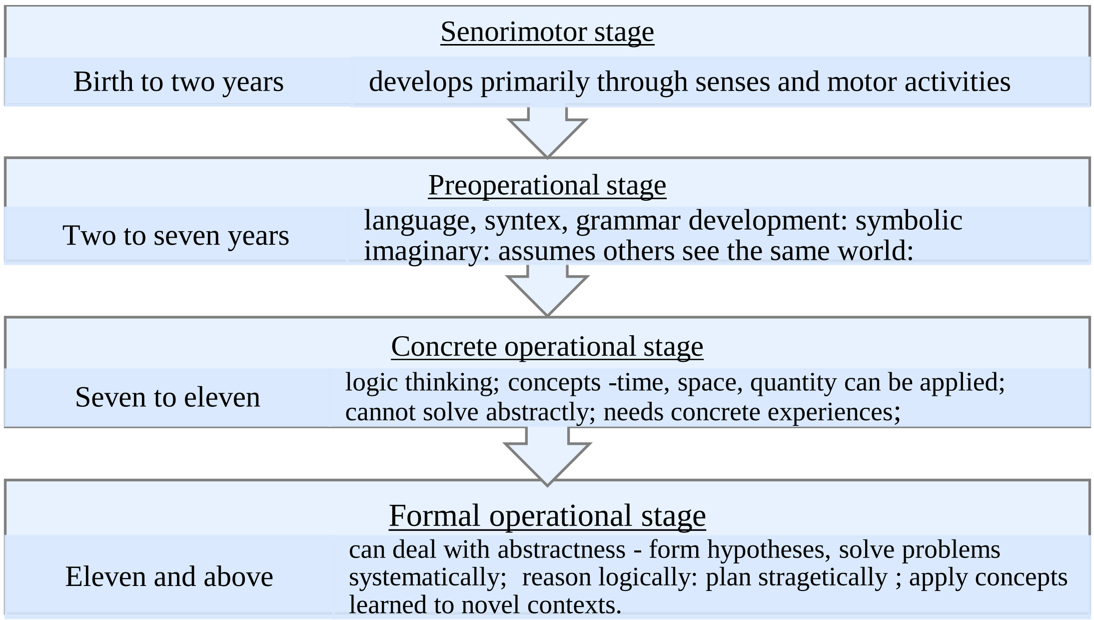


Figure 3.1 Piaget's Stages of cognitive development

Piaget also proposed that the development of intellectual growth within these stages proceeded through a cycle of adaptation and organization. In this concept of intellectual growth, adaptation involves assimilation and accommodation leading to the organization of stored knowledge to include the recently acquired information. He defined assimilation as the process of associating a new event/information/experience with previously acquired background knowledge and concepts. Accommodation occurred with the present store of knowledge being rearranged/readjusted to incorporate this new experience, with mental equilibrium balance being restored between the two processes. Disruption of this equilibrium can then be caused by exposure to another new experience/event, and so the cycle recommences. Despite criticisms levelled against Piaget's work, that the tasks he used were complex and outside the usual experience of children, that his conclusions were based on clinical testing and not within the context of classroom teaching, his theories on cognitive development and understanding were very evident, especially in the areas of mathematics and science teaching/learning (Rowell, 1984; Driver *et al.*, 2004). He contended that language followed cognitive understanding; verbal expression was possible once a concept was assimilated and accommodated. A key criticism of Piaget's four stages of cognitive development (as in Figure 3.1 above) was the age range associated with each, specifically with the age range he attributed to the concrete operational (7-11 years) and formal operation (11 years and above) stages. Adey et al. developed a series of science reasoning tasks that could determine the cognitive reasoning ability of students ages 11-14 (Adey, Shayer and Yates, 1989). They concluded (among other things) that students did not reach the formal operational stage until their mid-late teens (and that some may not reach this level during their formal schooling at all). Interestingly, studies by McCormack and Finlayson have shown that many third-level students were only at the initial stages of formal operational thought (McCormack and Finlayson, 2009). Bryant contended that cognitive knowledge development should also include knowing when to use this knowledge.

> *We have then to make a distinction between the possession of a logical ability on the one hand and, on the other hand, the way this ability is deployed. Children or, indeed, adults must not only be able to make a particular logical move: they must also recognize when that move is needed.*
>
> (Bryant, 1984, p. 255)

This categorisation of cognitive knowledge echoed research in the USA on cognition and metacognition, particularly that of Flavell (Flavell, 1963, 1971, 1979; Flavell and Wellman, 1975). Summarising papers read at a symposium 'What is Memory Development the Development of?' held in 1971, Flavell remarked that

> *There was a growing consensus that memory is, in good part, just applied cognition. That is, what we call 'memory processes' seem largely to be just the same old familiar, cognitive processes, but as they are applied to a particular class of problems…What, then, is memory development the development of? It seems in large part to be the development of intelligent structuring and storage of input, of intelligent search and retrieval operations, and of intelligent monitoring and knowledge of these storage retrieval operations – a kind of metamemory, perhaps?*
>
> (Flavell, 1971, pp. 273, 277)

By the mid-1970s, metamemory was renamed metacognition, highlighting the self-monitoring of one's knowledge and skills used in accessing this knowledge. According to Brown,

> *what is of major importance is knowledge about one's own cognitions rather than the cognitions themselves.* (Brown, 1977, p. 4)

Flavell described metacognition as a self-monitoring process comprising four categories, as shown in Figure 3.2 (Flavell, 1979). He defined metacognitive knowledge as all information and understanding of how factors act and interact to affect the outcome of a cognitive task. These factors, in turn, were classified as **strategies** (encompassed knowledge not only of effective strategies but also how and when to use them successfully), **tasks** (referred to the nature and rationale of the cognitive activity) and **self** (level of self-awareness of one's own learning abilities and understandings). As described by Flavell, metacognitive experiences were metacognitive knowledge entering the consciousness resulting in the knowledge component being affected positively or negatively by the experiences. He likened this relationship to that of Piaget's concept of intellectual growth of assimilation and accommodation described earlier. Although listed as separate categories (greyed out sections in Figure 3.2), Flavell considered Goals and Action within meta-cognitive knowledge and meta-cognitive experience.

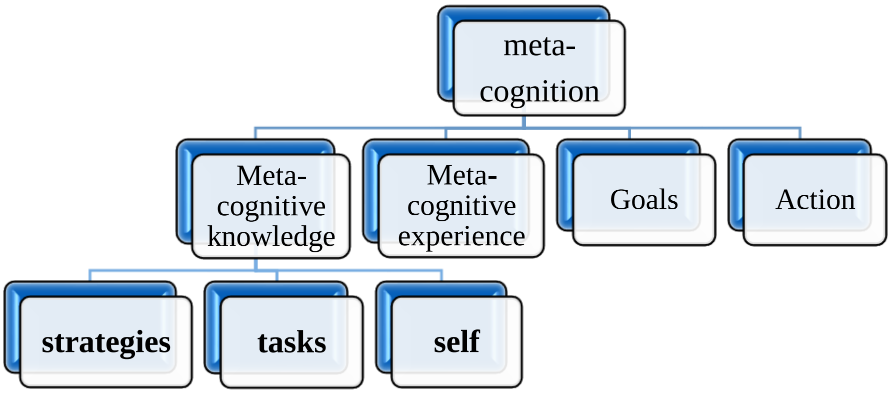


Figure 3.2 Flavell's Model of Metacognition

3.3 Assessment approaches

Three components of an education system are depicted in Figure 3.3. Each of the components is interconnected and mutually dependent. In this system, the expectation is that students will attain the standards as laid down in the standards/policy documents of the education authorities (Näsström and Henriksson, 2008). This expectation is realised through an assessment process which aligned with the standards. **Standards-Policy documents** refer to the written documentation that serves as references for teaching and assessment. **Teaching** is the learning and pedagogy which takes place in the classroom. **Assessment** or evaluation is the written record or test/examination based on the stated standards, the results of which are used to improve students' outcomes (Crowell and Tissot, 1986; N. Webb, 1997; Webb, 2007; Fulmer, 2011; Squires, 2012).

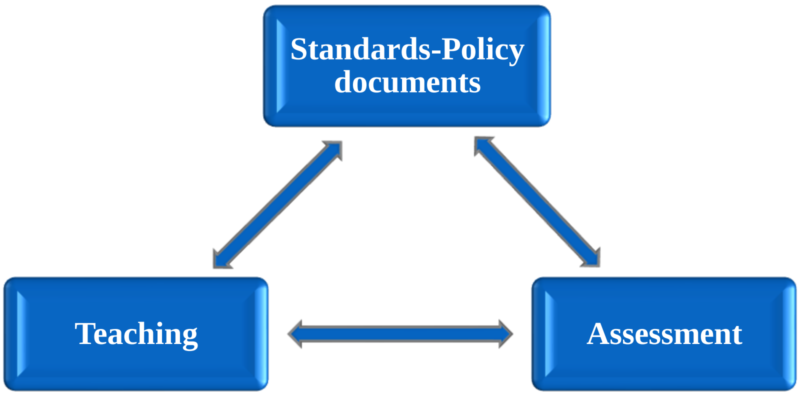


Figure 3.3 Education system as a Triangular alignment model.

The significance of this alignment is reflected in the importance of the terminal public high-stakes examinations, which mark the end of upper secondary education. Dufaux (2012) characterised such high-stakes examinations as being assessments for qualification and certification, that is

> *Qualification is the formal recognition of learning. It relies on a predefined standard of competencies that is achieved by the learner…Certification is an official document that records qualifications...In the case of assessment for qualification and certification in upper secondary education, certificates convey information in particular to higher education institutions and the labour markets.*
>
> (Dufaux, 2012, p. 8)

As indicated in Chapter 1, this thesis focuses on assessing the cognitive demands of high-stakes examinations in physics and chemistry, not on the alignment of the high-stakes examinations to the syllabi. Nonetheless, many of the models developed to assess the alignment of examinations and syllabi, such as Bloom's Taxonomy of Education Objective, Webb's evaluation model, Porter's Surveys of Enacted Curriculum (AEC), Marzano's New Taxonomy of Educational Objective, incorporate a framework or taxonomy which facilitate assessing the cognitive aspects of these high-stakes examinations(N. Webb, 1997; Porter and Smithson, 2001; Bhola, Impara and Buckendahl, 2003; Marzano and Kendall, 2007; Roach, Niebling and Kurz, 2008; Seaman, 2011).

Bloom's Taxonomy

Published in 1956, the *Taxonomy of Educational Objectives- the Classification of Educational Goals* (Bloom *et al.*, 1956) was the result of the collaboration of thirty-four academic educationalists to classify what they regarded as the educational objectives/intellectual skills to consider when designing curricula and examinations (Krathwohl, 2002). This taxonomy, sometimes referred to as Bloom's Taxonomy (OBT), presented these intellectual skills as a sequentially structured cumulative hierarchy comprising six categories, Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. The first category, Knowledge, was considered as the basic intellectual skill, with each subsequent category building on the previous c
ategories leading to the more complex category of Evaluation as shown in Table 3.1.

Table 3.1 Hierarchical Structure of Bloom's Taxonomy (1956).

Original Structures of Bloom's Taxonomy		
1.0	**Knowledge**	
	1.1	Knowledge of specifics
	1.11	Knowledge of terminology
	1.12	Knowledge of specific facts
	1.2	Knowledge of ways and means of dealing with specifics
	1.21	Knowledge of conventions
	1.22	Knowledge of trends and sequences
	1.23	Knowledge of classifications and categories
	1.24	Knowledge of criteria
	1.3	Knowledge of universals and abstractions in a field
	1.31	Knowledge of principles and generalizations
	1.32	Knowledge of theories and structures
2.0	**Comprehension**	
	2.1	Translation
	2.2	Interpretation
	2.3	Extrapolation
3.0	**Application**	
4.0	**Analysis**	
	4.1	Analysis of elements
	4.2	Analysis of relationships
	4.3	Analysis of organisational principles
5.0	**Synthesis**	
	5.1	Production of a unique communication
	5.2	Production of a plan or proposed set of operations
	5.3	Derivation of a set of abstract relations
6.0	**Evaluation**	

Revised Bloom's Taxonomy

The publication of *Bloom's Taxonomy: A Forty-year Retrospective* in 1994 prompted the possibility of revising the original taxonomy (Anderson, 1999). The function of the original taxonomy was two-fold – to facilitate the classification of learning objectives and to provide an assessment pathway for these. However, all the categories were presented more as learning outcomes without corresponding assessment metrics, thus showing a one-dimensional framework. Moreover, Bloom's original taxonomy did not adequately address education and cognitive psychology developments in the intervening years (Anderson, 2002; Krathwohl and Anderson, 2010; Seaman, 2011). Consequently, the Revised Bloom's Taxonomy was presented in 2001 in a two-dimensional format – the Knowledge and Cognitive dimensions (Anderson *et al.*, 2001). The original 1.0 Knowledge category (Table 3.1) was repurposed to form the Knowledge Dimension, as shown in Table 3.2. The original three subcategories of Knowledge, 1.1, 1.2 and 1.3, were retained but reclassified under the headings of Factual, Conceptual and Procedural knowledge. The addition of a fourth category, Metacognitive Knowledge, was a recognition of the evolution of educational development since 1956 (Flavell, 1979; Krathwohl, 2002; Pintrich, 2002).

Table 3.2 Comparing the Knowledge category (Bloom 1956) and the Knowledge Dimension (Revised Bloom 2001)

Original Taxonomy (1956)	**Revised Taxonomy (2001)**
Knowledge category	**The Knowledge Dimension**
1.1 Knowledge of specifics	**A. Factual Knowledge**
1.11 Knowledge of terminology	**1.11 Knowledge of terminology**
1.12 Knowledge of specific facts	**1.12 Knowledge of specific facts**
1.2 Knowledge of ways and means of dealing with specifics	**B. Conceptual Knowledge**
1.21 Knowledge of conventions	**1.23 Knowledge of classifications and categories**
1.22 Knowledge of trends and sequences	**1.31 Knowledge of principles and generalizations**
1.23 Knowledge of classifications and categories	**1.32 Knowledge of theories and structures**
1.24 Knowledge of criteria	**C. Procedural Knowledge**
1.25 Knowledge of methodology	**1.22 Knowledge of trends and sequences**
1.3 Knowledge of universals and abstraction in a field	**1.24 Knowledge of criteria**
1.31 Knowledge of principles and generalizations	**1.25 Knowledge of methodology**
1.32 Knowledge of theories and structures	**D. Metacognitive Knowledge**
	*** Strategic knowledge** *** Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge**

* Self-knowledge

Krathwohl detailed how the revised version now allowed for constructing a taxonomy table useful for determining alignment, outcomes or lack of same (Krathwohl, 2002).
Anderson listed four reasons for curriculum alignment –

- The need-to-know students' outcomes as a result of learning
- The need-to-understand effectiveness of learning on these outcomes
- The need-to-know effect of teaching on learning and
- The need-to-address accountability issues (Anderson, 2002, p. 257).

In his article *The Role of Metacognitive Knowledge in Learning, Teaching and Assessing*, Pintrich clarified the inclusion of metacognitive knowledge in the Revised Bloom's Taxonomy (Pintrich, 2002). He differentiated between metacognitive knowledge (general strategies for different activities, knowing the type of question could dictate preparation style) and metacognitive control and self-regulation, learning how to monitor, control and regulate knowledge and learning to fit within the six cognitive categories. Table 3.3 highlights the parallels between Flavell's metacognitive knowledge model and those elements of the newly added component of Metacognitive Knowledge.

Table 3.3 Comparing Metacognitive Knowledge in Flavell Model and Revised Bloom's Taxonomy

Metacognitive Knowledge In Flavell model		**Rationale for inclusion of Metacognitive Knowledge in Revised Bloom's Taxonomy**
Strategies	Strategic knowledge	Ways to memorise, rehearsal, mnemonics, strategies for paraphrasing, concept mapping, notetaking;
Tasks	Knowledge about cognitive tasks, contextual and conditional knowledge	Knowing what is difficult or not; need to know the what to use and how as well as when and why; view strategies as tools; understand domain-specific and domain-general
Self	Self- knowledge	Self-aware of own strengths and weakness; know what they know and do not know; know when and how to use more general strategies to find information; .judge own capabilities to carry out a task; self-aware of own motivations;

The cognitive dimension was formed with the original six categories but with important changes, as shown in Table 3.4. The hierarchical structure order was maintained with the verbal form replacing the previous noun categories. Knowledge was renamed ***Remember***, and Comprehension was retained at level two but renamed ***Understand***. Other name changes resulted in Application being changed to ***Apply*** and Analysis to ***Analyse***. The last two categories, Synthesis and Evaluation, were renamed ***Create*** and ***Evaluate,*** respectively, and recategorized, so *Evaluate* and *Create* were now in the fifth and sixth categories.

Table 3.4 Bloom's cognitive processes (1956) vs Revised Bloom Revised Taxonomy Cognitive Dimension (2001)

Structure of Bloom's Taxonomy (1956)	Structure of Revised Taxonomy (2001)	
1.0 Knowledge	**1.0 *Remember***	
1.1 Knowledge of specifics	1.1 Recognising	
1.2 Knowledge of ways and means of dealing with specifics	1.2 Recalling	
1.3 Knowledge of universals and abstractions in a field	**2.0 *Understand***	
2.0 Comprehension	2.1 Interpreting	
2.1 Translation	2.2 Exemplifying	2.5 Inferring
2.2 Interpretation	2.3 Classifying	2.6 Comparing
2.3 Extrapolation	2.4 Summarising	2.7 Explaining
3.0 Application	**3.0 *Apply***	
4.0 Analysis	3.1 Executing	
4.1 Analysis of elements	3.2 Implementing	
4.2 Analysis of relationships	**4.0 *Analyse***	
4.3 Analysis of organisational principles	4.1 Differentiating	
5.0 Synthesis	4.2 Organising	
5.1 Production of a unique communication	4.3 Attributing	
5.2 Production of a plan or a proposed set of operations	**5.0 *Evaluate***	
5.3 Derivation of a set of abstract relations	5.1 Checking	
6.0 Evaluation	5.2 Critiquing	
6.1 Evaluation in terms of internal evidence	**6.0 *Create***	
6.2 Judgements in terms of external criteria	6.1 Generating	
	6.2 Planning	
	6.3 Producing	

Anderson et al. (2001) presented this revised taxonomy as a two-dimensional framework - the Taxonomy Table (Figure 3.4), facilitating the classification of the curriculum objectives /learning outcomes. According to the authors, this involved parsing an objective to determine the active verb(s) and related noun(s) and locating their grid position in the Table. For example, one of the objectives of the Irish LC physics syllabus is that 'students should be able to interpret experimental data…' (Department of Education & Science/NCCA, 1998c, p. 36). Here the active verb is *to interpret*, which, according to Anderson et al., codes to cognitive demand, *understand*, whilst *the experimental data* relates to the Procedural knowledge. Thus, X represents the classification of the objective within the Taxonomy.

Knowledge dimension ↓	Cognitive dimension lower-order cognitive demand → higher-order cognitive demand					
	Remember	*Understand*	*Apply*	*Analyse*	*Evaluate*	*Create*
Factual knowledge						
Conceptual knowledge						
Procedural knowledge		**X**				
Meta-Cognitive knowledge						

Figure 3.4 The Taxonomy Table

Webb's evaluation model

In developing his criteria for alignment, Webb (1997) distinguished between what he termed the horizontal alignment and the vertical alignment within the education system (Figure 3.4); the horizontal alignment encompasses the standards/policies and the assessments, while the vertical alignment refers to the dynamic components of the education system as encompassed in the classroom environment, for example, teachers, pedagogy, students, resources.

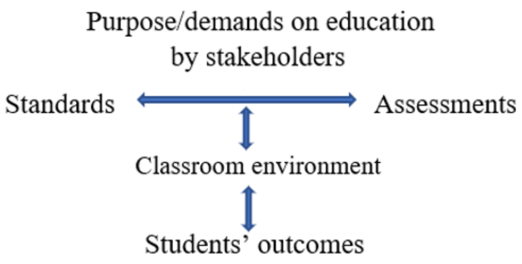


Figure 3.5 Horizontal and vertical alignments within education (Webb, 1997)

Webb categorised three possible standards or curriculum alignment approaches- sequential development, expert review and document analysis (Webb, 1997). He considered sequential development and specialist review methods time- and personnel-dependent methodologies. Documentary analysis depended on the coding of acceptable criteria applied to the documents to be analysed. Webb centred most of his work on the alignment of standards and assessments using document analysis. In *Determining Alignment of Expectations and Assessment in Mathematics and Science Education* (Webb, 1997), Webb outlined a complex system comprising five major categories, namely

1) Content Focus,

2) Articulation across grades and ages,

3) Equity and Fairness,

4) Pedagogical Implications and

5) System Applicability.

Furthermore, each of these categories is comprised of several subcategories. For example, the first category, Content Focus, consisted of six subcategories, namely,

- Categorical Concurrence
- Depth of Knowledge Consistency
- Range of Knowledge Correspondence
- Structure of Knowledge Comparability
- Balance of Representation
- Dispositional Consonance

Central to Webb's model is the Depth of Knowledge (DOK) subcategory (Webb, 1997; Webb, 2002), as the schematic representation Figure 3.5 shows. Level 1 is the lowest level requiring recall of facts and drawing simple diagrams-all could be considered within the realm of rote learning. Each successive level builds on the previous – at level 2 student now needs to explain relationships that at level 1 just required a simple statement. Level 3 focuses on more complex and demanding reasoning, justifying answers, whereas a simple explanation suffices at the previous level. Level 4 requires students to show how they apply their knowledge to complex scientific situations, finding solutions or analysing alternatives presented.

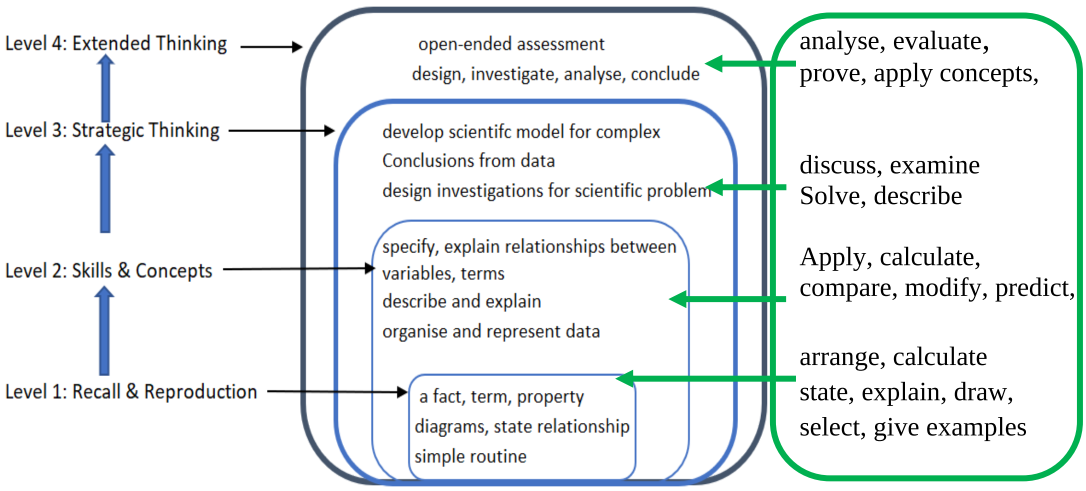


Figure 3.6 Schematic representation of Webb's Depth of Knowledge

Webb's DOK model could focus on the cognitive complexity of thinking involved in answering questions. The four levels on the DOK model allowed for an in-depth parsing of nature and the level of understanding and skills required in answering questions. One of the limitations of Bloom's taxonomy in framing questions was the reliance on verbs used in discerning the different taxonomy levels, specifically when many of these verbs appear in several different levels (Pugh and Gates, 2021).

Hess et al. proposed blending Bloom’s taxonomy and DOK (Hess *et al.*, 2009). Table 3.5 illustrates this matrix applied to Mathematics/Sciences areas (Hess, 2006). The authors presented this blending as a cognitive rigour (CR) matrix, which they believed facilitated a more rigorous interrogation of questions both of the cognitive classification according to Bloom’s taxonomy and, at the same time, highlighting the corresponding thinking skills according to DOK.

Hess' Cognitive Rigor Matrix & Curricular Examples: Applying Webb's Depth-of-Knowledge Levels to Bloom's Cognitive Process Dimensions – *M-Sci*

Revised Bloom's Taxonomy	**Webb's DOK Level 1 Recall & Reproduction**	**Webb's DOK Level 2 Skills & Concepts**	**Webb's DOK Level 3 Strategic Thinking/ Reasoning**	**Webb's DOK Level 4 Extended Thinking**
Remember Retrieve knowledge from long-term memory, recognize, recall, locate, identify	○ Recall, observe, & recognize facts, principles, properties ○ Recall/ identify conversions among representations or numbers (e.g., customary and metric measures)			
Understand Construct meaning, clarify, paraphrase, represent, translate, illustrate, give examples, classify, categorize, summarize, generalize, infer a logical conclusion (such as from examples given), predict, compare/contrast, match like ideas, explain, construct models	○ Evaluate an expression ○ Locate points on a grid or number on number line ○ Solve a one-step problem ○ Represent math relationships in words, pictures, or symbols ○ Read, write, compare decimals in scientific notation	○ Specify and explain relationships (e.g., non-examples/examples; cause-effect) ○ Make and record observations ○ Explain steps followed ○ Summarize results or concepts ○ Make basic inferences or logical predictions from data/observations ○ Use models /diagrams to represent or explain mathematical concepts ○ Make and explain estimates	○ Use concepts to solve non-routine problems ○ Explain, generalize, or connect ideas using supporting evidence ○ Make and justify conjectures ○ Explain thinking when more than one response is possible ○ Explain phenomena in terms of concepts	○ Relate mathematical or scientific concepts to other content areas, other domains, or other concepts ○ Develop generalizations of the results obtained and the strategies used (from investigation or readings) and apply them to new problem situations
Apply Carry out or use a procedure in a given situation; carry out (apply to a familiar task), or use (apply) to an unfamiliar task	○ Follow simple procedures (recipe-type directions) ○ Calculate, measure, apply a rule (e.g., rounding) ○ Apply algorithm or formula (e.g., area, perimeter) ○ Solve linear equations ○ Make conversions among representations or numbers, or within and between customary and metric measures	○ Select a procedure according to criteria and perform it ○ Solve routine problem applying multiple concepts or decision points ○ Retrieve information from a table, graph, or figure and use it solve a problem requiring multiple steps ○ Translate between tables, graphs, words, and symbolic notations (e.g., graph data from a table) ○ Construct models given criteria	○ Design investigation for a specific purpose or research question ○ Conduct a designed investigation ○ Use concepts to solve non-routine problems ○ Use & show reasoning, planning, and evidence ○ Translate between problem & symbolic notation when not a direct translation	○ Select or devise approach among many alternatives to solve a problem ○ Conduct a project that specifies a problem, identifies solution paths, solves the problem, and reports results
Analyze Break into constituent parts, determine how parts relate, differentiate between relevant-irrelevant, distinguish, focus, select, organize, outline, find coherence, deconstruct	○ Retrieve information from a table or graph to answer a question ○ Identify whether specific information is contained in graphic representations (e.g., table, graph, T-chart, diagram) ○ Identify a pattern/trend	○ Categorize, classify materials, data, figures based on characteristics ○ Organize or order data ○ Compare/ contrast figures or data ○ Select appropriate graph and organize & display data ○ Interpret data from a simple graph ○ Extend a pattern	○ Compare information within or across data sets or texts ○ Analyze and draw conclusions from data, citing evidence ○ Generalize a pattern ○ Interpret data from complex graph ○ Analyze similarities/differences between procedures or solutions	○ Analyze multiple sources of evidence ○ analyze complex/abstract themes ○ Gather, analyze, and evaluate information
Evaluate Make judgments based on criteria, check, detect inconsistencies or fallacies, judge, critique			○ Cite evidence and develop a logical argument for concepts or solutions ○ Describe, compare, and contrast solution methods ○ Verify reasonableness of results	○ Gather, analyze, & evaluate information to draw conclusions ○ Apply understanding in a novel way, provide argument or justification for the application
Create Reorganize elements into new patterns/structures, generate, hypothesize, design, plan, construct, produce	○ Brainstorm ideas, concepts, or perspectives related to a topic	○ Generate conjectures or hypotheses based on observations or prior knowledge and experience	○ Synthesize information within one data set, source, or text ○ Formulate an original problem given a situation ○ Develop a scientific/mathematical model for a complex situation	○ Synthesize information across multiple sources or texts ○ Design a mathematical model to inform and solve a practical or abstract situation

Table 3.5 Hess' Matrix: Applying Webb's DOK to Bloom's cognitive level

Porter's evaluation model

Introduced in 1998, Porter and Smithson developed the Surveys of Enacted Curriculum (SEC) (Porter and Smithson, 2001; Porter, 2002). They focused on the curriculum as composed of four components - the intended curriculum, the assessed curriculum, the learned curriculum and the enacted curriculum (Porter and Smithson, 2001). Figure 3.7 depicts the interlinks of all four. The arrows represent alignment procedures developed – Webb's evaluation model focused on aligning standards and assessment. Porter and Smithson's Surveys of Enacted Curriculum collated data on the assessment process and the classroom pedagogy. The dotted lines represent other possible alignment pathways.

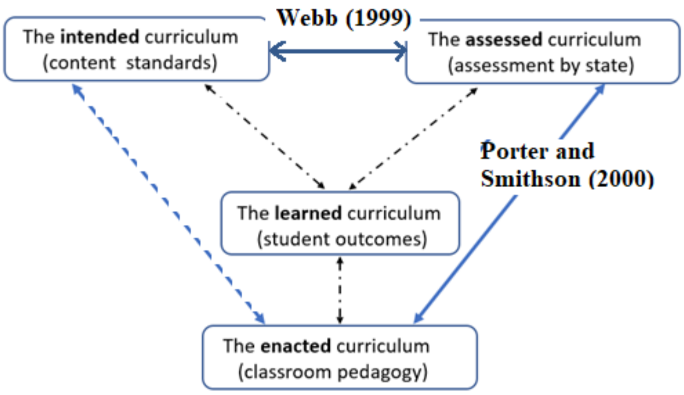


Figure 3.7 Representation of SEC alignment pathways adapted from Porter & Smithson (2001)

Porter and Smithson present curriculum alignment as a two-dimensional matrix comprising topics and cognitive categories, as shown by the example in Table 3.6. Having categorised the examination topics to the appropriate cognitive demands of a) the assessment /examination and b) the standards/syllabus, each matrix is converted into a (Number of topics) x 6 (cognitive demands of the assessment/standards) table. Each table is then standardised so that all cells are the proportions of the total of each matrix.

Table 3.6 Porter's matrix to calculate the degree of alignment between standards and assessment

Matrix X	**Category of cognitive demand of the standards/syllabus**					
	Remember	Understand	Apply	Analyse	Evaluate	Create
Topic 1						
Topic 2						
Matrix Y	**Category of cognitive demand of the assessment/examination**					
	Remember	Understand	Apply	Analyse	Evaluate	Create
Topic 1						
Topic 2						

To determine the degree of alignment between the assessment and the standards, Porter's alignment index, P, is then calculated from Porter's Alignment index, P, given by

$$P = 1 = \frac{\Sigma_{i=1}^{n}|x_i - y_i|}{2}$$

Where n= the total number of the cells in the table, i refers to a specific cell ranging from 1 to n, Xi refers to a cell in the standards table, and Yi refers to a cell in the assessment table.

The SEC is widely used in the USA and is presently web-based at (https://curriculumanalysis.org/resoruces.asp).

SOLO Taxonomy

The Structure of Observed Learning Outcomes (SOLO) was developed by Australians Biggs and Collis (Biggs and Collis, 1982). Based on a five-stage model (Figure 3.7), SOLO is used to classify a student's learning outcomes in terms of cognitive complexity. The first stage, termed pre-structural, is now at the uni-structural level when the student has little knowledge or understanding of the task at hand, gradually acquiring a limited understanding of the task at hand.

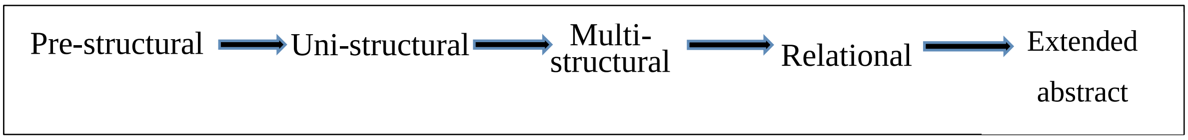


Figure 3.8 Representation of the five progressive stages in the SOLO framework

At the multi-structural stage, the student now has many disparate pieces of information but cannot link or connect the various parts of information. The relational stage is reached when the student can see a relationship between these disparate pieces and form a coherent understanding of the task. The extended abstract occurs when the student can expand the task. Each stage represents a better understanding than the previous level. These five interlinked-cognitive levels of understanding provide a framework to analyse a student's depth of knowledge.

3.4 Assessment of high-stakes written examinations:

Näsström and Henriksson(Näsström and Henriksson, 2008) researched nine different models to ascertain the most suitable for evaluating standards versus assessment of an upper secondary chemistry course (Table 3.7). The authors based this selection on four categories–

content, cognitive complexity (referring to the level of cognitive demand of the questions and cognitive skills demanded of students), the range of standards the assessment would cover and how well the assessment process reflects the standards expected. Of the four categories, the first two, content and cognitive complexity, were deemed essential,

Table 3.7 Nine models considered by Näsström and Henriksson (p.675)

Framework /taxonomy	Content criteria	Cognitive complexity	Other dimensions
Bloom's revised taxonomy	Knowledge dimension	Cognitive process dimension	
De Block	Content	Method	Transfer
De Cortes	Subject matter	Operation	The domain is the product
Guildford	Product	Operational categories	Content categories
Marzano	Knowledge domain	Level of thinking system	
Merrill	Content categories	Performance categories	
PISA	Scientific concepts	Scientific process	Scientific situations
Porter	Topics	Expectations for students	Mode of presentation (not used by Porter)
TIMSS	Content	Performance expectations	Perspectives

Having selected Bloom's revised taxonomy and Porter's taxonomy, the authors compared both models to determine the most useful for studying alignment. By comparing the results of applying both taxonomies to a syllabus and an assessment, they concluded that Bloom's revised taxonomy was more useful as a classification tool than Porter's taxonomy.

Tsaparlis and Zoller (2003) compared students' performances in chemistry examinations at the upper second level in Greece and university levels in Israel. The authors classified the questions as either lower-order cognitive demands (LOCs) of *remembering, understanding* and *applying* or higher-order cognitive demands (HOCs) of *analysing, evaluating* and *creating.* The researchers found that in Greece, students who performed well on HOCs-type questions did not necessarily result in these students performing equally well on LOCs-type. However, they found that most of the chemistry examination questions classified as LOCs had implications in the selection process for higher education. The Israeli component revealed that when given a choice between HOCs-type questions and LOCs-type, the university students considered high calibre preferred to answer the LOCs-type questions and achieve high grades without answering any HOCs-type questions. Notably, the Greece results, based on high-school examination questions and the Israeli results, based on selection choice of first-year undergraduates, highlighted the dominance of the LOCs-type questions over the HOCs-type questions.

A further study using Bloom's revised taxonomy compared the cognitive skill emphasis of the upper secondary exit 2006 examinations in physics for three different education systems – China (Jiangsu Province), the United States (New York) and Singapore (Liu et al., 2009). Despite a general agreement between the three curricula and the contents of the standardised tests, there were significant differences in the cognitive skills of the examinations. The Chinese examination had questions coding for the first four cognitive skills – *remember*, *understand* (being the dominant cognitive skill), *apply* and *analyse*; the New York examination questions coded for the first three (*remember*, *understand* and *apply*), with *apply* to be the dominant cognitive skill. Singapore, however, had questions which coded for all six categories, with *apply* being the dominant cognitive skill.

In Australia, school education is constitutionally the responsibility of each state, resulting in each state having its own independent education system. Fensham and Bellocchi (2013) investigated how higher-order thinking demands (HOTs) were facilitated in chemistry examinations in four Australian states, namely New South Wales, Southern Australia, Victoria and Queensland. An analysis of the curriculum documents of each of the four states indicated a strong emphasis on HOTs, such as using critical evaluation, developing problem-solving demands, using deductive reasoning, and creativity. Having classified the examination questions as either lower-order thinking demands (LOTs) or HOTs categories, they then focused on allocating marks to these questions. Despite the above-stated aims and objectives of the different curricula, the marks allocation greatly favouring questions requiring LOTs over those requiring HOTs.

Similarly, Allouh (2016) evaluated chemistry questions from the General Secondary Examination in Jordan from 2010-2015. This evaluation included measuring the level of cognitive demands based on Bloom's Taxonomy in the examination questions. The analysis showed that the two cognitive demands of *remember* and *understand* dominated two-thirds of the total number of questions, with the percentage of questions coding for *analyse, evaluate* and *create* less than ten per cent.

In contrast, Tikkanen and Aksela (2012) investigated the cognitive demands of the Finnish Matriculation chemistry examinations for 1996-2009. Their research indicated that 78% of the questions accounted for the cognitive demands *analyse* (35%), *evaluate* (16%) and *create* (27%), with no questions coding for the lower cognitive demand *remember*.
In these studies, there seems to be an emphasis on remembering, understanding and applying skills, as determined using the Revised Bloom's Taxonomy. Additionally, the use of the taxonomy facilitated the comparison of the cognitive demand of different examinations.

3.5. Previous studies of Leaving Certificate examinations

The first Leaving Certificate examination took place in 1925. In the 1929-30 *Statistical Report,* the Department of Education presented the Leaving Certificate as

> *Evidence of educational fitness…the results of the examinations being accepted by a considerable number of universities, professional bodies training colleges, etc., in Ireland and elsewhere.*
>
> (An Roinn Oideachais, 1931, p. 58)

In 2022 the NCCA website described the aims of Leaving Certificate

> *To provide learners with a broad, balanced education while also offering specialisation towards a particular career option.*

Despite the importance attached to the outcome of the Leaving Certification examinations (Mac Aogáin, 2005; Mac Aogáin, Millar and Kellaghan, 2011; O'Donoghue, Glesson and McCormack, 2017; McCormack, Gleeson and O'Donoghue, 2020), there have been few studies focusing on the cognitive demands of these examinations. The first analysis of the cognitive levels of the Irish Leaving Certificate examination took place in 1970 using the published Bloom's *Taxonomy of Educational Objectives* as the metric (Bloom *et al.*, 1956). Madaus & Macnamara entitled their work *Public Examinations: A Study of the Irish Leaving Certificate* (Madaus and Macnamara, 1970). Using the 1967 Leaving Certificate examination papers in nine subjects (English, Irish French, Latin, History, Geography, Mathematics, Physics and Chemistry), they set about to determine the reliability of the Leaving Certificate marks and the types of intellectual activity for which the marks were awarded. In compiling their report, as well as accessing the subjects' syllabi, the Department of Education provided the authors with the 1967 LC markings scheme made available by the Department of Education (it was not until 2003, with the establishment of the State

Examinations Commission, that marking schemes were publicly available). a select number of already marked student answer booklets - twelve booklets per level per subject being analysed. Copies of textbooks considered to be widely used in schools (it was a long-standing agreement that teachers were free to decide themselves on which text-book, if any, to use. Commercially available revision-type books which students often preferred over textbooks.

The importance of the reliability of marks related to the purpose for which marks were used. In addressing the question of reliability, the authors found the marking schemes were 'neither very explicit nor very complete'(p.12). Using the supplied marked answer booklets, Madaus and Macnamara examined how the correctors of the examinations applied the marking schemes rather than evaluating the marks assigned to the different questions. They concluded that the awarding of marks was unreliable due to the general nature of the questions and the associate marking schemes and that correctors were permitted to exercise some discretion (Macnamara and Madaus, 1969). They noted that this unreliability was evident in marking schemes of mathematics (and, by extension, mathematical problems in physics and chemistry). The marking schemes included deducting a range of marks in case of blunders or omissions leaving it to the markers to decide the degree of blunder, i.e. slips (-3), less serious blunders or omissions (-5), blunders or serious omissions (-10) a very serious blunder (loss of all marks) (p.17). There was no definition of these blunders to distinguish between the four. The tradition of awarding ' attempt' marks also contributed to the unreliability; there was no specific distinction between attempt marks and blunder marks. To lessen the effect of correctors' unreliability, the authors presented arguments for using multichoice questions. However, the principal focus of their research was on the types of intellectual/cognitive activity being assessed in the Leaving Certificate Examination at ordinary and higher levels. The authors used Bloom's *Taxonomy of Education Objectives* in classifying the cognitive demands, which they then matched to the allocated marks as laid down in the marking schemes. Considering the expected level of students' intellectual abilities for their age (17-18 years) and the materials available, applying the hierarchical structure of Bloom's taxonomy, each question was classified into the level of cognitive skill required. As the marking scheme was available to Madaus and Macnamara, the marks allocated to each question were included in the classification. Table 3.8 shows their findings for the higher-level physics examination. Most of the marks on the physics papers were allocated to three of the cognitive demands – knowledge (76%), comprehension (11%) and application (13%).

Table 3.8 Distribution of higher-level physics marks by question and taxonomic demand

Question No.	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation	Total marks
1	20		46				66
2	35	15	16				66
3	56		10				66
4	66						66
5	66						66
6	66						66
7	67						67
8	51		16				67
9	10	57					67
10	67						67
Total	504	72	88				664
Total %	76	11	13				

Although included in the analysis of the physics examinations, the following comment also encapsulated their overall analysis of the chemistry papers.

> *The emphasis …was on the recall of specific items of information. If knowledge of such items was the main purpose for studying physics, then the examinations have a high content validity. If, on the other hand, the courses were aimed at introducing students to the scientific method, if they were aimed at developing in students a general problem-solving ability which would transcend the details of their course and transfer to a wide range of problems in physics, then the examinations failed badly.* *(Madaus and Macnamara, 1970, page 99)*

Table 3.9 shows the findings for the higher-level chemistry examinations. A somewhat more expansive range of cognitive demands was classified on the chemistry paper – knowledge (69%), comprehension (21%), application (7%) and analysis (2%).

Table 3.9 Distribution of higher-level chemistry marks by question and taxonomic demand

Question No.	**Knowledge**	**Comprehension**	**Application**	**Analysis**	**Synthesis**	**Evaluation**	**Total marks**
1	66						66
2	66						66
3	6	60					66
4	66						66
4 (alt.)	66						66
5	48			18			66
6	39	15	12				66
7	15	27	25				67

7 (alt)	67						67
8		67					67
9	67						67
10	46		21				67
Total	552	169	58	18			797
Total %	69	21	7	2			

Likewise, the criticism levelled against the chemistry examinations equally applied to physics –

> *We cannot confidently answer…how well the chemistry examinations sample the course objectives (content validity) because the course objectives have not been stated clearly enough in the syllabus….questions worded so vaguely …expressions such as discuss, describe, give an account, unbacked by very explicated directions are as capable of as many interpretations as there were students.*
>
> (Madaus and Macnamara, 1970, p.106)

It was nearly forty years later before a similar study was undertaken. Using Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis and evaluation), McCrudden identifies the level of questioning in LC chemistry papers from 2000-2008 (McCrudden and Finlayson, 2009). The findings, based on a study of nine higher-level chemistry papers, showed the percentage of knowledge questions ranging from 74.4% (2001) to 82.5% (2008), comprehension decreasing from 40% (2000) to 20.4% (2008); application questions, on the other hand, were higher varying between 12% (2000) and 32%(2008); the percentage of analysis type questions ranged from a high of 25.6% (2001) to a low of 17.5% (2008). As in the Madaus & Macnamara study, there were no questions addressing the evaluation and synthesis demand in any of the nine papers of the study (p. 39-40). In 2016, Cullinane and Liston used Bloom's taxonomy to review the cognitive demands of Leaving Certificate Biology examinations for 1999-2008 (Cullinane and Liston, 2016). This period included examinations based on two different syllabi allowing a comparison between the demands of syllabi. Five of the examination papers were based on the first syllabus (Syllabus 1) and five on the present syllabus (syllabus 2). Table 3.10 compares the average changes in the cognitive demands of examinations based on the two syllabi. Of interest is the third column which shows the average percentage increase /decrease frequency of marks per cognitive demands of papers based on syllabus 2. Two of the cognitive demands showed an increase in the percentage of marks allocated to knowledge (+13.47%) and analysis (+4.08), with the remaining four showing a decrease in the percentage of marks for comprehension (-12.48%), application (-3.46%), synthesis (-3.0%) and evaluation (-0.29%).

Table 3.10 Comparison of five-year average percentage frequency of marks per cognitive demands of LC Biology based on two syllabi -adapted from Cullinane & Lister, p. 258

	Syllabus 1 (Papers 1999-2003)	Syllabus 2 (Papers 2004-2008)	Percentage change in cognitive demand of syllabus 2
Knowledge	41.9%	55.37%	**+ 13.47%**
Comprehension	39.95%	27.46%	-12.48%
Application	12.58%	9.12%	-3.46%
Analysis	4.32%	8.40%	**+4.08%**
Synthesis	0.73%	0.43%	-3.0%
Evaluation	0.50%	0.21%	-0.29%

A fourth study by Burns et al. focused on 23 subjects of the Leaving Certificate examinations (Burns *et al.*, 2018). Unlike the previous three studies, the authors presented their findings within the Revised Bloom Taxonomy framework in terms of the distribution of intellectual demands and the knowledge domains. Using the software programme, *Sketch Engine*, to build a corpus of command verbs in context from the examination papers, the authors then used a combination of computational and manual analysis to assign values for each intellectual demand and knowledge domain to occurrences of these command verbs. Their findings for physics and chemistry are presented in Table 3.11

Table 3.11 Percentage distribution of intellectual demands and knowledge domains in physics and chemistry (Burns et al. pgs. 360,364)

Subject	**Intellectual demands as % of occurrences in the subject**					
	Remember	Understand	*Apply*	Analysis	Evaluate	Create
Physics	47.3	26.4	25.6	0.5	0.2	0
Chemistry	53.5	30.1	13.0	2.6	0.7	0.1
	Knowledge domain as % of occurrence in the subject					
	Factual	Cognitive	Procedural	Metacognitive		
Physics	49.9	17.0	33.1	0		
Chemistry	37.5	19.2	43.30	0		

While these four studies examined the cognitive demands of the Leaving Certificate questions, comparing them against each other was impossible. Madaus & Macnamara's study used the original Bloom's taxonomy (1956) to analysis the cognitive demands based on a single year's examination (1967); McCrudden also used the original Bloom's taxonomy terminology but analysed nine chemistry examination papers (1999-2008) which span two different syllabi to that in use in 1967; Burns et al. used software programme, SketchEngine (https://www.sketchengine.eu/), to filter command verbs used across ten years examinations in twenty-three subjects and utilised these to match the cognitive demands according to the Revised Bloom's Taxonomy.

3.6 Justification of Bloom's taxonomy as assessment of choice

The two research questions guided this thesis, namely

> *What were the cognitive demands of the higher-level physics and chemistry questions in Ireland's high-stakes Leaving Certificate examinations (1966-2016)?*
>
> *Were there similar ranges of cognitive demands in selected comparable high-stakes written physics and chemistry examinations in other countries as in the Irish Leaving Certificate examination in these subjects in 2016?*

The researcher was an experienced physics and chemistry teacher familiar with the syllabus and the examination system. Therefore the selected assessment approach had to satisfy two conditions. Firstly, the approach selected had to facilitate as far as possible the researcher not having to make a judgment call or seek a consensus. Secondly, this approach had to be equally applicable to both research questions.

Madaus and Macnamara used *Bloom's Taxonomy of Educational Objectives* (Bloom *et al.*, 1956) to assess the 1967 Leaving Certification examinations. Since the publication of their work in 1970, several assessment models have been developed. The researcher reviewed five of them, including Bloom's taxonomy, before deciding which would best address both research questions.

Webb's Evaluation model used a complex system based on five categories to measure the alignment of standards and assessment. Of interest for this study was the subcategory of Depth of Knowledge (Figure 3.5), with its hierarchical structure of levels of complexity in thinking involved. According to Hess, cojoining the Revised Bloom's Taxonomy with Webb's DOK focused on deepening the learning process within the classroom rather than on the rigours of examination questions.

Porter's evaluation model centred on determining the degree of alignment of two components through a formulaic treatment. For example, between the cognitive demands of a topic assessed in an examination and the cognitive demands of the standards/syllabus. However, alignment was not the focus of the research question,

SOLO is more suited as a review or a guide to pedagogical tools rather than an independent analysis of examinations. It is not suitable for high-stakes examinations based on a nationwide curriculum.

That Bloom's revised taxonomy and the original Bloom's taxonomy are more useful was evident in the large number of studies on alignment, which used these taxonomies as the methodology tool. As well as providing a framework within which to assess the alignment of the examinations with associated curricula, the Revised Bloom taxonomy can facilitate the comparison of the cognitive demand demands of high-stakes examinations of different education systems (Anderson, 2002, 2012; Jones *et al.*, 2009; Liu *et al.*, 2009; Krathwohl and Anderson, 2010).

The Revised Bloom's taxonomy, including action-verbs as the metric tool, addressed both conditions listed. How these action-verbs were used in determining the cognitive demands of the LC physics and chemistry examinations questions and the cognitive demands of the international physics and chemistry examinations is detailed in Chapter 4.

Chapter 4 Methodology

4.1. Introduction

This research examines the cognitive demands of the higher-level physics and chemistry Leaving Certificate examinations between 1966 and 2016 through the lens of document analysis of the examination questions to address the research question

- *What were the cognitive demands of the higher-level physics and chemistry Leaving Certificate examination questions from 1966 to 2016?*

In addition

- *Were there similar ranges of cognitive demands in selected comparable high-stakes written physics and chemistry examinations in other countries as in the Irish Leaving Certificate examinations in these subjects?*

A two-study approach was adopted using the Revised Bloom's taxonomy as the framework. The first study (reported in Chapter 5) focused on the cognitive demands of the questions presented in Ireland's Leaving Certificate physics and chemistry examination papers from 1966 to 2016. The second study (reported in Chapter 6) compared the cognitive demands of the 2016 higher-level L.C. physics and chemistry examinations with similar examinations in five other countries (England, the Netherlands, New South Wales, Scotland and South Africa). This comparison included examining both the cognitive demands of similar topics across the six countries and the balance between the percentage of question parts and the percentage of marks as allocated to the question-parts

Section 4.2 explains the selection of Bloom's taxonomy as the framework of choice, with the cognitive demand levels defined via the action verbs used in the Irish and International examinations. Section 4.3. details the coding system applied in determining the cognitive demands of the Irish Leaving Certificate(LC) and the selected International examinations.

4.2. Selection of methodology

As the researcher had previously taught all three syllabi and was familiar with the L.C. examinations, the selected methodology needed to satisfy two conditions-

(a) address bias on the part of the research by facilitating, as far as possible, the researcher not having to make a judgment call or arrive at a consensus when determining a cognitive demand of a question

(b) the selected methodology also needed to be equally applicable in determining the cognitive demands of the L.C. and the International examinations.

In 1970, Madaus and Macnamara studied the Irish Leaving Certification examinations within *Bloom's Taxonomy of Education Objectives: Handbook 1, the cognitive domain* framework (Bloom *et al.*, 1956; Madaus and Macnamara, 1970). However, their study focused on a single year's results, 1967, with the authors giving access to material not publicly available, the marking scheme used, and a limited number of student examination answers already marked ((Madaus and Macnamara, 1970, pp. 28–29). Moreover, the format of Bloom's taxonomy(Table 3.1) used did not permit a direct interrogation of examination questions; instead, the allocation of the cognitive demand was at the discretion of the raters who

> *attempted to determine, from their experience of students and from materials supplied to them, at a level at which most students would have functioned in answering a particular question.*
>
> (Madaus and Macnamara, 1970, p. 28)

Several possible approaches or methodologies were reviewed in Section 3.3.such as

- Webb's model uses a complex evaluation system based on five categories to measure the alignment of standards and assessment. Of interest for this study is the subcategory of Depth of Knowledge (Figure 3.5), with its hierarchical structure of levels of complexity in thinking involved. However, Webb's DOK focuses on the depth of students' learning rather than the difficulty of examination questions. Hess' Cognitive Rigour (CR) Matrix incorporating Bloom's Revised Taxonomy with Webb's DOK (Table 3.5) deepens the learning process. Both Webb's DOK and Hess' CR focus on the learning process within the classroom rather than on the rigours of the examination questions.
- Porter's evaluation model is a formulaic treatment of the alignment of the examination with standards (Table 3.6). The researcher's study was to focus solely on the examination questions without referencing the standard/syllabus.
- SOLO is more suited as a review or guide to pedagogical tools rather than an independent analysis of examinations. It is not suitable for high-stakes examinations based on a nationwide curriculum.

Bloom's taxonomy, specifically the revised taxonomy with the inclusion of action-verbs as the metric, fulfilled the conditions (a) and (b) listed above. A list of action-verbs was drawn up before being applied to the examination questions.

4.2.1 Compiling of Action Verbs for use with the Irish Leaving Certificate Examinations**.**

Since 2003, the State Examinations Commission (SEC) has managed all aspects of the State's education examinations in Ireland. These comprise the established Leaving Certificate, Leaving Certificate Vocational Programme, Leaving Certificate Applied, and the Junior Certificate Examinations. The SEC publication, *A Manual for Drafters, Setters and Assistant Setters* (State Examinations Commission, 2007), states the cognitive domain of Bloom's taxonomy as being

> *the one most usually drawn upon in formulating questions in a written examination. The cognitive domain involves knowledge and the development of intellectual demands. This includes the recall or recognition of specific facts, procedural patterns and concepts that serve in the development of intellectual abilities and demands. An assessment grid should chart a progression through questions that elicit the lower-order demands of knowledge, comprehension and application to those that additionally require the higher-order demands of analysis, synthesis and evaluation as appropriate to the subject and level.*
>
> (State Examinations Commission, 2007, p. 49)

The manual includes a chart (Figure 4.1.) showing the connections between these domains and question cues through exemplars. The researcher, therefore, decided that this chart was an appropriate aid for mapping the cognitive demands of the L.C. physics and chemistry examinations as it included typical command words, i.e. the action- verbs which the setters should use. However, the researcher decided to use the Revised Bloom's Taxonomy terminology of remember, understand, apply, analyse, evaluate and create instead of those used by the SEC – knowledge, comprehension, application, analysis, synthesis and evaluate.

Level	Learner Ability/Action	Typical Command Words		Typical Question Cues	
Knowledge (recall and recognition)	Simple recall of previously learned material Remembering, Memorising, Recalling identification	• List, • Define • Label • Identify/Name • Draw	• Find • Match • Recite • Mention • Describe	Which one? What is the best one? Who, what, when, where, how?	• How much? • What does it mean?
Comprehension (translating, interpreting and extrapolating)	Ability to make sense of the material. Restate in own words; recognise previously unseen examples of a concept; grasp meaning.	• Describe • Associate • Categorise • Summarise • Translate • Retell	• Demonstrate • Identify • Paraphrase • Report • Discuss • Interpret	State in your own words Give an example What seems to be? Which statements support this? Is this the same as? explain	• What do you think he meant when he said? • Show in a graph/table • What part doesn't fit? • Select the best definition? • Which is the odd one out?
Application (to situations that are new to, or have a new slant for students	Ability to use learned material in a new situation with a minimum amount of help or direction. Apply rules /principles to a problem, without being given the rule; problem-solving	• Apply/use • Demonstrate • Calculate/compute • Illustrate • Solve	• Dramatise • Role-play • Select • Show	,Predict what would happen if What would result? Identify the results of According to our definition of…which of the following would be considered to be?	• How is…an example? • How much change would there be? • Why is…significant? • Judge the effects
Analysis (breaking down into parts, forms)	Break material into component parts so that its structure may be understood. Break complex concepts down to component parts and analyse how parts are related to each other; seeing patterns, recognising hidden meanings	• Analyse • Compare/Contrast • Separate • Order/Classify • Explain • Characterise	• Develop • Distinguish • Examine • Outline • Debate • Deduce	What assumptions Make a distinction What is the relationship between? What conclusions What state is relevant What evidence can you list for…?	• What ideas justify conclusion? • What does the author believe, assume? • Stae the point of view • What is fact, opinion? • Implicit in the statement is • What is the function of?
Synthesis (combining elements into a pattern not clearly there before)	Put parts together to form a plan new to the learner; generalise. Rearrange component parts to form a new whole; may be in verbal form or a physical form	• Combine • Modify • Rearrange • 'What-if' • Generalise • Construct	• Create • Design/plan • Develop • Propose • Formulate • make	How would you test? Propose an alternative How else would you? What would you infer/predict from?	• Solve the following • State a rule
Evaluation (according to some set of criteria, and state why)	Ability to judge the value of material based on certain criteria. Evaluate, make judgements of the worth of a concept for a purpose; resolve controversies/ differences of opinion…verify value of evidence	• Assess • Decide • Grade/rank • Recommend • Explain • Judge • Conclude • Summarise	• Argue • Convince • Conclude • Justify • Support • Predict • Prove • Select/choose	What is more important, moral, logical, valid appropriate What fallacies, consistencies, inconsistencies appear	• Find the errors

Figure 4.1 Extract of Questions Cues and Bloom's Taxonomy from Manual for Drafters, Setters and Assistant Setters pg.98-99

A preliminary coding process was conducted with a sample of three LC examination papers from the three physics and chemistry syllabi (Table 4.1). N represents the total number of questions per subject per syllabus.

Table 4.1 Sample of LC Examinations for a preliminary coding process

Representative of Syllabus 1	Representative of Syllabus 2	Representative of Syllabus 3
1966, 1967, 1968	**1986.1987,1988**	**2006, 2007, 2008,**
$N_{physics}$ **= 34:** $N_{chemistry}$ **= 30**	$N_{physics}$ **= 39:** $N_{chemistry}$**= 30**	$N_{physics}$ **= 48:** $N_{chemistry}$ **= 44**

This exercise highlighted two aspects of the SEC list of action-verbs used,

(a) the omission, in the SEC list, of some action-verbs frequently used in the examinations, such as **State**
i.e. *State Newton's second law of motion* *(Physics, 1966, Question 1);*
State one important way carbon dioxide is constantly added to the atmosphere (Chemistry, 2007, Question 11)

(b) the occurrence of some action-verbs in more than one cognitive demand level that is, the action-verb **identify** was listed under the *Remember* and *Understand* cognitive demand categories.

In order to forestall a recurrence of other omissions, a second longer list of action-verbs (Revised Bloom Taxonomy), based on work by Anderson and Krathwohl (Anderson *et al.*, 2001), was drawn up beside the SEC list in Figure 4.2.

In the event of an action-verb being in more than one cognitive demand level, in consultation with other experienced teachers of the subjects, the context of the question was investigated to decide which cognitive demand level was applicable.

Remember		Understand		Apply		Analyse		Evaluate		Create	
SEC	**Revised Bloom's taxonomy**	***SEC***	**Revised Bloom's taxonomy**	***SEC***	**Revised Bloom's taxonomy**	**SEC**	**Revised Bloom's taxonomy**	**SEC**	**Revised Bloom's taxonomy**	**SEC**	**Revised Bloom's taxonomy**
Define	Define	*Demonstrate*	Demonstrate	*Apply*	Apply	*Analyse*	Analyse	*Appraise*	Appraise	*Combine*	Combine
Find	Find	*Explain…*	Explain	*Select*	Select	*Classify*	Classify	*Assess*	Assess	*Compose*	Compose
Label	Label	*Interpret*	Interpret	*Solve*	Solve	*Compare*	Compare	*Choose*	Choose	*Construct*	Create
List	List	*Show…*	Show	*Calculate*	Build	*Contrast*	Contrast	*Conclude*	Conclude	*Design*	Design
Match	Match	*Summarise*	Summarise	*Compute*	Choose	*Distinguish*	Distinguish	*Decide*	Decide	*Develop*	Develop
Name	Name	*Translate*	Translate	*Demonstrate*	Construct	*Examine*	Examine	*Explain*	Explain	*Formulate*	Formulate
What?	What	*Associate*	Classify	*Dramatise*	Develop	*Characterise*	Assume	*Judge*	Judge	*Make*	Make up
Where?	Where	*Categorise*	Compare	*Illustrate*	Experiment with	*Debate*	Categorise	*Justify*	Justify	*modify*	Modify
Who?	Who	*Describe*	Contrast	*Role-play*	Identify	*Deduce*	Conclusion	*Prove*	Prove	*Plan*	Plan
Describe	Choose	*Discuss*	Extend	*Show*	Interview	*Develop*	Discover	*Recommend*	Recommend	*Propose*	Propose
Draw	How	*Identify*	Illustrate	*Use*	Make use of	*Explain*	Dissect	*Select*	Select	*Create*	Adapt
Identify	Omit	*Paraphrase*	Infer		Model	*Order*	Divide	*Support*	Support	*Generalise*	Build
Mention	Recall	*Report*	Outline		Organise	*Outline*	Function	*Argue*	Agree	*Rearrange*	Change
Quote	Relate	*Retell*	Relate		Plan	*Separate*	Inference	*Convince*	Award	*What if*	Choose
Recite	Select	*Select…*	Rephrase		Utilise		Inspect	*Grade*	Compare		Compile
How?	Show	*State…*					List	*Predict*	Criticise		Construct
	Spell						Motive	*Rank*	Deduct		Delete
	Tell						Relationships	*Summarise*	Defend		Discuss

Figure 4.2 List of action- verbs from SEC Manual and list of action verbs associated with Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001)

4.2.2 Compiling of action-verbs for use in the six International Examinations.

The set of action verbs used to analyse the Irish examinations was based on the SEC/Revised Bloom's Taxonomy list Chart (Section 4.1.1), the first referent. Rather than use this set of action verbs to analyse International examinations, a separate set was compiled for this second analysis. As Ireland was one of the six countries in this second analysis, the researcher considered it would make for a better-balanced comparison if all six examinations were coded according to a separate set of action-verbs. A new set of action verbs was compiled from two independent studies; one by Stanny and one by Newton et al. (Stanny, 2016; Newton, DaSilva and Peters, 2020). Stanny analysed thirty lists of action verbs posted on websites (primarily USA based) in the light of their alignment to the different cognitive demand levels of both Bloom's Original Taxonomy and the Revised Bloom's Taxonomy. The author reduced the collection to 433 verbs, of which 236 appeared in only one category. Figure 4.3 is a sample list of these action verbs. The columns marked *f* indicate the frequency of occurrence of that action verb in the specified cognitive demand level in Stanny's final list. For example, twenty-eight of the lists analysed by Stanny assigned the action-verb 'explain' to the *Understand* category, indicating this action-verb occurred in twenty-seven of the thirty of the analysed list.

Remember	***f***	**Understand**	***f***	**Apply**	***f***	**Analyse**	***f***	**Evaluate**	***f***	**Create**	***f***
list	27	**explain**	28	use	25	Analyse	24	judge	25	construct	29
recall	24	describe	22	apply	22	compare	24	appraise	22	design	24
state	23	paraphrase	22	demonstrate	20	distinguish	21	rearrange	19	arrange	22
name	22	discuss	21	act	19	differentiate	20	compare	18	organise	21
define	21	translate	21	solve	19	categorise	19	assess	17	plan	21
label	21	summarise	20	organise	17	contrast	19	evaluate	16	rate	21
identify	20	classify	18	sketch	17	examine	18	synthesise	16	compose	19
repeat	20	express	17	dramatise	16	relate	17	defend	15	create	19
cite	17	interpret	17	employ	16	infer	14	estimate	15	develop	18
select	16	infer	15	interview	15	test	14	manage	15	formulate	18
describe	14	restate	15	practice	15	diagram	12	set up	15	write	17
match	14	review	15	construct	13	divide	12	critiques	14	assemble	14
recognise	14	identify	14	produce	13	point out	12	conclude	13	combine	14
record	13	convert	13	show	13	question	12	argue	12	devise	13
recite	12	defend	12	operate	12	select	12	prepare	12	produce	13

outline	11	distinguish	12	relate	12	appraise	11	reconcile	12	prepare	12
relate	11	predict	12	choose	11	criticise	11	criticise	11	revise	12
reproduce	11	rewrite	12	prepare	11	discriminate	11	choose	10	generate	11
locate	10	compare	11	schedule	11	classify	10	discriminate	9	invent	10
memorise	10	estimate	11	calculate	10	outline	10	explain	9	modify	10
quote	7	extend	11	compute	10	separate	10	mediate	9	collect	9
duplicate	7	generalise	11	modify	10	subdivide	10	supervise	9	originate	9
underline	7	recognise	11	change	9	calculate	9	verify	9	propose	9
arrange	6	locate	10	predict	9	experiment	9	contrast	8	reconstruct	9
order	5	report	10	discover	8	inventory	9	invent	8	reorganise	9
draw	5	illustrate	9	implement	8	break	8	test	8	specify	9
write	5	differentiate	8	classify	6	debate	8	value	7	explain	8
tabulate	4	select	7	generalise	5	identify	7	select	5	categorise	7

Figure 4.3 Sample list of action verbs from ‘Re-evaluation Bloom’s Taxonomy’ (Stanny, 2016).

The second study, by Newton et al.(2020), used Stanny’s study as a springboard to compile a similar list based on thirty-five publicly available education resources and textbooks used in U.K. universities (Newton, DaSilva and Peters, 2020). The authors’ final list of 401 distinct action verbs was filtered from forty-seven separate lists of action verbs, of which 251 appeared in only one of the categories. Figure 4.4 is a sample of the final list of action verbs with the frequency of occurrence, f, of that action-verb in the specified cognitive as determined by Newton et al.

Remember	**f**	**Understand**	**f**	**Apply**	**f**	**Analyse**	**f**	**Evaluate**	**f**	**Create**	**f**
List	**43**	**Explain**	**43**	**Demonstrate**	**36**	**Compare**	**38**	**Design**	**24**	**Judge**	**25**
Define	**42**	**Discuss**	**36**	**Use**	**36**	**Differentiate**	**38**	**Modify**	**24**	**Assess**	**24**
Name	**35**	**Translate**	**32**	**Solve**	**33**	**Contrast**	**36**	**Compose**	**23**	**Appraise**	**22**
Recall	**32**	**Classify**	**28**	**Operate**	**32**	**Distinguish**	**34**	**Plan**	**21**	**Evaluate**	**22**
Describe	**29**	**Summarise**	**28**	**Apply**	**29**	**Analyse**	**29**	**Construct**	**20**	**Rate**	**19**
Identify	**28**	**Identify**	**27**	**Illustrate**	**23**	**Examine**	**27**	**Formulate**	**20**	**Compare**	**18**
State	**28**	**Describe**	**25**	**Sketch**	**23**	**Question**	**25**	**Argue**	**18**	**Design**	**17**
Label	**25**	**Paraphrase**	**23**	**Interpret**	**22**	**Relate**	**24**	**Judge**	**17**	**Develop**	**16**
Repeat	**24**	**Predict**	**23**	**Compute**	**20**	**Categorise**	**22**	**Appraise**	**16**	**Justify**	**16**
Recognise	**23**	**Locate**	**22**	**Prepare**	**20**	**Produce**	**22**	**Defend**	**16**	**Conclude**	**15**
Match	**21**	**Report**	**22**	**Choose**	**19**	**Appraise**	**19**	**Organise**	**15**	**Formulate**	**14**
Select	**20**	**Interpret**	**20**	**Employ**	**19**	**Criticise**	**19**	**Combine**	**14**	**Construct**	**13**

Memorise	**19**	**Match**	**20**	**Relate**	**19**	**Separate**	**19**	**Revise**	**14**	**Criticise**	**13**
Relate	**18**	**Recognise**	**20**	**Change**	**18**	**Infer**	**18**	**Select**	**14**	**Revise**	**13**
Duplicate	**15**	**Extend**	**19**	**Practice**	**18**	**Test**	**18**	**Support**	**14**	**Choose**	**12**
Reproduce	**15**	**Distinguish**	**18**	**Produce**	**17**	**Outline**	**17**	**Develop**	**13**	**Discriminate**	**12**
Outline	**14**	**Estimate**	**18**	**Schedule**	**17**	**Calculate**	**16**	**Generate**	**13**	**Estimate**	**12**
Present	**12**	**Select**	**18**	**Show**	**17**	**Discriminate**	**16**	**Summarise**	**13**	**Modify**	**12**
Quote	**10**	**Convert**	**17**	**Dramatise**	**16**	**Identify**	**15**	**Critique**	**12**	**Support**	**12**
Underline	**10**	**Infer**	**17**	**Modify**	**16**	**Diagram**	**14**	**Manage**	**12**	**Argue**	**11**
Recite	**9**	**Restate**	**17**	**Predict**	**16**	**Break Down**	**13**	**Relate**	**12**	**Defend**	**11**
Tell	**9**	**Generalise**	**15**	**Construct**	**14**	**Illustrate**	**13**	**Arrange**	**11**	**Plan**	**11**
Arrange	**8**	**Review**	**15**	**Discover**	**14**	**Point Out**	**13**	**Assemble**	**11**	**Write**	**11**
Find	**8**	**Give Example**	**14**	**Manipulate**	**13**	**Select**	**13**	**Collect**	**11**	**Predict**	**10**
Order	**8**	**Compare**	**13**	**Implement**	**12**	**Classify**	**11**	**Conclude**	**11**	**Assemble**	**9**
Locate	**7**	**Indicate**	**13**	**Calculate**	**8**	**Subdivide**	**11**	**Devise**	**11**	**Compose**	**9**
Write	**6**	**Defend**	**12**	**Classify**	**8**	**Debate**	**10**	**Explain**	**11**	**Contrast**	**9**
Enumerate	**5**	**Contrast**	**11**	**Execute**	**8**	**Organise**	**10**	**Value**	**11**	**Modify**	**9**
Know	**5**	**Illustrate**	**11**	**Reframe**	**8**	**Deduce**	**9**	**Propose**	**10**	**Summarise**	**9**
Copy	**4**	**Rewrite**	**10**	**Complete**	**7**	**Conclude**	**8**	**Rearrange**	**10**	**Invent**	**8**

Figure 4.4 Sample list of action verbs from A Pragmatic Master List of Action Verbs - Newton et al. 2020

Combining the action verbs from Stanny's list and Newton et al. list, a master sheet of action verbs was compiled for this study (Figure 4.5). A limitation of using such lists is the occurrence of action verbs in more than one cognitive category (Pugh and Gates, 2021). To anticipate this, the researcher, having compiled the final list of action verbs to be used with the six International examination papers, searched the frequency of their occurrence in the final master sheet. As highlighted in Figure 4.5, eight such verbs (describe, explain, identify, illustrate, predict, show, calculate and write) were identified.

Remember		Understand		Apply		Analyse		Evaluate		Create	
Newton et al.	Stanny	Newton et al.	Stanny	Newton et al.	Stanny	Newton et al.	Stanny	Newton et al.	Stanny	Newton et al	Stanny
Acquire	Arrange	Discuss	Articulate	Act	Act	Analyse	Analyse	Appraise	Appraise	Adapt	Arrange
Arrange	Choose	Annotate	Associate	Act Out	Adapt	Adapt	Appraise	Rate	Argue	Animate	Assemble
Extract	Cite	Arrange	Characterise	Actuate	Apply	Advertise	Break	Adapt	Arrange	Appraise	Categorise
Favour	Copy	Associate	Cite	Administer	Back	Appraise	Test	Alter	Assess	Argue	Choose
State	Define	Determine	Clarify	Apply	Calculate	Arrange	Calculate	Anticipate	Attach	Arrange	Collect
Choose	Describe	Observe	Classify	Arrange	Change	Assemble	Categorise	Argue	Choose	Assemble	Combine
Collect	Draw	Categorise	Compare	Articulate	**Choose**	Associate	Classify	Arrange	Compare	Assess	Compile
Complete	Duplicate	Change	Contrast	Assess	Classify	Assumption	Compare	Assemble	Conclude	Improve	Compose
Copy	example	Chart	Convert	Build	Complete	Attribute	Conclude	Assess	Contrast	Attach	Construct
Count	Indicate	Cite	Defend	**Calculate**	Compute	Select	Contrast	Associate	Core	Categorise	Create
Define	Label	Clarify	Organise	Carry Out	Construct	**Calculate**	Correlate	Attach	Counsel	Organise	Design
Describe	List	Classify	Describe	Change	Produce	Catalogue	Group	Award	Create	Build	Develop
Detect	Locate	Comment	report	Chart	Develop	Categorise	Debate	Buildup	Criticise	**Write**	Devise
Know	Match	Compare	Discuss	Choose	Discover	Classify	Deduce	Categorise	Critiques	Change	Estimate
Discover	Memorise	Compile	Distinguish	**Show**	**Predict**	Collect	Detect	Check	Decide	Choose	Evaluate
Draw	Name	**Show**	Estimate	Collect	Employ	Combine	Diagnose	**Explain**	Defend	Collaborate	**Explain**
Draw On	Order	Explore	**Explain**	Complete	Experiment	Compare	Diagram	Collaborate	**Describe**	Collect	Facilitate
Duplicate	Outline	Conclude	Express	Compute	**Explain**	Compose	Manage	Collect	Design	Combine	Formulate
Elaborate	Quote	Contrast	Extend	Conduct	Generalise	Infer	Discover	Combine	Determine	Write	Generalise
List	Read	Convert	Extrapolate	Construct	**Identify**	Conclude	Assume	Comment	Support	Modify	Generate
Examine	Recall	Defend	Generalise	Contribute	**Illustrate**	Conclusion	Dissect	Judge	Estimate	Plan	Originate
Find	Recite	Delineate	Give	**Write**	Implement	Connect	Distinguish	Compare	Criteria	Compile	Improve
Highlight	Recognise	Find	**Predict**	Review	Interpret	Construct	Divide	Compile	Judge	Compose	Integrate
Indicate	Record	**Describe**	**Identify**	Design	Interview	Contrast	Evaluate	Comply	Grade	Conclude	Invent
Measure	Relate	Example	**Illustrate**	Determine	Manipulate	Correlate	Examine	Compose	Invent	Criticise	Make
Order	Draw	Estimate	Give example	Develop	Sketch	Identify	Explain	Manage	Weigh	Decide	Contrast
Place	Extend	Change	Observe	**Explain**	Select	Translate	Identify	Determine	Grade	Compare	Plan
Outline	Record	Comment	Match	Sketch	Use	Prepare	Predict	**Describe**	Connect	Derive	Specify
Present	Recall	Describe	Relate	Modify	Illustrate	Include	Calculate	Generate	Consider	Discover	Devise

Figure 4.5 Master list of action-verbs for the determination of cognitive demands of International examinations

Using Krathwohl's definition of each of the cognitive demands, a supplementary list (Figure 4.6) of these eight action-verbs was compiled to include the verbs' meaning (Krathwohl, 2002, p. 5)

Remember	Understand	Apply	Analyse	Evaluate	Create
		Calculate (mathematical calculations)	Calculate (organising)		
Describe (recalling)	Describe (explaining)			•Describe (judgement using criteria)	
	Explain (meaning of terms)	Explain (a procedure)		•Explain (judgment using criteria)	Explain (generating original view)
	•Identify (denoting)	•Identify (procedure)			
	•Illustrate (meaning)	•Illustrate (a procedure)			
	•Predict (infer)	•Predict (results of procedure)			
	Show (meaning)	•Show (procedure)			
		•Write (procedural formulae)			Write (original views)

Figure 4.6 Supplementary list of eight action verbs common to cognitive domains

4.3. Method to determine cognitive demands of examinations.

The two sources of material for this research were -

(a) LC higher-level physics and chemistry examinations for the period 1966-2016, that is, 51 physics and 51 chemistry examination papers

(b) the 2016 high-stakes physics and chemistry examinations in England, Ireland, the Netherlands, New South Wales (NSW), Scotland and South Africa.

Figure 4.7 outlines the four-stage process used in determining the cognitive demands of both the LC and International examination papers. The purpose of this process was to provide, as far as possible, a clear, unambiguous objective pathway not open to a subjective interpretation by the researcher. Moreover, this process was equally applied to analysing the LC and 2016 International examination questions.

In Stage 1, all the question-parts were identified and recorded. The allocated marks to these question-parts were recorded in Stage 2. Using a pre-compiled list of action-verbs based on the revised Bloom's taxonomy, the focus of Stage 3 was on determining the cognitive demand level of the action -verbs of all the question-parts (as identified in Stage 1). In Stage 4, the marks allocated to the question-parts (from Stage 2) were used to calculate the total marks assigned to each cognitive demand level.

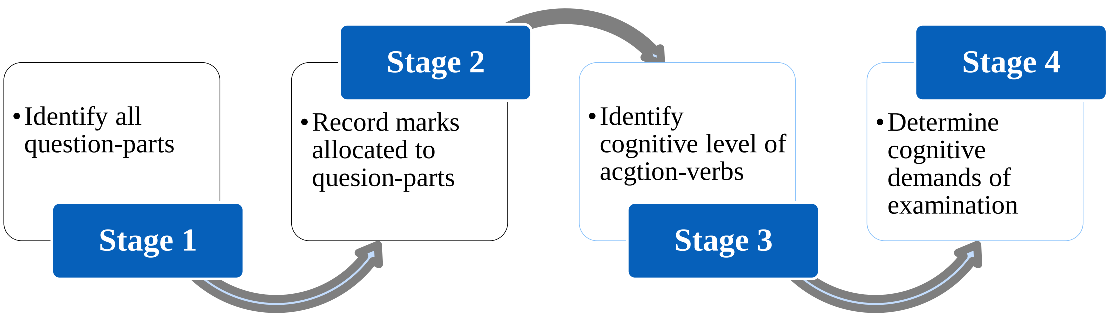


Figure 4.7 The process used in determining the cognitive demands of all the examinations

All the data obtained at each Stage was entered into an Excel spreadsheet. A more detailed account of applying this four-stage process to each LC examination paper (1966-2016) is provided in Section 4.3.1 and to the 2016 International examinations in Section 4.4.1.

4.3.1. Determining cognitive demands of Leaving Certificate examinations

The Irish physics and chemistry examination papers are freely available at https://archive.maths.nuim.ie/staff/dmalone/StateExamPapers/.

The following background material was available either in print form or online

- print-version of syllabi pre-2001 at Trinity Library, Dublin,
- post 2001 online versions of syllabi on the State Examinations Commission website.

The following textbooks (Figure 4.8) served as references when required.

	Physics textbooks	Author & Publishers	Chemistry textbooks	Author & Publishers
Syllabus P1	A modern course in physics: Mechanic & Heat: Light & Sound: Electricity, Magnetism & Atomic Physics	Con O'Donoghue: Fallon, 1970	Leaving Certificate: Chemistry	The Christian Brothers: Folens & Co. Ltd. Dublin (n.d.)
Syllabus P2	Fundamental Physics –(revised edition):	B. Casserly & B. Horgan: The Educational Company, 1990	Chemistry for Today	R.L.Henly: 3rd edition
Syllabus P3	Real World Physics	D. O'Regan: Folens, 2000	Chemistry Live	D. Kennedy: Folens, 2000

Figure 4.8 Background reference textbooks for Irish physics and chemistry syllabi.

The Leaving Certificate physics and chemistry papers have always been offered to students at ordinary and at higher-level. The introduction in 1969 of a 'points system' as the metric for obtaining access to third-level education resulted in most aspiring university students sitting the higher-level examinations in their chosen subjects. Consequently, in this study, only the higher-level examination papers in physics and chemistry were selected for analysis. All the Irish examination papers from 1966-2016 inclusive formed the non-probability sample data where the number of physics papers, N_p = 51 and the number of chemistry papers, N_c =51.

Compiling the cognitive demands data of the LC examinations

This section details the four-stage process (Figure 4.7) applied to the fifty-one LC physics and fifty-one LC chemistry examination papers for the 1966-2016 inclusive period.

- **Stage 1: Identifying and recording all question-parts**

The LC examination questions, be they physics or chemistry, have always been composed of several individual questions, usually called question-parts, as illustrated in Figure 4.9.

Leaving Certificate Physics Examination – 1998 Section B, question 7
In an experiment to determine the electrochemical equivalent of copper, a student passed a current of 0.4 A through a copper sulphate solution for 20 minutes. The mass of copper liberated from the solution in this time was found to be 0.14 g. **Calculate** the value for the electrochemical equivalent of copper, which would have been obtained by the student. (12)

Draw a circuit diagram for this experiment, labelling the anode and cathode.	(9)
Give the steps involved in finding the mass of copper liberated.	(9)
Using too large a current might have introduced an error into the value obtained for the mass of copper liberated. **Explain.**	(9)

Figure 4.9 Example of a question with four question parts

This question comprised four question-parts with the bracketed assigned mark. As question-parts were not always uniquely identified within the question (as in the example above), the researcher assigned each question-part with two identifiers: the question number and a lowercase Roman number, that is, 7(i), 7(ii), 7(iii) and 7(iv).

In instances where a question-part was composed of more than one part, that is, sub-question-parts, such as in Figure 4.10, an adjustment was made to identify these question-parts.

Leaving Certificate Chemistry Examination – 1998, Question 2 question part (ii)
2(ii) Name the indicator used when a solution of iodine is titrated against a solution of sodium thiosulphate. At what stage in the titration is the indicator added? What is the colour change at the endpoint in the presence of the indicator? (12)

Figure 4.10 Example of question-parts within a question-part.

In this case, a second lowercase Roman numeral was added; for example, the identifiers for the three (sub) question-parts were recorded as 2(ii)-i, 2(ii)-ii and 2(ii)-iii.

The following information was recorded on an Excel spreadsheet with the above questions in Figures 4.9 and 4.10 as exemplars.

Table 4.2 Sample Excel spreadsheet for recording examination question-parts(Stage 1)

Subject	**Year**	**Question no.**	**Question-parts**
Physics	1998	7	7(i)
			7(ii)
			7(iii)
			7(iv)
Subject	**Year**	**Question no.**	**Question-parts**
Chemistry	1998	2(ii)	2(ii)-i
			2(ii)-ii
		.	2(ii)-iii

- **Stage 2: Recording marks allocated to question-parts.**

Having identified and recorded all question-parts on an examination paper, the marks accorded to each were noted, as shown in Table 4.3. When question-parts were not individually allocated marks, such as in the example in Figure 4.10, these were allocated according to the examination marking scheme; the three sub-question parts were each allocated four marks.

Table 4.3 Sample Excel spreadsheet recording marks allocated to the question -parts(Stage 2)

Subject	Year	Question no.	Question - part	Marks/question-part
Physics	1998	7	7(i)	12
			7(ii)	9
			7(iii)	9
			7(iv)	9

Subject	Year	Question no.	Question - part	Marks/question-part
Chemistry	1998	2(ii)	2(ii)-**i**	4
			2(ii)-**ii**	4
			2(ii)-**iii**	4

Each question was allocated an overall mark in the LC examination papers for 1966-1984. While it was possible to identify separate parts in each question in these instances, there was no indication of how the overall mark would be split or weighted to the particular question-parts. Rather than eliminate these papers from the study, the researcher, in consultation with other experienced teachers and using later examination papers and marking schemes available for 2001-2016 as a model, reworked the marking system to assign proportion marks to each question.

- **Stage 3: Identifying the cognitive demand level of the action-verbs**

The schematic diagram in Figure 4.11 represents the systematic process used by the researcher to identify the cognitive demand level of the action-verbs. When determining the cognitive demand of a question, the action verb was matched firstly to the corresponding SEC list (Figure 4.2); if there was a match, the next question was whether the action -verb was in one cognitive level category or more than one. If in one cognitive level category, the matched action verb was identified to that category. On the other hand, should the action verb be matched in more than one category, the context of the question determines the category (Newton, DaSilva and Peters, 2020). If there was any ambiguity, the researcher consulted with several other experienced teachers in these subjects for a consensus view.

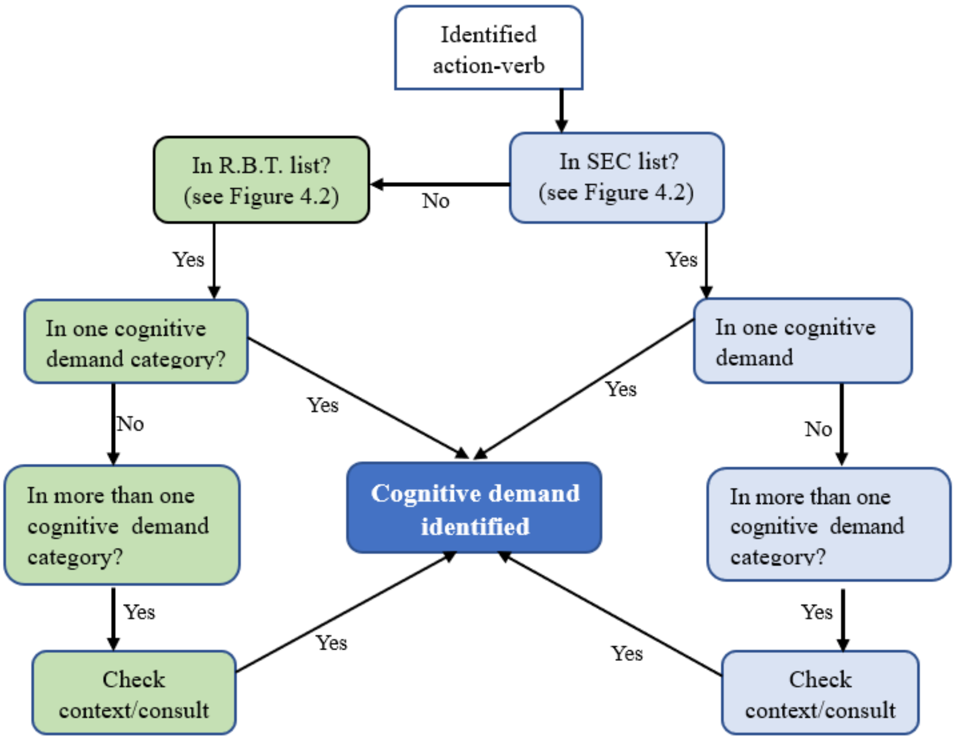


Figure 4.11 Schematic representation of the cognitive demand identification process(Stage 4)

In the case of no match with the SEC list match, the Revised Bloom Taxonomy list was then referenced. The subsequent process in identifying the cognitive demand of the matched action-verb mirrored the systematic process for the action-verb that matched the SEC process, as depicted in Figure 4.11. The Excel spreadsheet was extended to include the action-verbs and corresponding cognitive demand levels, as shown in Table 4.4.

Table 4.4 Sample Excel spreadsheet extended to include the cognitive demands levels of action-verbs at Stage 3

Subject	Year	Question	Question-part	Question-part marks	Action-verb	Cognitive demand
Physics	1998	7	7(i)	12	Calculate	Apply
			7(ii)	9	Draw	Remember
			7(iii)	9	Give steps…	Understand
			7(iv)	9	Explain	Analyse
Chemistry	1998	2(ii)	2(ii)-i	4	Name	Remember
			2(ii)-ii	4	At what Stage	Understand
			2(ii)-iii	4	What is…	Remember

- **Stage 4: Determining the cognitive demands of questions**

After identifying all the action-verb to their respective cognitive demand as described in Stage 3, the cognitive demand column was transposed to rows, as illustrated by the exemplar in Table 4.5.

Table 4.5 Sample spreadsheet of question-parts marks allocated to cognitive demands(Stage 4)

Subject	**Question & question -parts**		**Marks per question part**	**Remember**	**Understand**	**Apply**	**Analyse**
Physics	7	(i)	12			12	
		(ii)	9	9			
		(iii)	9		9		
		(iv)	9				9
Chemistry	2(ii)	2(ii)-i	4	4			
		2(ii)-ii	4		4		
		2(ii)-iii	4	4			

Table 4.6 represents the results of the four-stage process as applied to a completed set of questions on an examination paper. The final calculations represented the examination's overall cognitive demands. However, since the total mark per examination varied yearly, this final calculation was rewritten as percentages (as highlighted) to ensure fair comparisons between the examinations.

Table 4.6 Marks per question-part allocated to relevant cognitive demand for the examination paper.

Question No	**Question – parts**	**Total marks**	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***
1	(i)	6	6				
	(ii)	6	6				
2	(i)	24	3	6	3	3	
	(ii)				6	3	
	(iii)	15	6		9		
	(iv)	12		6		6	
3	(i)	12		3	6		3
	(ii)	12		6		6	
4	(i)	9	3		6		
	(ii)	6		6			
5	(i)	18		3	6	3	6
Total marks	(10 question-parts)	120	24	30	36	21	9
Percentage mark per cognitive demand			***20 %***	***25 %***	***30%***	***17.5%***	***7.5%***

Having applied the four-stage process to all the examinations, the Excel master sheet of the percentage marks per cognitive demand for all the examinations was drawn up. Table 4.7 is an extract of the master sheet[6] drawn up for the physics examinations 1966-2016.

[6] Completed master sheets -Appendix E (physics), Appendix F(chemistry)

Table 4.7 Extract of the master sheet showing percentage marks per cognitive demand.

Physics	Year	Total marks per examination	Remember	Understand	Apply	Analyse	Question-parts per examination
Syllabus 1	1966	994	55%	25%	18%	2%	68
	1967	730	73%	16%	11%	0%	49
	1968	730	69%	23%	9%	0%	51
	1969	729	34%	38%	19%	9%	54
	1970	726	32%	40%	19%	9%	52
	1971	819	18%	66%	16%	0%	56
	1972	756	28%	48%	19%	4%	57
	1973	750	42%	36%	22%	0%	57
	1974	756	24%	60%	9%	8%	60
	1975	756	15%	55%	13%	17%	57
	1976	756	26%	53%	20%	1%	67

The analysis of all the data compiled at the end of Stage 4 is presented in Chapter 5.

4.3.2. Determining the cognitive demands of International examinations.

The following criteria were applied in the selection of the International examinations,

- The Physics and chemistry syllabi upon which the examinations were based had to be comparable to those of the Irish Leaving Certificate physics and chemistry syllabi.
- The selected examinations were state-wide, standardised, designed, administered and certified by that state's educational authorities
- Examination papers, together with marking schemes, were to be publicly available.
- The examinations were to be written paper-based assessments with separate papers for physics and chemistry.

Six countries were selected based on these: England, Ireland, the Netherlands, New South Wales (NSW), Scotland, and South Africa. All the examination papers, marking schemes, and syllabi for England, the Netherlands, New South Wales, Scotland and South Africa were freely available on the respective countries' websites listed in Chapter 6. The online application, *DeepLTranslator* (*https://www.deepl.com/translator*) was used in translating all the material required from the Netherlands. No translation was necessary for the South African examinations as the Department of Basic Education, South Africa, published the English and Afrikaans versions of all materials required for the physics and chemistry examinations. The examination papers of the six countries formed the sample set where ${}_2N_p$ = 6 and ${}_2N_c$ = 6.

Compiling the cognitive demands data of the international examinations

Two aspects of the cognitive demands of the international examinations were to be considered. Firstly, the overall cognitive demands of the examination papers and, secondly, the cognitive demands of similar topics presented by the examinations. The four-stage process used in Section 4.3 would be sufficient to determine the overall cognitive demands of the examination but not the cognitive demands of similar topics. As described in Sections 6.3 and 6.4, a list of the physics and chemistry topics common to the six examinations was drawn up (Table 4.8).

Table 4.8 Topics common to the 2016 physics and chemistry examinations.

Physics	**Chemistry**
Newtonian physics	Periodic/Atomic structures
Heat	Chemical Bonding
Electricity	Chemical Equilibrium
Wave Motion	Volumetric Analysis
Radioactivity	Rates of Reaction
Electron	Organic Chemistry
Motors & Generators	Industrial Chemistry
	Electrochemistry

In order to address these two aspects while at the same time maintaining the same systematic process already used with the LC examinations, Stage 2 was amended to include the question's topic/s. This amendment did not materially influence the determination of cognitive demands. Rather, it allowed for a deeper interrogation of the International examinations.

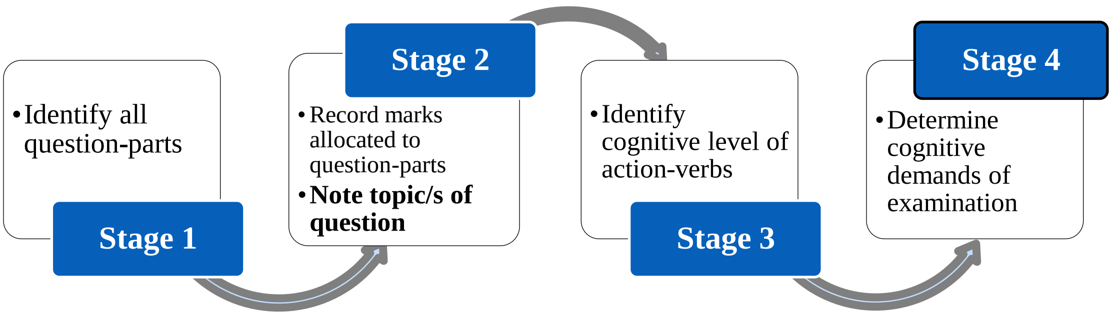


Figure 4.12 The amended process used in determining the cognitive demands of the International examinations

The same four-stage process, as described in 4.2.3, was applied to the international physics and chemistry examinations. Similarly, the data collected was entered into an Excel spreadsheet.

- **Stage 1: Identifying and recording all question-parts**

All the question parts were identified and recorded on an Excel spreadsheet. Except for Ireland, all the question-parts in the ten examinations were indicated. In the case of Ireland, when required, the researcher adopted the same process for assigning identifiers, i.e. the question number and a lowercase Roman number; thus, the four question-parts in Figure 4.13 were recorded as 5(c)-i, 5(c)-ii, 5(c)-iii, 5(c)-iv.

Leaving Certificate Chemistry Examination- 2016 Section B, question 5(c)
Atomic energy levels first described by Bohr are now known to contain energy sublevels and orbitals. Define an atomic orbital. Distinguish between a 2*p* orbital and a 2*p* sublevel. Write the *s*, *p* electron configuration for a calcium atom. Explain, in terms of energy sublevels, why the arrangement of electrons in the main energy levels in a calcium atom is 2, 8, 8, 2 and not 2,8,10. (17)

Figure 4.13 Example of a 2016 LC chemistry question with four parts.

- **Stage 2: Recording marks allocated to all question-parts**

The marks allocated to the question-parts in all the examinations were recorded on the Excel spreadsheet. In addition, the topic/s of the question or question- was recorded, as shown in

Table 4.9. This addition allowed for comparing the cognitive demands of similar topics across the six examinations.

Table 4.9 Sample Excel spreadsheet recording marks and topic of each question-parts(Stage 2)

Question No.	Question-part	Marks	Question-part marks	Topic/s
1	1(i)	24	12	Periodic/Atomic
	1(ii)		12	Bonding
2	2(i)	15	15	Equilibrium
	2(ii)	12	12	Rates of Reactions
3	2(1)	11	11	Organic chemistry

- **Stage 3: Identifying the cognitive demand level of the action-verbs**

Rather than re-apply the list of action-verbs (Figure 4.2.) previously used in the analysis of the Irish examinations, the researcher considered it a fair and better-balanced comparison if all six examinations were coded according to a separate set of action-verbs. Section 4.2.2. describes the compilation process of this set used in this Stage (Figure 4.5). Moreover, a supplementary list (Figure 4.6) was drawn up in anticipation of an action-verb being in more than one cognitive demand level.

The schematic diagram in Figure 4.13 represents the systematic coding process used during Stage 3. The identified action-verb in the question was matched to the Master List (Figure 4.5). The next step was to determine if it was in one cognitive demand category, and if so, then that action-verb was identified to that category. The supplementary list was referenced to identify the relevant cognitive demand when the action-verb matched in more than one category.

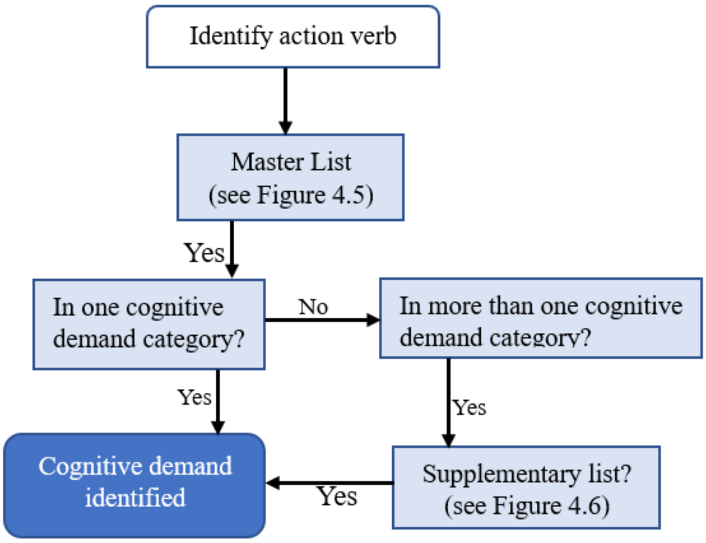


Figure 4.14 Schematic representation of the cognitive demand coding process for the 2016 International examinations

Table 4.10 shows the extended spreadsheet to include the associated action-verb and the corresponding cognitive demand category.

Table 4.10 Sample spreadsheet extended to include the cognitive demands levels of action-verbs(Stage 3)

Question No.	Marks	Question-part	Question-part marks	Topic/s	Action-verb	Cognitive demand
1	24	1(i)	15	Periodic/Atomic	Identify	Apply
		1(ii)	9	Bonding	Explain	Understand
2	15	2(i)	3	Equilibrium	State	Remember
		2(ii)	12	Rates of Reactions	Compare	Analyse
3	11	3(i)	11	Organic chemistry	Show	Apply

Stage 4: Determining the cognitive demands of the examinations.

The procedure previously described in Section 4.3.1 was similarly applied to the International examinations. With the Action verb category redundant, the final column, Cognitive demand, was transposed to match the allocated marks to the respective cognitive demand categories, as shown in Table 4.11. Again, due to the variation of the total marks of the examinations, the marks per cognitive demand (as highlighted) were recalculated as a percentage of the total marks[7].

Table 4.11 Sample spreadsheet of question-parts marks allocated to cognitive demands (Stage 4)

Question no.	Question parts	Marks	Topics	Remember	Understand	Apply	Analyse
1 (24)	1(i)	15	Periodic/Atomic			15	
	1(ii)	9	Bonding		9		
2 (15)	2(i)	3	Equilibrium	3			
	2(ii)	12	Rates of reaction				12
3(11)	3(i)	11	Organic Chemistry	4		7	
Total	5	50		7	9	22	12
Percentage of total marks per cognitive demand				**14%**	**18%**	**44%**	**24%**

With Table 4.11 as a guideline, the percentage of question-parts per cognitive demand was calculated as follows. Four of the five topics were coded for one category, while Organic chemistry was coded for two categories *(remember* and *apply).* The ratio of marks per cognitive demand to the marks allocated to that question-part was calculated. For example, for the topic Period Table, the ratio equals 1 (apply); for the topic Organic Chemistry, the ratios were 0.4 *(remember)* and 0.6 (*apply*). Table 4.12, with the ratio numbers entered in

[7] Coompleted data sheets in Appendices G (physics) and H (chemistry)

the respective cognitive categories, provided the means to analyse the percentage of question-parts per cognitive demand as highlighted.

Table 4.12 Calculating ratio of question-parts per cognitive demand.

Question no.	Question parts	Marks	Topics	Remember	Understand	Apply	Analyse
1(24)	1(i)	15	Periodic/Atomic			1	
	1(ii)	9	Bonding		1		
2(15)	2(i)	3	Equilibrium	1			
	2(ii)	12	Rates of reaction				1
3(11)	3(i)	11	Organic Chemistry	0.4		0.6	
Total	5			1.4	1	1.6	1
Percentage of total question-parts per cognitive demand				**28%**	**20%**	**32%**	**20%**

The shaded portion in Table 4.13 represents the percentage cognitive demand per topic; for example, topic Periodic/Atomic, cognitive demand *apply* was assigned 15 marks. As the total mark was 50, then the percentage cognitive demand a*pply* for Periodic/Atomic = 30%.

Table 4.13 Calculating the percentage cognitive demand per topic

Marks per question	Topics	Remember	Understand	Apply	Analyse	Remember	Understand	Apply	Analyse
15	Periodic/Atomic			15				30%	
12	Bonding		9				18%		
	Equilibrium	3				6%			
12	Rates of reaction				12				24%
11	Organic Chemistry	4		7		8%		14%	
Total marks= 50									

Table 4.14 is a representation of the data collected during Stage 4 to determine the cognitive demands of the international countries. The analysis of this data is described in Chapter 6.

Table 4.14 Example of a completed master sheet of all data compiled for an International Examination

				Marks per cognitive demand				**Question parts per cognitive demand**				**Percentage cognitive demand per topic**			
Question no(marks)	Question parts	Marks	Topics	Remember	Understand	Apply	Analyse	Remember	Understand	Apply	Analyse	Remember	Understand	Apply	Analyse
1 (24)	1(i)	15	Periodic/Atomic			15				1				30%	
	1(ii)	9	Bonding		9				1				18%		
2 (15)	2(i)	3	Equilibrium	3				1				6%			
	2(ii)	12	Reaction rates				12				1				24%
3(11)	3(i)	11	Organic Chem.	4		7		0.4		0.6		8%		14%	
Total	5	50		7	9	22	12	1.4	1	1.6	1				
Percentage of total marks per cognitive demand				**14%**	**18%**	**44%**	**24%**								
			Percentage of question-parts per cognitive demand					**28%**	**20%**	**32%**	**20%**				

Chapter 5 Fifty Years of Irish physical sciences examinations

5.1. Introduction

This chapter presents the analysis of applying the revised Bloom's taxonomy to the higher-level Irish Leaving Certificate (LC) examination papers in physics and chemistry from 1966 to 2016. As detailed in Section 4.3.1, having identified action verbs of all question-parts and matched them with the allocated marks on the examination papers, the total mark for each cognitive demand was then calculated as a percentage of the overall mark for the examination. The percentage marks per cognitive demand for each examination were drawn up to form the data set for analysis.

As explained previously, the physics and chemistry syllabi were revised three times during this period; that is,

in physics Syllabus P1 from 1966 to 1985,
Syllabus P2 from 1986 to 2001,
Syllabus P3 from 2002 to the present;
in chemistry, Syllabus C1 from 1966 – 1984,
Syllabus C2 from 1985 to 2001,
Syllabus C3 from 2002 to the present.

Sections 5.2 and 5.3 examine and compare the range of cognitive demands in the physics and chemistry examinations based on each of the three revised syllabi. Section 5.4 presents the trends in cognitive demands of the physics and chemistry examinations. As this analysis focused on assessing the examination questions identified through the action verbs within the Revised Bloom's taxonomy structure, the term 'cognitive demand' is used throughout rather than 'cognitive domain'.

5.2. Cognitive Demands of Leaving Certificate physics examinations

5.2.1. Cognitive demands of examinations for Syllabus P1 (1966-1985)

One of the consequences of introducing free access to second-level education for all in 1966 was the restructuring /revision of the Leaving Certificate programme. Consequently, the analysis of the cognitive demands of the physics examinations 1966-1985 based on Syllabus P1 is presented in two parts – examinations 1966 – 1970 based on Syllabus Pa (an itemised list of topics) and examinations 1971-1985 based on Syllabus Pb, (clarification of the depth of the topics listed in Syllabus Pa) (An Roinn Oideachais, 1971).

- **Physics Examinations for Syllabus Pa (1966-1970)**

The cognitive demands of the physics examinations based on Syllabus Pa are shown in Figure 5.3. For the examination years 1966-1968, over fifty per cent of the marks were allocated to questions coding for *remember* indicating a high reliance on students' memorising ability. The findings for 1967 are particularly striking, where 73% of the marks available (533 marks out of 730) were assigned to the lowest cognitive demand *remember*. This reliance on *remember* was evident across all ten questions on the examination paper, indicating that students' ability to achieve high marks in this examination correlated with their ability to memorise information. Having analysed both the higher- and ordinary levels 1967 physics examinations, Madaus and Macnamara (1970) wrote the following in their report (commissioned by the Department of Education)

> *The emphasis in both papers is on the recall of specific items of information. If knowledge of such items was the main purpose for studying physics, then the examination(s) had a high content validity. If, on the other hand, the courses were aimed at introducing students to the scientific methods, if they were aimed at developing in students a general problem-solving ability which would transcend the details of their course and transfer to a wide range of problems in physics, then both examinations failed badly.* (Madaus and Macnamara, 1970a, p. 99)

Although still based on Syllabus Pa, there was a marked difference in emphasis on cognitive demands for the 1969 and 1970 examinations compared to the first three years of Syllabus Pa. The percentage of marks assigned to questions coding for *remember* almost halved from an average of 66% (1966-1968) to an average of 33% for 1969-1970. On the other hand, the percentage of marks coding for *understand* increased from an average of 20% (during 1966-1968) to 39% (during 1969-1970) of the total marks. The percentage of marks assigned to *apply* increased from 9% to 19% across the five years. Most of these *apply* questions were computational, requiring students to recall/*remember* the appropriate formula/e. Often recalling and applying a formula was insufficient to answer these questions; prior manipulation was required before applying the correct formula. There was also an increase in the percentage of marks assigned to cognitive demand *analyse* to 9%. On the other hand, no question-parts were coding for the other two cognitive demands of *evaluate* and *create* in any of the Syllabus Pa examinations.

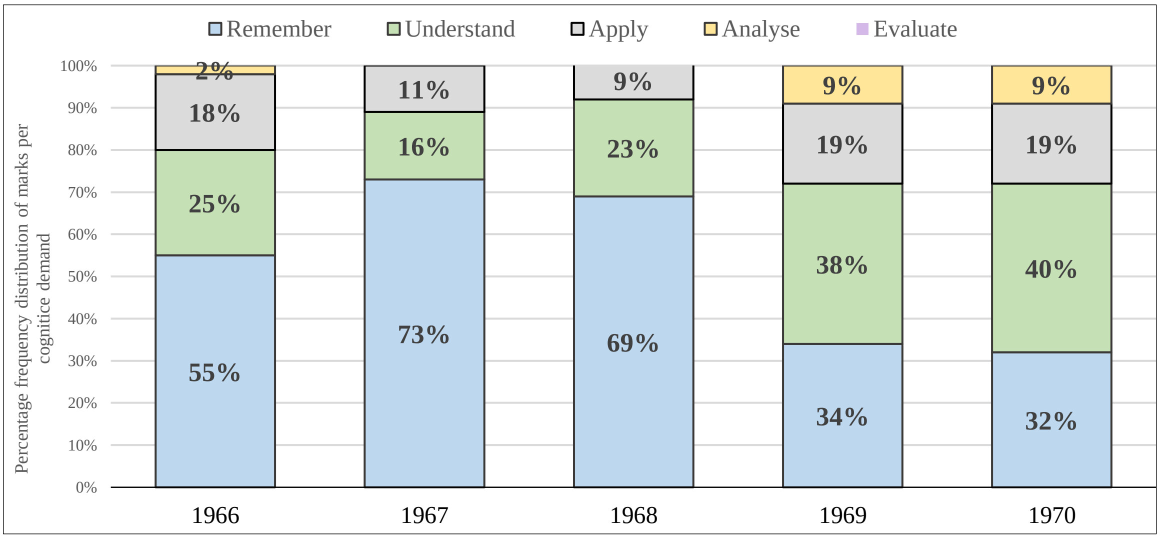


Figure 5.1Percentage distribution of marks per cognitive demand of physics examinations based on Syllabus Pa (1966-1970)

The examination papers for these five years did not reveal any apparent difference between the format of the 1969 and 1970 examination papers and those of 1966-1968. However, there was a noticeable change in the focus on cognitive demands of *remember* and *understand*, as shown in the following two examples:

From Paper 1967 Question 1	***From Paper 1969 Question 1***
1. (a) Discuss Newton's law of gravitation. If the acceleration due to gravity at the surface of the Earth is 981 cm. per sec^{2,} and the radius of the Earth (assumed spherical) is 6.4 x 10^6 metres, calculate the acceleration due to gravity at a height of 8 x10^5 metres above the surface of the Earth.	*1. (i) State Newton's laws of motion or Newton's law of gravitation. (ii) Calculate the acceleration due to gravity on the surface of a certain planet given that the acceleration due to gravity on the surface of the Earth is 9.8 metres per sec.$^{-2}$ and the* $\frac{\textit{radius of Earth}}{\textit{radius of planet}} = \frac{15}{8}$ $\frac{\textit{Mean density of Earth}}{\textit{mean density of planet}} = \frac{10}{7}$

Figure 5.2 Example of similar questions with different cognitive demands

In the 1967 question above (Figure 5.4), there was no guideline as to the depth required to 'discuss Newton's law of gravitation', whereas, in the 1969 question, a statement of the law was sufficient. Before carrying out the calculation required in the 1967 question, students had to *remember* the associated formula,

$$F = G\frac{m_1 m_2}{r^2},$$

Then manipulate it to obtain the ratio of acceleration on Earth ($g_{(e)}$) to acceleration at height, h, above Earth ($g_{(e+h)}$) in terms of the ratio of respective radii ($R_{(e)}$, and $R_{(e+h)}$) that is

$$\frac{g_{(e+h)}}{g_{(e)}} = \frac{R_{(e)}^2}{R_{(e+h)}^2}$$

and then substitute the relevant values. Likewise, prior to carrying out the calculation in the 1969 question, the same formula had to be manipulated to incorporate the density, that is

$$F = mg = G\frac{\frac{4}{3}\pi\rho R^3}{R^2}$$

to obtain the ratio

$$\frac{g_{(e)}}{g_{(p)}} = \frac{\rho_{(e)}R_{(e)}}{\rho_{(p)}R_{(p)}}$$

The 1967 and 1969 questions were variations of the first question on the 1964 examination paper (Figure 5.4), which students would undoubtedly have analysed and prepared.

From Paper 1964 Question 1

1. Define Newton's gravitational constant, G.

Taking 980 cm per sec^2 as the value for the acceleration due to gravity on the Earth's surface, calculate the corresponding value for gravity on the surface of a certain planet if the $\frac{\text{radius of Earth}}{\text{radius of planet}} = 3$ *and the* $\frac{\text{mean density of Earth}}{\text{mean density of planet}} = \frac{5}{3}$

Figure 5.3 Comparison question from 1964

In their study of the Irish Leaving Certificate examinations, Madaus and Macnamara commented on the ability of both teachers and students to interpret past examinations as preparation for future ones (Madaus and Macnamara, 1970b).

However, these changes in emphasis on the cognitive demands in the last two years of Syllabus Pa (1969-1970) coincided with several developments in science education in Ireland that occurred in the 1960s stemming from the findings of the *Investment in Education* survey (Fitzgerald, 1965; Department of Education, 1966; Fleming and Harford, 2014; Loxley, Seery and Walsh, 2014). These included the implementation of a new Intermediate Certificate programme for lower second-level and the introduction of refresher courses for science teachers (An Roinn Oideachais, 1964, pp. 60–61), the inclusion of teachers in the Science Syllabus Committee (Coolahan, 2007, pp. 218–266), and the expansion of third level institutions to include higher technical colleges (Walsh, 2018).

- **Physics Examinations for Syllabus Pb (1971-1985**)

In the examinations of Syllabus Pb, a new format for questions was introduced, with the first question composed of fifteen short questions. For the first time, sketches/diagrams were included in some of the short questions. These short questions covered all the topics, for example:

> *Give an example of the conversion of chemical energy to thermal energy (1971)*
> *Define the unit of force, i.e. the newton (1973)*
> *What is the basic principle of the moving-coil meters? (1977)*
>
> *Sketch a graph showing how the activity of a sample of radioactive material changes with time. (1983)*

The remainder of the question formats in Syllabus Pb were similar in layout and style to Syllabus Pa. Figure 5.6 shows the data from the analysis of the examination papers from 1971-1985. Except for the 1973, 1981 and 1982 examinations, the percentage of marks assigned to question-parts coding for this cognitive demand *understand* ranged between 35% (in 1980) and 66% (in 1971) and was generally more significant than the percentages assigned to cognitive demand *remember.* There was an increase in the percentage of marks assigned to cognitive demand *apply* compared to previous years, ranging from 16% (in 1971) to 28% (in 1982). Most of these *apply* questions were computational, involving the manipulation and application of appropriate formulae.

The percentage of question-parts coding for the cognitive demand *analyse* ranged from 0% (1971, 1973, 1980 and 1984) to a high of 17% in 1975. Once again, there were no question-parts coding for the cognitive demands of *evaluate* or *create.*

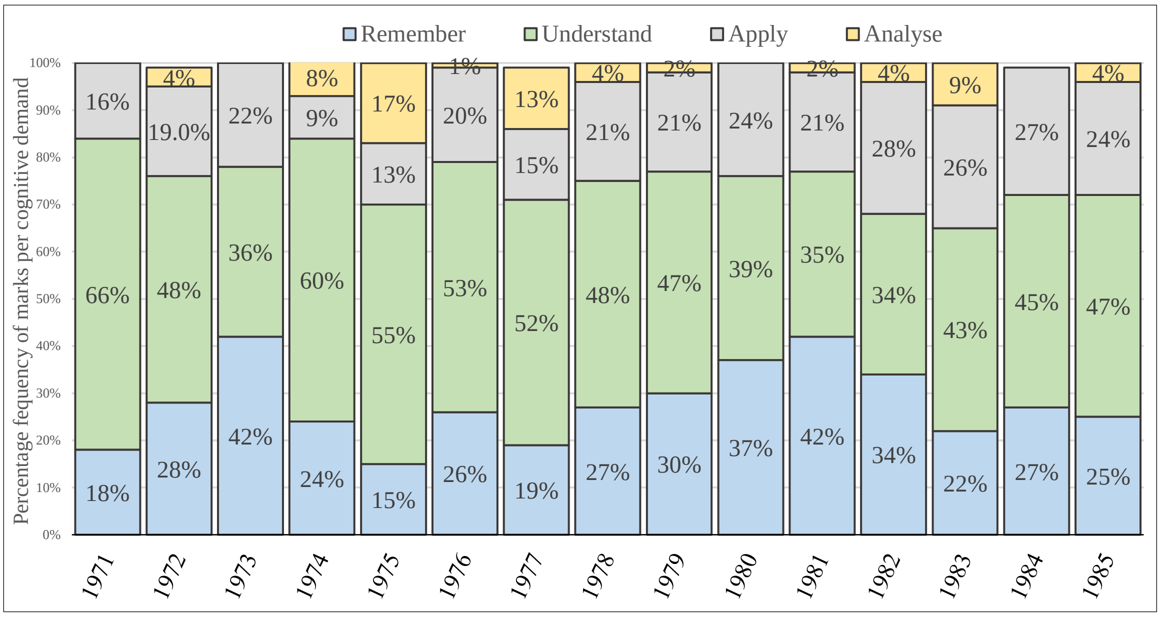


Figure 5.4 Percentage frequency distribution of marks per cognitive demand of physics examinations based on Syllabus Pb (1971-1985)

Throughout Syllabus P1 (1966-1985), the emphasis on question-parts coding for *understand* was consistently higher for Syllabus Pb than Syllabus Pa. However, over the twenty years, the majority of the marks (greater than 70%) were assigned to questions coding for the two cognitive demands of *remember* and *understand,* with less than 30% of marks assigned to *apply* and *analyse*. There were no question-parts coded for the cognitive demands of *evaluate* and *create.* This agrees with the findings Madaus and Macnamara (1970) reported in their 1967 LC physics examinations analysis.

5.2.2 Cognitive demands of examinations for Syllabus P2 (1986-2001)

As outlined in Chapter 2, the emphasis of Syllabus P2 was on the experimental nature of physics (An Roinn Oideachais, 1985). In keeping with the change in emphasis, the examination paper was arranged into three sections, A, B and C. Section A was compulsory and consisted of six multiple-choice-questions (MCQs) on a range of topics and thirty short questions requiring brief single-sentence responses. Section B consisted of three questions based on experiments listed in the syllabus, and students were required to answer any two of these questions. Section C comprised six questions based on physics' theoretical and practical applications.

The cognitive demands of the examinations based on this syllabus are shown in Figure 5.7. The percentage frequency distribution of marks assigned to question-parts coding for cognitive demand *remember* varied between 30% (1993 and 1996) and 56% (1987). In tandem with these, the percentage frequency distribution of question-parts coding for *understand* ranged from 12% (1987) to 49% (1996).

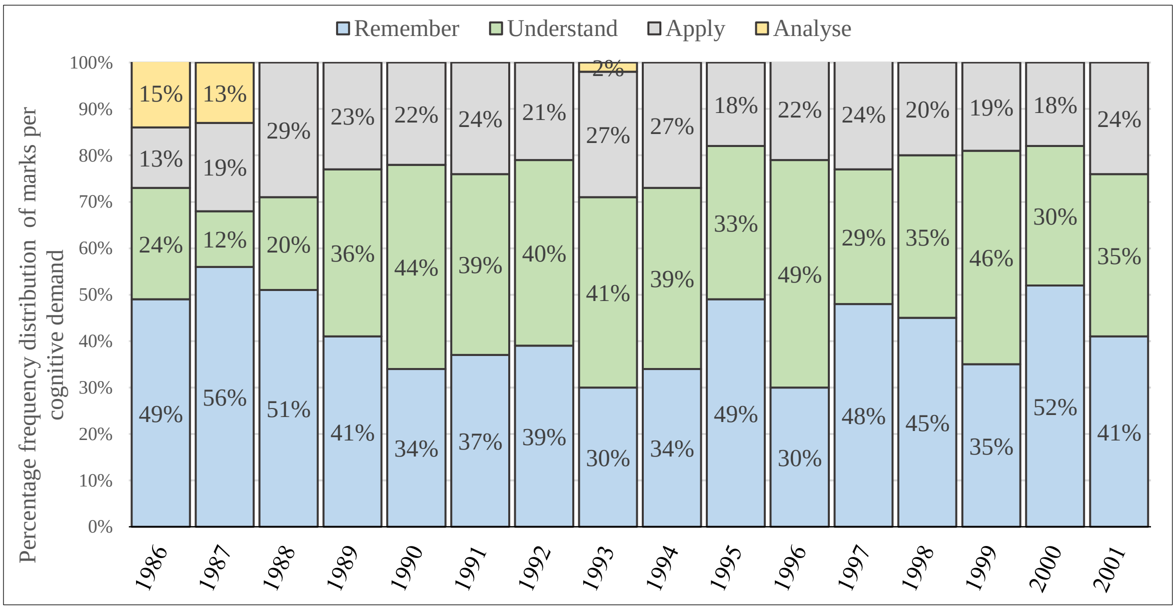


Figure 5.5 Percentage frequency distribution of marks per cognitive demands of physics examination based on Syllabus P2

With the emphasis on the experimental and practical applications in this syllabus, textbooks now included possible layouts for students to adopt when writing their reports of the practical work carried out in class; for example, the following from *Fundamental Physics* by Casserly and Horgan emphasised the headings:

Title
1. Apparatus + detailed labelled diagram of set-up to be used
2. Procedure – a step-by-step account of the procedure,
3. Data – recording all readings and presentation
4. Errors- sources of errors, precautions to take.

(Casserly and Horgan, 1990)

Each of the questions in Section B of the examination papers was composed of three or four question-parts, each related to a different aspect of record keeping of the experimental work. For example, from Question 7(1991) in Figure 5.8:

The following is a student's account of an experiment to determine the resistivity of nichrome. "The length of wire was measured and found to be 68.5cm. The diameter of the wire was measured

at five places, and the values found were 0.20mm, 0.21mm, 0.19mm, 0.22mm and 0.21mm. The resistance of the wire was found to be 26.4Ω.

Present the measurements given in this account in the form of a table. *(6)*

Name the instrument normally used to find the diameter of the wire and explain how it is used. *(12)*

Mention two precautions which should be taken when determining the length of the wire to ensure a more accurate result. *(6)*

Use the data given to calculate the resistivity of nichrome. *(15)*

Figure 5.6 Question 7 (1991) - based on class-based experimental work

Nothing was unfamiliar to students in these question-parts - as these questions just presented a laboratory report in a question format. The challenge for students would be to *remember* the formula for the resistivity of the wire, $\rho = \frac{RA}{l}$. The percentage of marks assigned to cognitive demand *apply* was 13% to 29%. However, as in Syllabus P1, most of these question-parts were computational types which again depended on students using the correctly *remembered* relevant formula. Even with the emphasis on experimental aspects, of the sixteen examination papers (1986-2001), just three question-parts coded for the higher-cognitive demand *analyse* (1986, 1987 and 1993), with just two per cent of the 1993 question-parts coding for this cognitive demand. This was quite a change from the previous cycle based on Syllabus P1, with fourteen of the twenty examination papers having question-parts coding for analysis. As with syllabus P1, no questions coded for the higher-cognitive demands of *evaluate* and *create*.

5.2.3. Cognitive demands of examinations for Syllabus P3 (2002-2016)

Physics Syllabus P3 provided a more detailed description of syllabus content, including a list of twenty-four mandatory experiments (as discussed in Section 2.4.1). For the first time, the objectives of the syllabus were included. These were grouped under Knowledge, Understanding, Skills, Competence, and Attitude. Moreover, the syllabus was to be assessed according to the first four headings (Department of Education and Science, 1999a). The examination papers based on Syllabus P3 comprised two sections - Section A (focused exclusively on the mandatory experiments) and Section B (questions based on the three components – pure science, application of science and social aspects of science.

The cognitive demands of the examinations based on this syllabus are shown in Figure 5.9. The percentage frequency of marks assigned to question-parts coding for *remember* varied between 24-50%; from 2002 – 2010, these values fluctuated. In comparison, from 2011 to 2016, there was a steady, if slight, increase from 25% to 38%. For 2002-2010, the percentage frequency distribution of marks assigned to question-parts coding for *understand* followed a similar fluctuating pattern to *remember*. On the other hand, from 2011-2016, the frequency percentage marks for this cognitive demand decreased from 42% to 27%. In contrast, with two exceptions (for 2002, 2003 and 2008), the percentage frequency distribution of marks assigned to question-parts coding for *apply* remained within the 28-36% range. The percentage of marks assigned to the higher cognitive demand *analyse* was in the single digits, with the majority of marks between 1% and 3%.

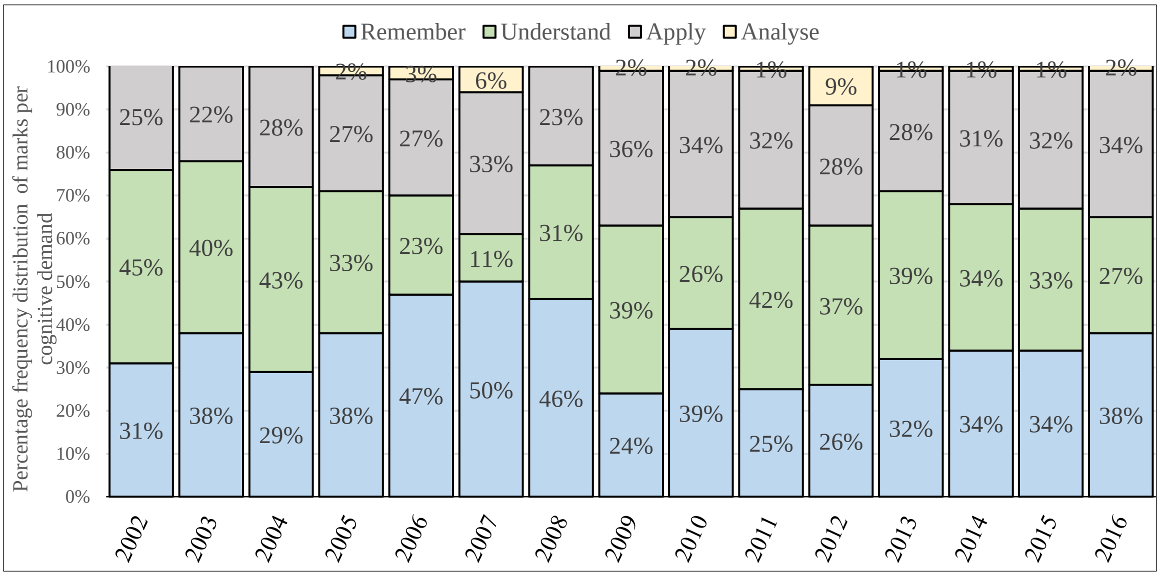


Figure 5.7 Percentage frequency distribution of marks per cognitive demands of physics examinations based on Syllabus P3

Before 2010, students had access to a *Mathematical Tables* booklet during the examinations. However, it was of marginal use in physics examinations since it contained a limited number of s mechanics- related formulae under the heading of *Applied Mathematics*. From 2010, the *Formulae & Tables* booklet was permitted for use in examinations (State Examinations Commission, 2014). This booklet contains a range of physics-related formulae, which students previously needed to memorise.

5.2.4 Summary of cognitive demands of physics examinations

The cognitive demands of the physics examinations based on the three physics syllabi across fifty years (1966-2016) included only question-parts in remembering, understanding, applying, and analysing. There were no question-parts in the domains of *evaluate* and *create*. Table 5.1 shows the average percentage of questions for each cognitive demand for the years a syllabus was taught. Of note is the difference in emphasis of the cognitive demands of examinations based on Syllabi Pa and Pb (highlighted). Although the topic content of both syllabi was unchanged, Syllabus Pb contained clarifications omitted in Syllabus Pa. The dominant cognitive demand for examinations based on Syllabus Pa was *remember* followed by *understand*; the reverse emphasis was observed in the examinations based on Syllabus Pb, when *understand* now was the dominant demand. There was also an increase in emphasis on the cognitive demands of *apply* and *analyse* compared to the cognitive demands of the examinations based on Syllabus Pa.

Table 5.1 Average percentage of cognitive demands of physics examinations 1966-2016

Domain	Syllabus Pa	Syllabus Pb	Syllabus P2	Syllabus P3
Years	*1966-1970*	*1971- 1985*	*1986-2001*	*2002-2016*
Remember	**53 ± 19**	28 ± 8	**42 ± 8**	**35 ±8**
Understand	28 ±10	**47 ± 9**	35 ±10	34 ± 9
Apply	15 ± 5	20 ± 5	22± 4	29 ± 4
Analyse	4 ± 5	6 ± 5	10 ± 7	3 ± 3

However, the average values for examination questions based on syllabi P2 and Syllabus P3 were more notable. The average value in both instances was that for *remember* followed closely by *understand.* Questions based on Syllabus P3 had the most significant average percentage of *apply* questions due mainly to the increased number of questions based solely on calculations. At the same time, the lowest average percentage for *analyse*-type questions of all the syllabi was recorded. To summarise, irrespective of the syllabus, clarifications of contents and despite access to marking schemes and Chief Examiners reports (available since 2001), the two dominant cognitive demands of the higher-level examinations in physics throughout the fifty years, 1966 to 2016, were *remember* and *understand*.

5.3. Cognitive Demands of Leaving Certificate chemistry examinations

5.3.1. Cognitive demands of examination for Syllabus C1 (1966-1984)

As the chemistry syllabus, like the physics syllabus, was revised in 1969, the cognitive demands of the chemistry examinations during this period are presented in two parts – Ca (an itemised list of topics) between 1966-1970 (An Roinn Oideachais, 1964) and Cb between 1971-1984 syllabus which presented clarification of the topics (An Roinn Oideachais, 1971).

- **Examinations for Chemistry Syllabus Ca (1966-1970)**

The cognitive demands of the chemistry examinations based on this syllabus (Figure 5.10) are strikingly similar to those of physics (Figure 5.1). Like physics, C1 consisted of Ca (1966-1969) and Cb (1970-1983). Both physics and chemistry had high percentages of the marks assigned to question-parts coding for *remember* for the examination years 1966-1968. Again, like physics, there was a notable decrease in the percentage of marks assigned to *remembe*r for 1967 and 1968, with a corresponding increase in marks assigned to question-parts coding for *understand.* The percentage of marks assigned to questions coding for *apply* was between 5% and 17%. Although computational, students had to manipulate the appropriate chemical equations and *remember* the relevant mathematical formula before carrying out the required calculation.

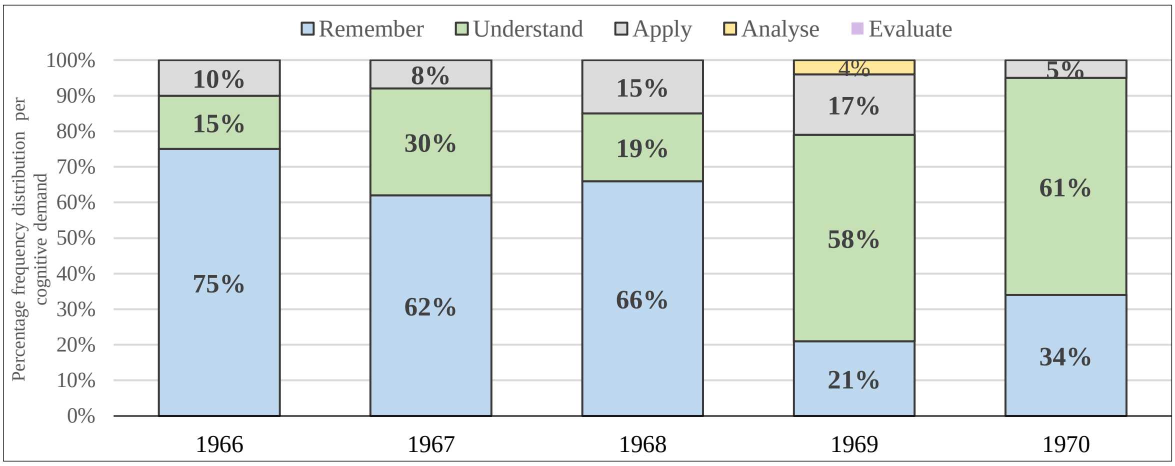


Figure 5.8 Percentage frequency distribution of marks per cognitive demands of examination based on syllabus Ca

However, unlike physics, there was a discernible change in the framing of the questions for 1969 and 1970. This change resulted in an emphasis from *remember* to *understand*, as in the highlighted cognitive demands. The following questions in Figure 5.9 illustrate this change in emphasis:

From Paper 1967 Question 6 (ii)	***From Paper 1970 Question 10***
6. (ii) Explain how an indicator works. Name an indicator which could be used in the titration of a strong acid with a weak base; name, also, an indicator which would be unsuitable for this titration.	*10. (ii) Explain what an indicator is and how it works.* *Mention any two indicators and explain when and why you would use each of them.*

Figure 5.9 Similar questions but different cognitive demands

Each question tested *understanding* of '*how an indicator works'*, but the remainder of both questions showed different emphases; in question 6, naming the indicators spoke to *remember*, whereas, in question 10, as well as naming two indicators, the student needed to show *understanding* of the *use of these indicators*. Another example was a short question on catalysis - in 1966. Students were asked to

'*write a concise note on catalysis'* (question 10 (iii), 1966)

whereas in 1970, the question was more explicit in the depth of the expected account:

Write a short account of catalysis. In your answer, refer to homogeneous catalysis, heterogeneous catalysis and autocatalysis.

(question 9(b), 1970).

- **Examinations for Chemistry Syllabus Cb (1971-1984)**

The cognitive demands of the examinations from 1971-1984 are shown in Figure 5.12. Though the revised Syllabus, Cb, was first examined in 1971, there was no change in the examination format until 1974, when question-parts of each question were enumerated. The range of percentage marks allocated to question-parts coding for *understand* (between 33% and 63%) was almost double that of percentage marks assigned to *remember* question-parts (17% to 35%). With percentages fluctuating between 17% and 34%, the percentage of marks assigned to *apply* was less than, equal to or slightly greater than percentage marks assigned to *remember*. Question-parts coded for the higher cognitive demand *analyse*, with the percentage of marks assigned to these varying between 1% to 20%. No question-parts coded for the other higher cognitive demands of *evaluate* or *create*.

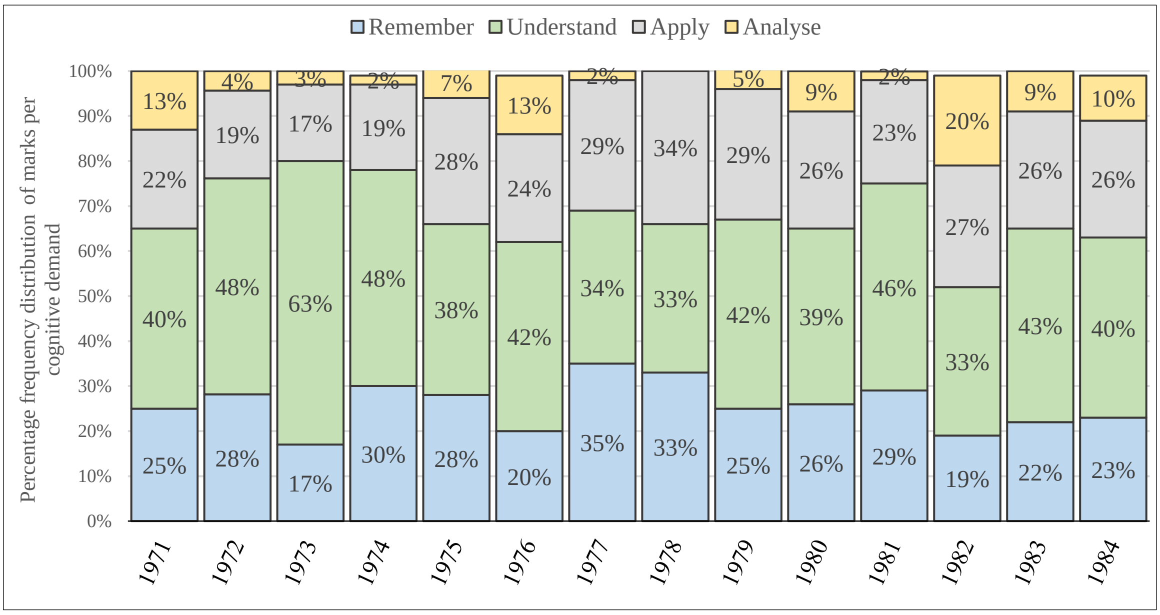


Figure 5.10 Percentage frequency distribution of marks per cognitive demands of chemistry exams based on Syllabus Cb

5.3.2. Cognitive demands of examinations for Syllabus C2 (1985-2001)

The presentation of the examination papers based on Syllabus C2 (Figure 5.13) was more organised than previous examination papers, with all question-parts enumerated and allocated marks. As well as including the aims of the syllabus, the objectives were presented under the heading of Knowledge, Experimental/Manipulative Skills, Comprehension & Application, Evaluation, and Expression.

The analysis data of the first examination (1985) based on this syllabus indicated that just 17% of the marks were allocated to cognitive demand *remember* and three times this to questions coding for *understand*, maintaining the emphasis on *understand* over that of *remember* as noted for the examinations based on Syllabus Cb (Figure 5.12). However, from 1986 to 2001, the percentage marks assigned to question-parts coding for *understand* (between 24% and 44%) was within the same range of percentage marks assigned to question-parts coding for *remember* (26% to 53%).

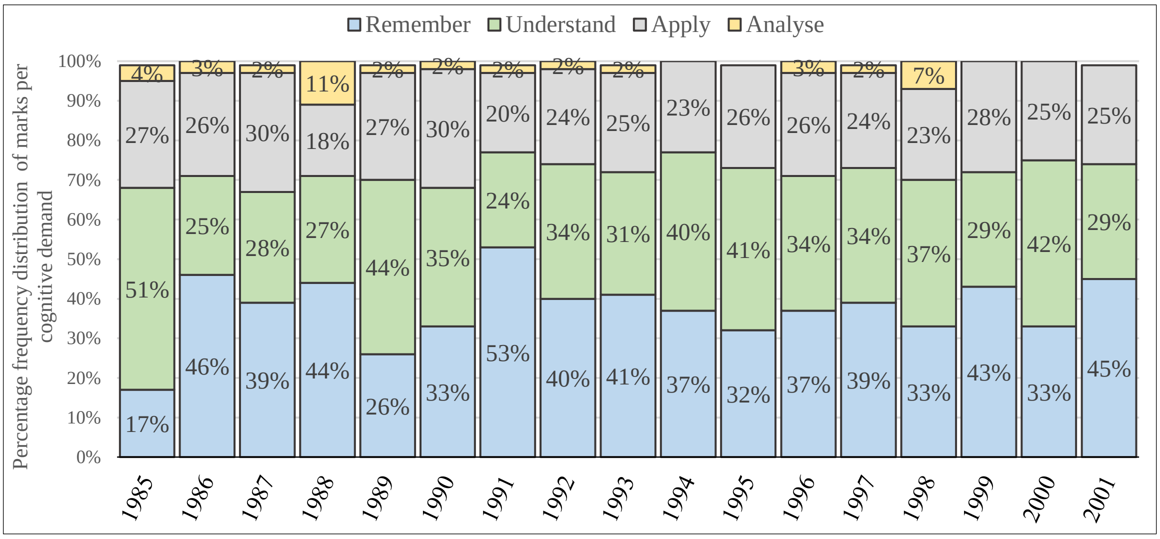


Figure 5.11 Percentage frequency distribution of cognitive demands of chemistry exams based on Syllabus C2

This change in emphasis was observed when comparing question-parts on the 1985 examination to similar ones on later examination papers, for instance,

From 1985, Q.6
(a) Explain the term eutrophication of water. What are its causes and effects? *(9)*

And

From 1995, Q.10
(b) Define (i) eutrophication, (ii) Biochemical Oxygen Demand (B.O.D.) *(9)*

Both question-parts were allocated nine marks. However, the highlighted action-verb in 1985 coded for *understand*, whereas the highlighted action-verb in 1995 coded for *remember*. Like in physics, the chemistry Syllabus C2 stated the importance of the experimental aspect of chemistry (An Roinn Oideachais, 1985, pp. 213–214). In the syllabus, the Department of Education highlighted

> *laboratory work as an intrinsic part of the syllabus… recommended that about two class periods per week (c. 40% of teaching time) be devoted to practical work.*
> (An Roinn Oideachais, 1985, pp. 213–214)

Two of the examination questions focused on the experiments listed in the syllabus. Authors of school textbooks included guidelines for laboratory reports as well as details of the procedures to be carried out (Henly, 1983, 1979). Each of the two questions based on the experiments was composed of six or seven question-parts such as the following experiment based on the hardness of water, from 2000, Chemistry higher-level

2. A sample of water, which contained both temporary and permanent hardness, was analysed in the school laboratory. The water was titrated in 50cm^3 volumes against a 0.01 mol dm^{-3} solution of EDTA using a suitable indicator, and the mean titre was found to be 12.2 cm^3. A 1 dm^3 volume of the sample was then boiled in a beaker for about thirty minutes. When it had cooled to room temperature, it was filtered, and then the original volume was accurately restored using deionised water. When this water was titrated in 50 cm^3 volumes against the same EDTA solution, the mean titre was 5.5cm^3

(i) What is hard water? Explain the terms temporary and permanent hardness. (9)

(ii) Describe how you would accurately restore the boiled water to its original volume and explain why it is necessary to do so. Why is deionised used? (15)

(iii) Name a suitable indicator and state the colour change at the end-point of the titration. Why is it necessary to use a buffer solution? (12)

(iv) Name one compound that could have been responsible for the temporary hardness and one compound that would have been responsible for the permanent hardness in the water sample. Write an equation for the reaction that took place when the water was boiled. (12)

(v) Using H_2Y^{2-} to represent the EDTA anion and M^{2+} to represent the cation responsible for hardness, the titration reaction may be represented by:

$$H_2Y^{2-} + M^{2+} \qquad MY^{2-} + 2H^+$$

(a) Calculate the total titration, (b) the permanent hardness, (c) the temporary hardness of the water sample, expressing your answers in terms of parts per million (p.p.m.) of calcium carbonate (18)

5.3.3. Cognitive demands of examinations for Syllabus C3 (2002-2016)

Although the presentation of Syllabus C3 was quite detailed (Department of Education & Science/NCCA, 1998c, pp. 35–72), the examinations based on it were similar in construction to that of physics; Section A (focusing on three mandatory experiments) and Section B (with eight questions on all aspects of the syllabus). Figure 5.14 presents the cognitive demands of the examinations based on this syllabus. The dominant cognitive demand was that of *remember* with a percentage frequency distribution often double that of *understand*, not dissimilar to that shown for chemistry (Figure 5.9). The percentage distribution of marks assigned to the cognitive demand *apply* varied between 13% and 22%. This was quite a reduction in the percentage frequency distribution of marks assigned to the cognitive demand *apply* compared to previous years, as shown in Figure 5.13 relative to Figure 5.12. There also was a noticeable decrease in the percentage frequency of marks allocated to cognitive demand analysis compared to previous years.

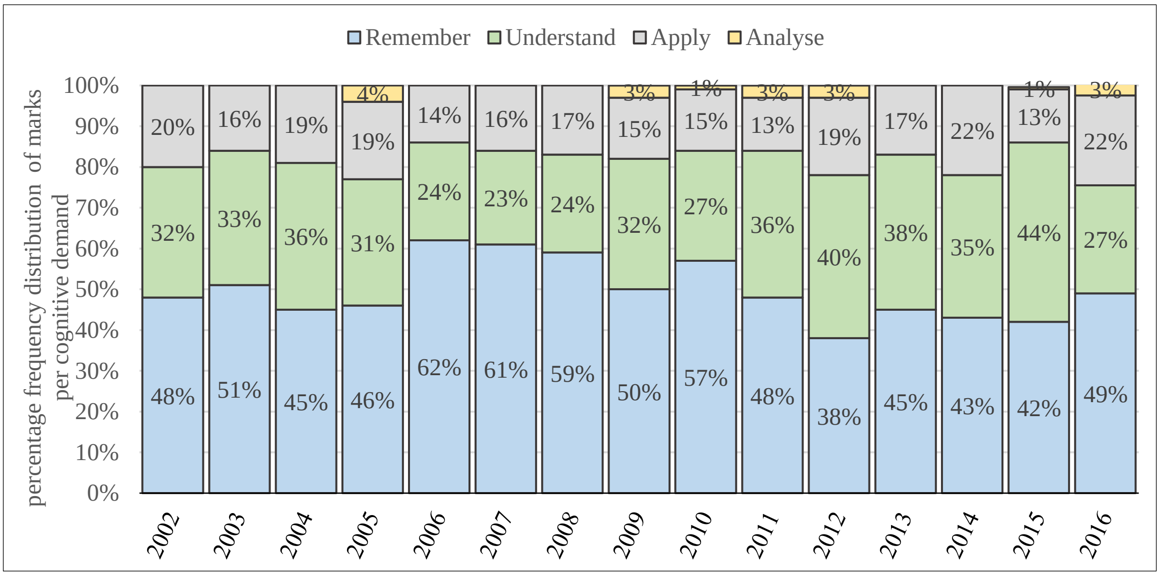


Figure 5.12 Percentage frequency distribution of cognitive demands of chemistry exams based on Syllabus C3.

5.3.4. Summary of cognitive demands of chemistry examinations

Table 5.2 summarises the average percentage of cognitive demands of the chemistry examinations from 1966 to 2016. Like physics, irrespective of the syllabus, all the marks on the chemistry examinations were assigned to four cognitive demands *remember*, *understand*, *apply* and *analyse.* No marks were assigned to the domains of *evaluate* and *create.*

Table 5.2 Average percentage cognitive demands of chemistry examinations 1966-2016

Domains	**Syllabus C1**		**Syllabus C2**	**Syllabus C3**
	(Syllabus Ca	Syllabus Cb)		
Years	*1966-1970*	*1971-1984*	*1985-2001*	*2002-2016*
Remember (%)	**52 ± 23**	26 ± 5	**38 ± 8**	**50 ± 7**
Understand (%)	35 ± 19	**42 ± 8**	34 ± 7	32 ± 6
Apply (%)	11 ± 5	25 ± 5	25 ± 3	17 ± 3
Analyse (%)	1± 2	8 ± 5	3 ± 3	3 ± 1

The average percentage for cognitive demand *remember* was most significant across C1, C2 and C3 despite differences in the presentation of the syllabi, i.e., Syllabus C1 consisted of an itemised list compared to Syllabus C3, which consisted of more detailed content together with *Guidelines for Teachers* (Department of Education & Science/NCCA, 1999c, 1998). Syllabus Ca placed a greater emphasis on the demand *understand* than the three other syllabi and had the lowest emphasis on the demand *remember*. There was an emphasis on cognitive demands *apply* across all three syllabi ranging from an average of 11% in Syllabus Ca to 25% in Syllabus Cb and Syllabus C2. There was a slight emphasis on the demand *analyse* across all three syllabi, ranging from an average of 1% to 8%.

5.4 Trends in Leaving Certificate Physics and Chemistry examinations.

That these syllabi were revised rather than radically changed in content and that the examination formats year on year were comparable, presented an opportunity to investigate possible trends in the cognitive demands across the entire period (Patrick, 1996). This section examines trends in the percentage uptake of higher-level physics and chemistry and those awarded honours grades, distribution of marks per cognitive demand, question-parts distributions and the trend in procedural and conceptual knowledge based on the cognitive demands of the examinations (1966-2016).

5.4.1. Trends in uptake and award level in the higher-level Physics and Chemistry

- **Determining award levels**

Pre-1969, marks obtained on a higher-level paper equal to or greater than 60% of the total marks allocated to a subject, were considered an honours grade, and between 59-40% were a pass. In 1969, a seven-banded system (Table 5.3) replaced this binary honours and pass system (Department of Education, n.d.). The first row in Table 5.3 shows the grade designations. The second row denotes the percentage range per grade, while the third row indicates the actual marks per percentage range. For example, marks from 339-280 inclusive were equivalent to a percentage range of 84-70 of total marks, which merited a B grade.

Table 5.3 LC grading system used 1969-1991

Grade	A*	B*	C*	D	E	F	NG†
Marks (%)of total marks	100-85	84-70	69-55	54-40	39-25	24-10	< 10
Marks/400	400-340	339-280	279-220	219-160	159-100	99-40	<40

* = honours grade: † = No Grad

The introduction, in the late 1960s, of a third-level education grant system led to an increase in applications to third-level institutions. Such was the demand that the institutions had to restrict admission by imposing a quota system by placing applications in some order of merit. The principal method was applying a points system based on the LC results. In 1992, a fourteen-grading system replaced this seven-grading system (Table 5.4) (ESRI *et al.*, 2019; Department of Education, n.d.1991-1992). This change aimed to reduce the random selection of students on the same points, i.e. from A, B, C … to A1, A2, B1, B2…

Table 5.4 LC grading system used 1992-2016

Grade	A1*	A2*	B1*	B2*	B3*	C1*	C2*
Marks(%) of total marks	100-90	89-85	84-80	79-75	74-70	69-65	64-60
Marks/400	400-360	359-340	339-320	319-300	299-280	279-260	259-240
Grade (continued)	C3*	D1	D2	D3	E	F	NG†
Marks (%) of total marks	59-55	54-50	49-45	44-40	39-25	24-10	<10
Marks/400	239-220	219-200	199-180	179-160	159-100	99-40	<40

*= honours grade: † = No Grade

In 2017, the SEC introduced a new numerical grading system. (https://www.examinations.ie/?l=en&mc=ca&sc=ma) by replacing the fourteen-grading alphabetical system with eight grades. 1-8 with prefix H denoting honours level and O denoting ordinary level, H1/01 (the highest grade) to H8/O8 (the lowest).

All the LC examination results published by the Department of Education/SEC were always within the grade bandings rather than the actual examination marks obtained. Since 1998, students have been allowed to view their marked scripts and apply for recheck should they so wish.

Using the Department of Education's *Historical Statistics Reports* (Department of Education, n.d.), the following calculations determined the percentage of LC students awarded an honours grade in physics and chemistry:

(a) the total number of students who sat the LC examination (= N)
(b) the total number of students who sat a higher-level paper in physics (Hp) and chemistry(Hc)
(c) percentage of the total number of students who sat a higher-level paper in physics (Hp/N)x100: in chemistry (Hc/N)x100

(d) the total number of students awarded an honours grade (HG) in physics (HGp) and chemistry (HGc)

(e) the percentage of students awarded an honours grade (HGp/Hp)x100:

Using data from (a)-the total number sitting LC exams, (c)-the percentage who sat higher-level physics and chemistry exams, and (e) -the percentage awarded honours grades the awarded in physics and chemistry examinations were mapped against the percentage of those awarded an honours grade as shown in Figure 5.13. While the total number of students sitting LC increased over the years (Figure 2.4), the percentage of those sitting a higher-level paper in either subject remained within the low digits range (5% - 15%). In contrast, there was an increase in the percentage awarded an honours grade in physics and chemistry from 41% in the 1970-1980s to over 70% in the 2000s. This notable increase was possibly due to the revised syllabi, an increased level of motivation of students, the amended grade structures, or the level of preparation for the examinations.

In 1969 the new grading system (Table 5.3) was introduced. However, for the years 1969 to 1972, the *Statistical Reports* (Department of Education, n.d.) did not differentiate between those who obtained honours (A, B, C grades) and pass grades (D). Instead, the data published referred collectively to those who obtained a Grade of D (pass grade) or higher on an honours paper. As this research focused solely on those who obtained higher-level grades, including these years was not considered appropriate. Between 1972 and 1986, the Statistical Reports data listed the number of students awarded honours grades of C or higher. From 1987 onwards, the *Statistical Reports* listed the number of students awarded a grade at higher or ordinary levels. [The Department of Education did not publish examination results for any subject for 1981, 1982, 1985 and 1986. In the *1980-81 Statistical Report*, the Department of Education (Department of Education, n.d., p. 60 (1980-1981)) referenced the absence of grades awarded per subject due to numbers taking the subjects, indicating that such information was to be published in the following year's Statistical Report. Such reports did not materialise, nor was any reason given for the omissions].

- **Trends in uptake and award level in LC physics (1966-2016)**

As detailed in Section 5.2, the LC physics examinations during the fifty years were based on three revised syllabi. Figure 5.15 presents the percentage of students who sat the higher-level paper in physics mapped against those awarded honours grades from 1966-2016. Overall, the percentage sitting the higher-level exam remained equal to or less than 13% of the total LC cohort. Except for 1969, which showed 15% sitting the higher-level examination. The introduction of free education for all led to an increase in the numbers sitting the LC examinations, with 1969 being the first year to include students availing of free education, which may account for this singular increase in the percentage of honours grades awarded. In contrast, there was quite a variation in the percentage of honours grades awarded when examined in the light of the different syllabi.

Syllabus P1 (1966-1985)

As detailed in Section 5.2.1, the LC physics examinations between 1966-1985 were based on two syllabi – Syllabus Pa for 1966- 1971 and Syllabus Pb for 1971 – 1985. For the first three years of Syllabus Pa, 40% of those sitting the physics higher-level examination were awarded an honours grade, that is, their examination marks were equal to or greater than 240 (60% of marks for physics). For 1966-73, as the number sitting LC examination (Figure 2.3), the percentage sitting a higher-level paper dropped from 15% to 6%. However, no data on the number of students awarded an honours grade was published for this period (Figure 2.4).

In 1973, the time allocated for answering the physics paper was readjusted from 2.5 to 2.75 hours. Nonetheless, over the next five years (1973-1978), there was a steady decline in the percentage of honours grades awarded, from 50% to 41%. In contrast, the sharp increase (from 41 to 58%) in honours grades awarded in 1979 coincided with an increase in the exam time to 3 hours, followed by a significant drop in the percentage of grades awarded the following year to 51%. On the other hand, the paucity of data until 1987 makes it difficult to establish a trend, particularly as the format and grading of the examination papers remained unchanged between 1971-1985.

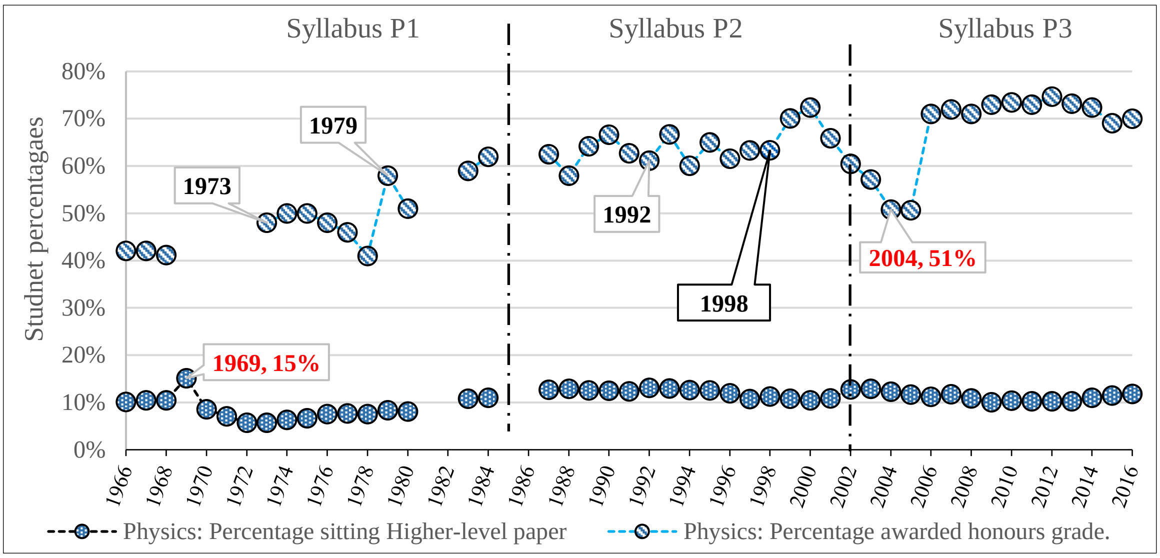


*Figure 5.13 Percentage of students awarded honours grades in higher-level **physics** examinations 1966-2016*

Syllabus P2 (1986-2001)

The outline pattern of the percentage of honours grades awarded between 1987-2001 resembled a series of 'sawtooth effects' or waveforms (Ofqual, 2016; Cuff, Meadows and Black, 2019). The authors used the sawtooth metaphor to illustrate a resultant pattern formed when the reform of high-stakes assessment results in a sudden drop in grades but, with familiarity with the examination format and grading systems, rises again. As described in Section 2.4.1, Syllabus P2 content and the examination format based on P2 were quite different. Moreover, in 1992, the grading system in place since 1969 (Table 5.3) was replaced by a more complex grading system (Table 5.4). These changes would appear to hinder teachers and students from building a familiarity with the examination process. In 1998, all LC students could view their scripts and appeal the given grade. At the same time, the marking schemes became available, thus providing some insights into the examination processes. Despite the accessibility of such material and the immediate increase in the percentage awarded honours (1998-2000), it is notable that the awarded honours grades decreased again from 2001. Unlike the Chemistry (C2) syllabus, the physics syllabus did not identify the subject objectives. Perhaps this lack contributed to the grade fluctuations for this period.

Syllabus P3 (2002-2016)

For the first time, Syllabus P3 included the list of the objectives (Table 2.8) against which the syllabus would be assessed in the LC examination (Department of Education and Science, 1999a, pp. 4, 24). Initially, the LC data for the examinations based on P3 displays the typical characteristics of the 'sawtooth' effect as described by Cuff et al. (Cuff, Meadows and Black, 2019). The first examination, based on this syllabus, took place in 2002. The percentage of awarded honours grades decreased from 60% (2002) to 51% (2004/2005). However, this decrease was followed by an immediate increase to 71% in 2006. While the percentage of those sitting the higher-level examination was 10-12% of the total cohort sitting LC examinations, the percentage of honours grades awarded varied between 69-75% of the total cohort. On the hand, while there was a slight increase in the percentage of those sitting higher-level physics between 2013-2016, at the same time the percentage of honours grades awarded noticeably decreased.

- **Trends in uptake and award level in LC chemistry (1966-2016)**

Figure 5.16 shows the percentage of students who sat the higher-level chemistry examination mapped against the percentage awarded honours grades from 1966-2016. The percentage of those sitting a higher-level paper has been marginally greater than those for physics. Like physics, the percentage (16%) of those sitting higher-level chemistry in 1969 was the exception due to an increase in the number availing of free access to second-level education.

Syllabus C1 (1966-1984)

Like physics, the examination time for C1 was adjusted twice in 1973 (from 2.5 to 2.75 hours), which coincided with an increase in the percentage of honours grades awarded. The second adjustment in 1979 (2.75 to 3 hours) coincided with increased grades awarded; the subsequent year saw a decrease in honours grades awarded (from 56- 52%). Similar to physics, due to a lack of published Statistical Reports for 1969-1972, and 1981-1982, it was challenging to decern an overall trend for examinations based on Syllabus C1.

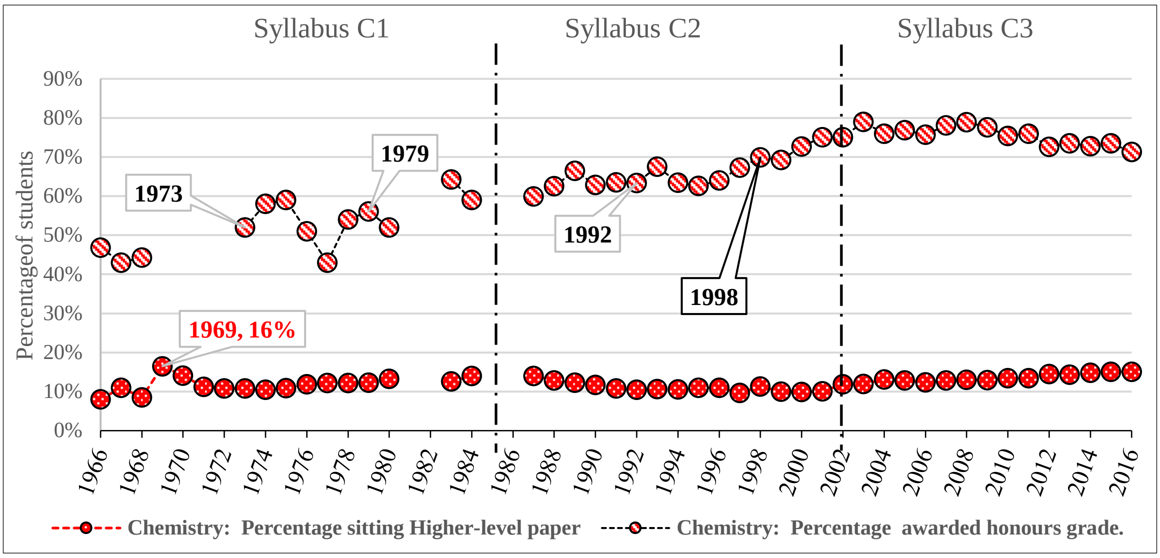


*Figure 5.14 Percentage of students awarded honours grades in **chemistry** examinations 1966-2016*

Syllabus C2 (1985-2001)

The examinations based on Syllabus C2 were subjected to the same interventions as for P2, in terms of grade changes in 1992 and facilitating students in viewing their scrips. However, the format of the examination papers remained unchanged. Overall, the percentage of honours grades awarded increased from 60% (1987) to 75% (2001). This gradual increase could have been due to the students' familiarity with the syllabus content or was a consequence of practising or learning for the test (Madaus and Macnamara, 1970a; Cuff, Meadows and Black, 2019; ESRI *et al.*, 2019). One of the recommendations of Madaus and Macnamara was the inclusion of explicit syllabus objectives (Madaus and Macnamara, 1970b). Section 2.4.2 lists the syllabus objectives for chemistry (An Roinn Oideachais, 1985, pp. 213–214). These objectives may have contributed to the relatively steady percentage increase of honours grades awarded.

Syllabus C3 (2002-2016)

There was a gradual increase in the percentage of students sitting the higher-level examination from 12% (2002) to 15% (2016). However, at the same time, the gradual increase in the percentage of honours grades awarded seen in the Syllabus C2 portion of Figure 5.14 reversed from 79% (2003) to 71% (2016). This increase in those sitting higher-level while at the same time, there was a decrease in those obtaining honours grades is similar to that noted for Syllabus P3.

- **Uptake of other LC Subjects (1987-2016)**

With the introduction of a points system as the metric for accessing third-level education in the 1970s, several subjects were gradually anecdotally perceived as 'easy' to obtain those high grades (hence allocated more points). In contrast, others were viewed to be more difficult (Madaus and Macnamara, 1970a). Some were concerned that students would choose 'easy' subjects to increase their chances of attaining high grades. To tentatively test this, the researcher selected the 1987 – 2016 higher-level Geography, Biology and Accounting results and matched them against the same period's physics and chemistry examination results. Figure 5.17 maps the percentage of students who sat a higher-level paper in physics, chemistry, biology, accounting and geography. Overall, there was a much more significant percentage of students who selected biology and geography than those selecting the other three subjects, which were perceived anecdotally as 'more difficult' subjects. Between 1987 and 2016, new syllabi were first examined in Accounting (1999), Physics(2002), Chemistry (2002), Biology (2006) and Geography (2008). The percentage of students selecting chemistry and biology increased after introducing the new syllabi, while physics and accounting numbers declined until 2013. Except for Geography, the percentage sitting these subjects has steadily increased, with Biology showing the most noticeable increase.

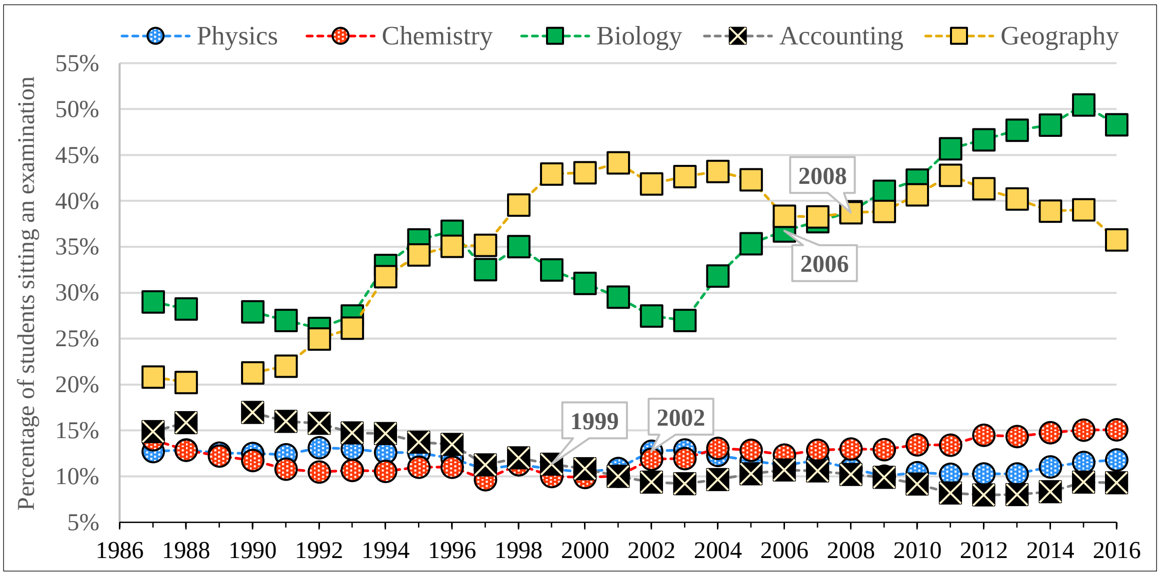


Figure 5.15 The percentage of LC students who sat higher-level examinations in selected subjects.

Figure 5.18 presents the percentage of students who achieved higher grades of A, B or C in these subjects over the same time frame. In 1987, the percentage range of those achieving honours grades was between 57% - 63%. By 2002, this range had increased to 66% - 76%. In 2016, there was an increase in the uptake of the subjects, and the percentage of those achieving honours was in the range of 69-77%.

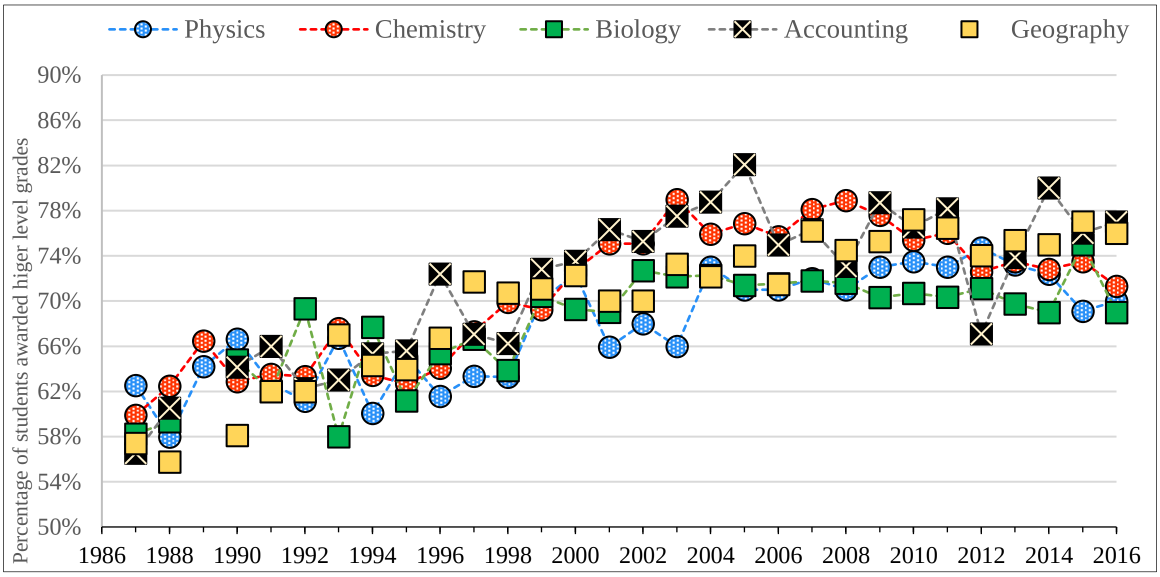


Figure 5.16 Percentage of students who achieved higher grades in the selected subjects.

A more interesting and perhaps telling statistic is the number of years that the percentage of students achieving higher grades in physics and or chemistry was comparable if not greater than those for the more popular and perceived 'easier' science subject, biology.

5.4.2. Trends in the cognitive demands of physics and chemistry examinations

The data analysis in Sections 5.2 and 5.3 focused on the cognitive demands of the LC examinations based on each of the three syllabi. The Department of Education styled these syllabi as revised, meaning much of the previous syllabus remained with some additional topics. For example, a topic on optical instruments was listed in Syllabus P2 (1986-2001) but not in Syllabus P3. Nonetheless, the traditional topics, such as mechanics, light, and electricity, were retrained across the three syllabi in physics and chemistry. Moreover, the examination formats, year on year, were comparable, thus presenting an opportunity to investigate any possible trends across the cognitive domains examined from 1966 to 2016 (Patrick, 1999).

- **Trends in cognitive demands of physics examinations (1966-2016)**

Figure 5.19 shows contrasting scatterplot charts of the percentage distribution of marks for the cognitive demands of *remember*, *understand*, *apply* and *analyse* for each of the three physics syllabi. While visually, patterns of the distribution of the marks are quite irregular, not fitting any discernible overall pattern, there are some interesting observations.
Firstly, based on the maximum and minimum percentage marks, as indicated in Figure 5.7, the range of the percentage of marks per cognitive demand across the three syllabi was reduced.

Remember: the percentage range of marks allocated in P1 is 15-73% through 30-56% (Syllabus P2) to 24-50% (syllabus P3):

Understand: percentage distribution of marks ranged from 16-66% (syllabus P1) through 12-49% (Syllabus P2) to 11- 45% (syllabus P3):

Apply: percentage distribution of marks ranged from 9-28% (syllabus P1) through 13-29% (Syllabus P2) to 22-36% (Syllabus P3):

Analyse: percentage distribution of marks ranged from 1-17% (syllabus P1) through 10-15% (syllabus P2) to 1-9%(syllabus 3).

Secondly, the standard deviation across the three syllabi decreased for *remember* (16-8%). However, the data values were still dispersed over a wide range, with the spread forming a sawtooth pattern with four possible clusters. Three clusters occurred when four or five data points formed an upward trend for 1977-1981, 2004-2007 and 2012-2016. The fourth cluster, 1987-1990, followed a downward trend. On the other hand, the data spread for *understand* appeared to be a mirror image of that for *remember*. For instance, Figure 5.17 shows that 56% of the marks were assigned to *remember* (1987) while 12% of the marks to *understand* for the same year.
Similarly 1996, 30% of marks were allocated to *remember*, while 49% were to *understand*. The question arises - is this mirror-image pattern coincidence or the result of a conscious decision surrounding questions as this pattern was repeated across all three syllabi? The standard deviation, for *apply*, across the three syllabi, from 6-4%, indicates that the spread of values was within a narrow range, decreasing across the three syllabi. The data for *analyse* highlighted the low level of challenging questions testing students' analytical skills.

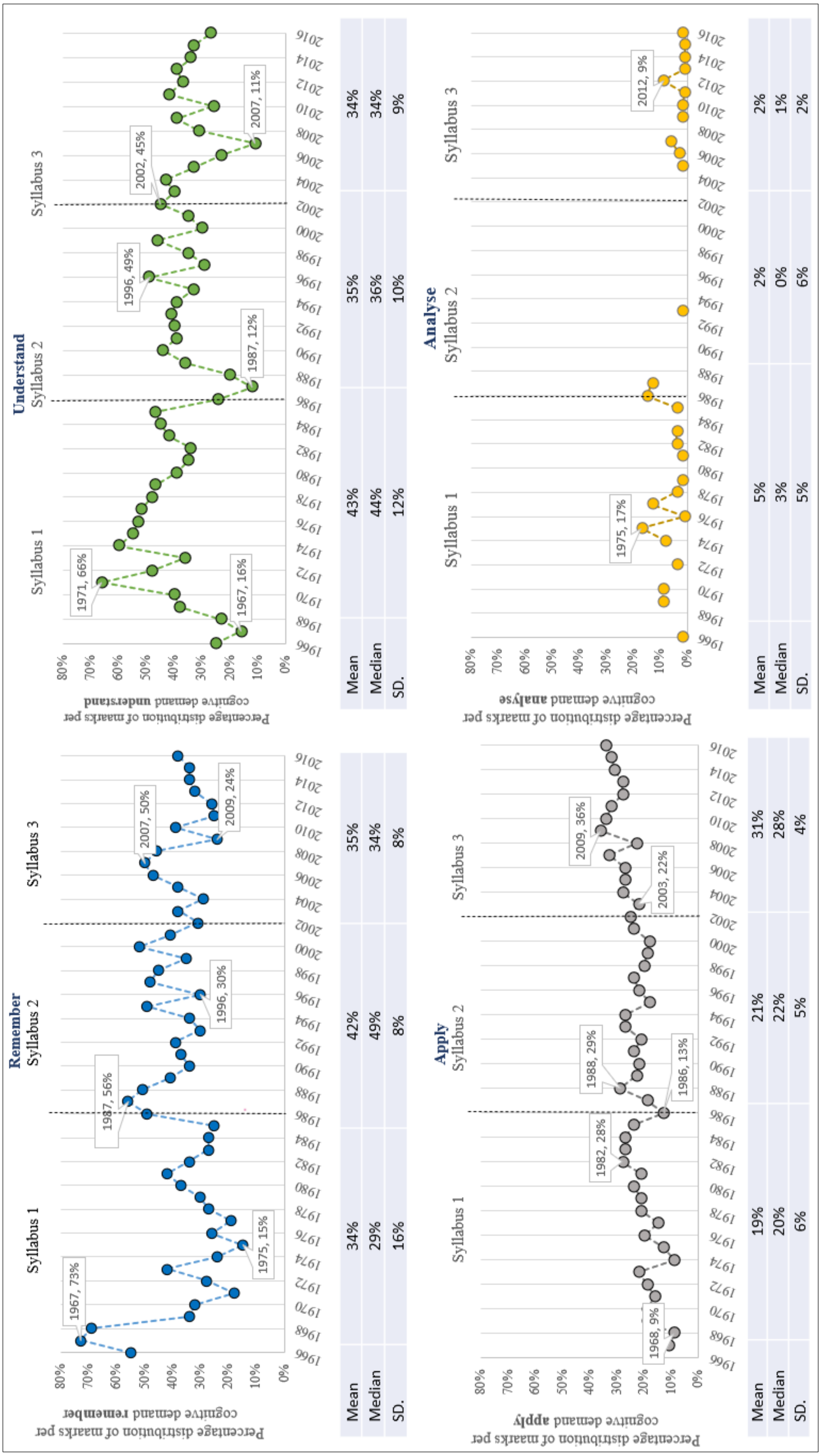


Figure 5.17 Trends of the percentage of marks per cognitive demands in higher-level physics examinations.

Trends in cognitive demands of chemistry examinations 1966-2016

Figure 5.20 shows contrasting trend graphs for the cognitive demands of *remember, understand, apply* and *analyse* for each of the three syllabi for chemistry. Like with physics, the range of the percentage of marks per cognitive demand across the three syllabi was reduced –

Remember: percentage distribution of marks ranged from 17-75% (syllabus C1) through 17-53% (syllabus C2) to 38 - 62% (syllabus C3)

Understand: percentage distribution of marks ranged from 33-63% (syllabus C1) through 24-51%(syllabus C2) to 23-44% (syllabus C3)

Apply: percentage distribution of marks ranged from 5-34%(syllabus 1) through 18-30%(syllabus C2) to 13- 22%(syllabus C3)

Analyse: percentage distribution of marks ranged from 2-17% (syllabus 1) through 2-11% (syllabus C2) to 1- 4% (syllabus C3)

Secondly, the standard deviation across the three syllabi decreased for *remember* (17-7%) and *understand* (12-6%). Despite being a different subject, it is notable that, like physics, the chemistry data showed that the overall pattern for *remember* was a mirror image of that for *understand.* Once again, the question arises, is this coincidence? Or a result of a lack of longitudinal reviews of the examinations? Patrick (1996), while acknowledging the appropriateness of four- or five-year reviews, also indicated that comparisons made over more extended periods could alert authorities to potential problem areas that merit monitoring and investigating. The standard deviation, for *apply*, across the three syllabi, from 8-3%, indicates that the spread of values was within a narrow range, with the percentage of marks allocated to *apply* decreasing across the three syllabi. Like physics, the data for *analyse* highlighted the low level of challenging questions testing students' analytical skills.

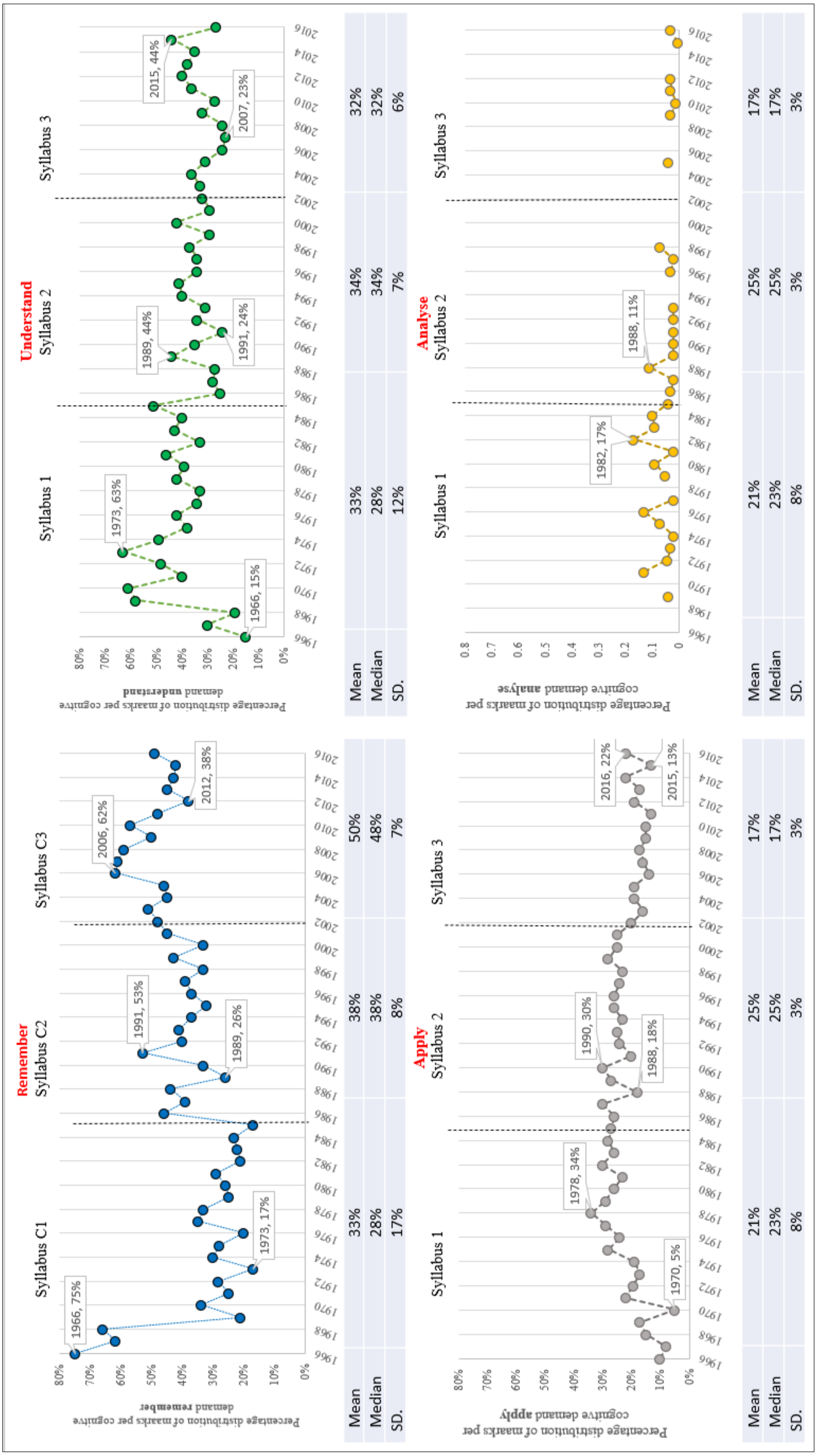


Figure 5.18 Trends of the percentage of marks per cognitive demands in higher LC chemistry examinations 1966-2016

5.4.3. Trends in the question-parts of physics and chemistry examinations

The following brief overview of the examination papers will contextualise the question-parts. Typically an examination paper is comprised of several questions, which in turn contain a number of question-parts. For instance, in examinations based on Syllabus 1, the physics paper had ten questions, and the chemistry paper had eleven questions; in examinations based on Syllabus 2, there were thirteen questions on the physics paper and eleven questions on the chemistry paper; examinations based on Syllabus 3, had twelve questions on the physis paper and eleven questions on the chemistry paper (Malone and Murray, 2016).

Table 5.5 summarises the number of question-parts for each year's physics and chemistry examinations based on the relevant syllabus. For example, the 1997 physics examination comprised twelve questions, and according to Table 5.5, there were 94 question-parts; thus, on average, each of the twelve questions contained eight question-parts.

Table 5.5 Comparison of question-parts in physics and chemistry examinations.

Syllabus 1			**Syllabus 2**			**Syllabus 3**		
Year	Physics	Chemistry	Year	Physics	Chemistry	Year	Physics	Chemistry
	Ten questions per paper	*Eleven questions per paper*		*Thirteen questions per paper*	*Eleven questions per paper*		*Twelve questions per paper*	*Eleven questions per paper*
1966	68	51	1985	75	83	2002	89	73
1967	49	47	1986	72	85	2003	86	76
1968	51	34	1987	65	89	2004	82	82
1969	54	58	1988	80	72	2005	73	80
1970	52	49	1989	80	80	2006	82	88
1971	56	63	1990	76	78	2007	73	88
1972	57	72	1991	74	75	2008	114	83
1973	57	53	1992	79	72	2009	74	77
1974	60	75	1993	76	74	2010	78	84
1975	57	81	1994	65	62	2011	67	76
1976	67	66	1995	85	73	2012	76	80
1977	57	85	1996	74	111	2013	115	82
1978	63	82	1997	94	82	2014	98	84
1979	64	92	1998	89	72	2015	92	120
1980	62	72	1999	75	73	2016	110	70
1981	65	78	2000	93	76			
1982	69	72	2001	82	80			
1983	72	92						
1984	72	85						
1985	75	83						

Historically, since the first LC examinations in 1925, students have self-selected the required number of questions as indicated on the examination paper. One of the consequences of question options was that all questions had to assess approximately the same cognitive skills to maintain comparability between all the questions (Bramley and Crisp, 2019). According to the authors, such a choice allows for more areas of the syllabus to be treated in the examination, giving students opportunities to self-select their preferred topics. Syllabus 3 for physics and chemistry syllabi each consisted of nine topics, 24 mandatory experiments and two options, all of which were examinable. However, drafters of questions would be required to apply the same marking allocations to all questions, potentially diluting the quality of the examinations (He and Black, 2020).

5.4.4. Trends in procedural and conceptual knowledge questions in higher-level Physics and Chemistry examinations

As outlined in Chapter 3, the Revised Bloom's Taxonomy was presented in a two-dimensional format – the Knowledge and the Cognitive dimensions. The Knowledge dimension encompasses factual, conceptual and procedural knowledge; that is

(a) Conceptual knowledge entails an *understand*ing of concepts which underpins the ability to analyse challenges within this *understanding.*

(b) Procedural knowledge focuses on knowing how and then applying that knowledge to solve problems. (Anderson *et al.*, 2001)

By considering the combination of /defining the two cognitive demands of *remember* and *apply* as a representation of *procedural knowledge* and the combination of the cognitive demands of *understand* and *analysis* as a representation of *conceptual knowledge*, this researcher examined the possibility of exploring the knowledge dimension of the physics and chemistry examinations. Using the cognitive demand data of this study, two other categories, conceptual and procedural, were determined, as the example in Table 5.6.

Table 5.6 Sample table for calculating the categories of Conceptual and Procedural knowledge.

Year	**Remember**	**Understand**	**Apply**	**Analyse**	**Conceptual (understand+ analyse)**	**Procedural (remember + apply)**
1966	55%	35%	18%	2%	(35 +2) = **37%**	(55+18) = **73%**
1967	73%	16%	11%	0%	(16 + 0) =**16%**	(73 + 11) = **84%**
1969	34%	38%	19%	9%	(38 + 9) = **47%**	(34 +19) = **53%**

Figure 5.19 is a possible representation of two categories of the knowledge dimension, conceptual and procedural, as applied to physics examination questions; for examinations based on Syllabi 2 and 3, conceptual knowledge (questions coded for understand and

analyse) garnered between 20-50% of the total marks, whereas procedural knowledge (questions coded for remember and apply) merited between 50-80% of the total marks. Noticeably, the apparent separation of conceptual and procedural knowledge questions for Syllabi 2 and 3 around an axis of symmetry. In comparison, there is no such demarcation for Syllabus 1, inferring a balanced distribution of conceptual and procedural knowledge-based questions for these examinations.

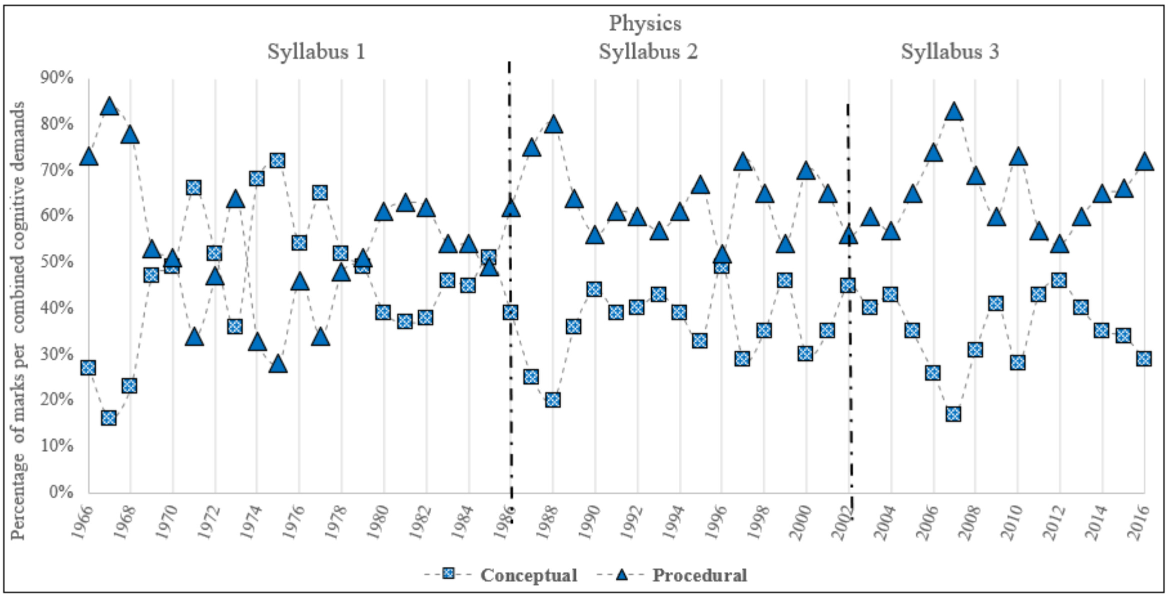


Figure 5.19 Conceptual vs Procedural Knowledge of higher-level physics examinations

A similar comparison of chemistry's conceptual and procedural knowledge levels is presented in Figure 5.20. As with physics, conceptual and procedural knowledge levels for

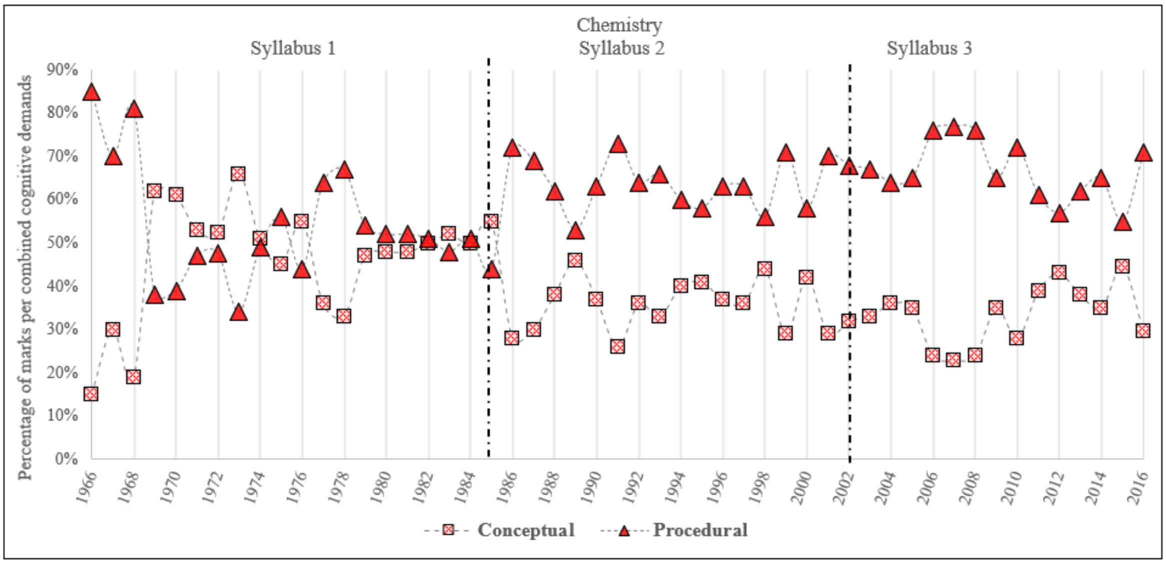


Figure 5.20 Conceptual vs Procedural Knowledge of higher-level chemistry examinations

examinations based on syllabi 2 and 3 highlight the dominance of procedural knowledge questions. The percentage of marks allocated to conceptual knowledge-based questions was between 30-50%.

5.5. Conclusions

This chapter addresses the first research question –

> *What were the cognitive demands of higher-level physics and chemistry examinations from 1966-2016?*

The cognitive demands of higher-level physics and chemistry examination questions were *remember*, *understand*, *apply* and *analyse*. Neither physics nor chemistry examinations had questions coding for the two higher cognitive demands of *evaluate* or *create.*

Between 1966 and 2016, three syllabi in physics and chemistry were implemented. The cognitive demands of the examinations based on each syllabus were determined as described in Section 4.3.1. Figure 5.21 is a graphic representation of the cognitive demands of all the higher-level physics examinations from 1966 to 2016. The cognitive profile indicates that for each of the fifty years, 60-80% of the examination marks were allocated to the combined demands of *remember* and *understand*. Over the years, the percentage of marks allocated to remember increased noticeably for Syllabus 3 examinations.

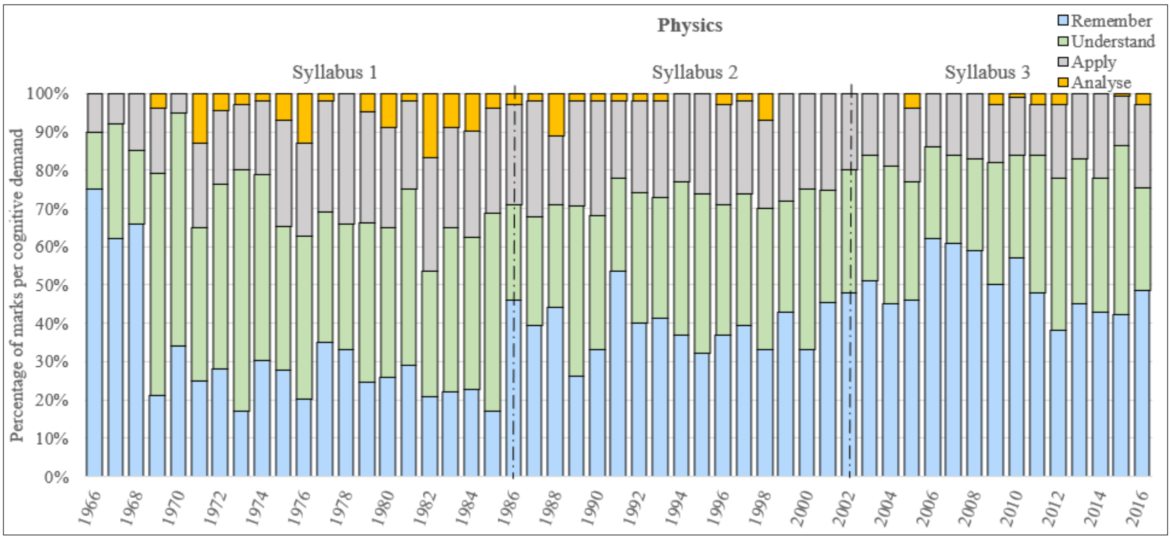


Figure 5.21 Cognitive demands of Higher-level LC physics examinations 1966-2016

While there was what could be termed a creeping decrease in the percentage of marks allocated to *apply*, there was a noticeable decrease in questions assessing *analyse*, with some years not coding any question-parts for this cognitive demand.

Likewise, Figure 5.22 is the graphic representation of the cognitive demands of chemistry for the same fifty-year period. Although the overall combined percentage of marks allocated to *remember* and *understand* was approximately between 55-85%, the data indicated the percentage for *understand* decreased from 65% in the 1970 to 27+% in the 2000s. There was also a noticeable decrease in questions coding for *analysis;* for example, between 1988 and 2004, just one year (1993) had a question-part assessing this demand.

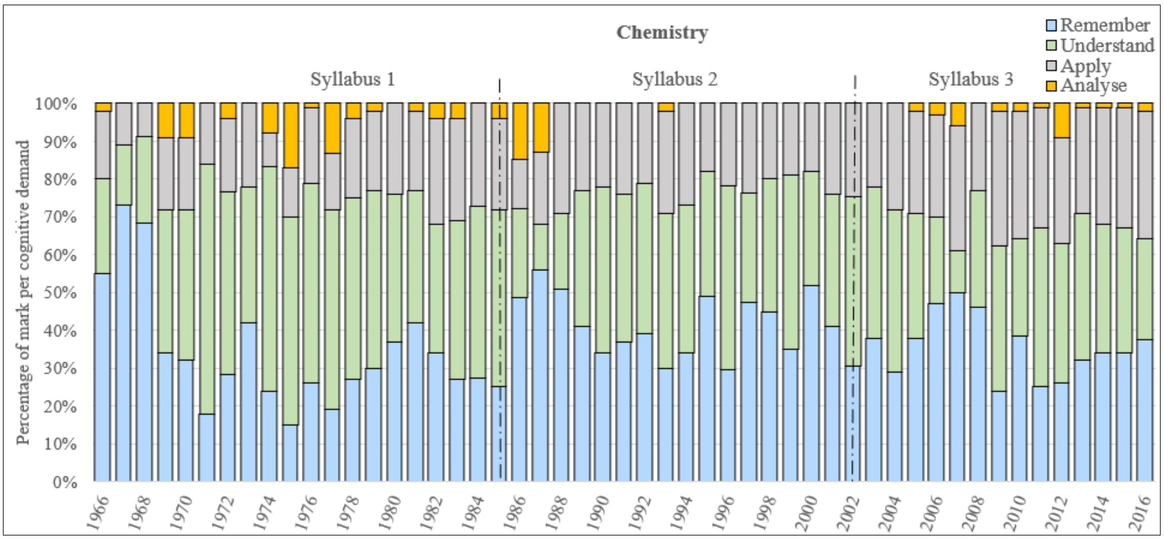


Figure 5.22 Cognitive demands LC higher-level chemistry examinations 1966-2016,

Writing of difficulties encountered in their study, Madaus and Macnamara (1970) highlighted the lack of subject objectives.

> On Physics:
>
> *One of the most important questions about any examination is how thoroughly does it sample the universe of questions which might be based on the syllabus. Since the syllabus specifies only topics and not what the student is expected to be able to do with the topics, we cannot really answer the questions.*
>
> (Madaus and Macnamara, 1970a, p. 98)
>
> On Chemistry:
>
> *We cannot confidently answer the question of how well do the chemistry examinations sample the course objectives (course validity), because the course objectives are not stated clearly enough in the syllabus.*
>
> (Madaus and Macnamara, 1970a, p. 105).

The 2000 syllabi for both physics and chemistry were very detailed – the aims of the syllabi, the list of objectives (physics: Figure 2.11, chemistry: Figure 2. 19), clarification on aspects of the syllabus, and *Guidelines for Teachers* (Department of Education and Science, 1999a; Department of Education & Science/NCCA, 1998c, 1999d, 1999b). Nevertheless, the cognitive profile of both subjects is not too dissimilar from previous years, despite such a detailed revision of Syllabus 3. In 2019, in Queensland, Australia, the reforming of the senior cycle curriculum centered on developing the students' cognitive skills, appropriate to each subject, (Johnson, Boon and Dinan Thompson, 2022). In their analysis of the cognitive demands of senior physics, chemistry and biology syllabi, the authors found that 59-62% of the cognitive learning objectives favoured lower-order thinking skills. This raises the question- what are the cognitive demands of the objectives of the present Irish physics and chemistry syllabi? This question is particularly pertinent in light of the present Senion Cycle Review being conducted by the NCCA (NCCA, 2022),

Figures 5.17 (physics) and 5.18 (chemistry), showing the trends of the percentage of marks per cognitive demand, highlight the constant disproportional distribution of marks for the cognitive demands of *remember* and *understand* versus those for the cognitive demands of *apply* and *analyse*. Typically between 50-70% of marks for questions coded for *remembe*r and *understand* gives credence to the opinion that the Leaving Certificate examinations in physics and chemistry assessed memory retention and rote abilities rather than a broader range of cognitive capabilities. The relatively low percentage of marks for the cognitive demand of *apply* and the even lower percentage for *analyse* highlights the lack of challenging questions.

In the course of reviewing the examination papers, three aspects emerged that merit consideration, namely

- The choice element – historically, students freely selected what questions to answer.
- The increasing number of question-parts per examination, as illustrated in Figure 5.23
- The time allowed per examination had not changed since 1979; the number of questions to choose from and the required number of questions to answer have increased.

These aspects, individually or collectively, had the potential to encroach on a student's 'thinking time' in framing answers. However, to date, the cognitive demands of the examinations have included a limited number of questions to assess *analyse* and no questions assessing the higher-order skills of *evaluate* or *create.*

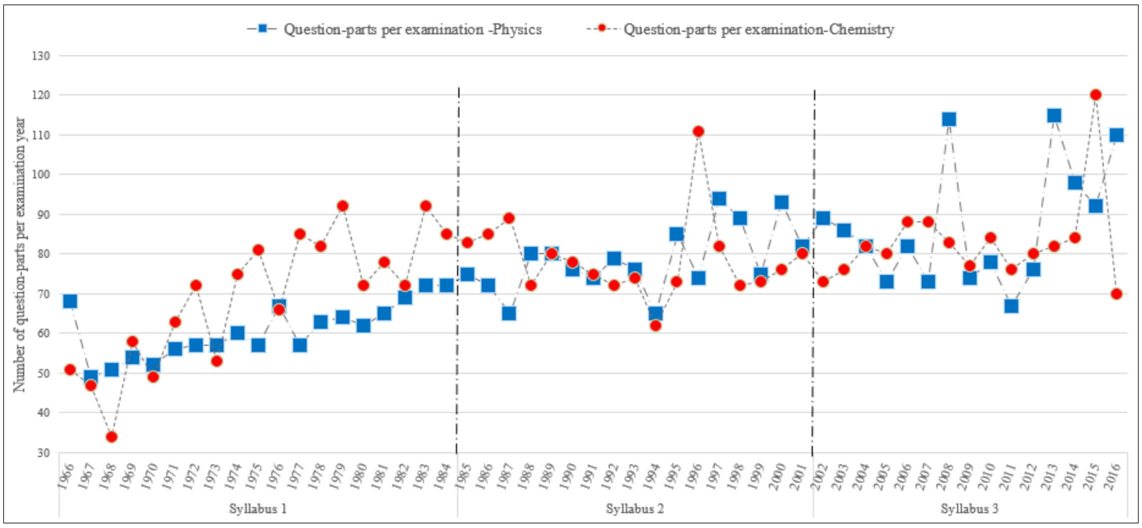


Figure 5.23 Trend of question-parts per examination in physics and chemistry 1966-2016

Leaving Certificate physics and chemistry syllabi and assessment

The introduction revised third syllabi of physics (2002-to present) and chemistry (2002-to present) was supported by a new in-service model, focusing on the needs of local teachers. This form was particularly beneficial given the emphasis placed on the experimental aspects of both subjects. Teachers, individually or as a small group, could request a visit from an Inservice team to address specific needs, for example, how best to manage experimental (such as oscilloscopes, sonometers) and clarify topics or concepts. Such meetings took place in a school laboratory during the school day and lasted about an hour. Published in 2002, the *Task Force on Physical Sciences* presented the first in-depth analysis of the state of physical sciences in Ireland (Central Policy Unit, 2002). It was a forward-looking analysis encompassing issues impacting science education at all levels. Recommendations included more concentration on upskilling teachers in the pedagogy and science content and the need to speed up curriculum reforms, but assessment also needed to support these changes. Of particular interest were several recommendations for the Senior cycle, i.e. Leaving Certificate programme-

- immediate provision for the implementation of assessment of practical work within the sciences,
- conducting feasibility of a new general science subject at Leaving Certificate level (there was a general science course until discontinued in 1969),
- establishing science as a core subject at the lower-second level.

The *Task Force's* report is reminiscent of *Investment in Education* (Department of Education, 1965, 1966). Twenty years after its publication, most of the *Task Force*'s recommendations are still recommendations. In 2018, the SEC issued a detailed report

(SEC 2018) on the feasibility of assessing practical work. Irrespective of the positive outcomes of the report, it was deemed not cost-efficient, an outcome reminiscent of the cost-benefit vs cost-efficient debates of the 1960s (Whitaker, 1958; Department of Finance, 1964; OECD, 1968). As this trial was within the context of draft specifications (previously referred to as syllabi), it is worth recalling that the 2000 syllabi (that is, syllabus 3 in earlier chapters) for physics and chemistry referenced practical work as being

> *an integral part of each subject but that it will initially be assessed through the medium of the written examination paper. An element of practical assessment may be included as part of the overall assessment at a later stage.*
>
> (Department of Education & Science/NCCA, 1998c, p. 3)

In 2022 two reports were issued: *Leaving Certificate Reform: The Need for a New Senior Cycle* (Joint Committee on Education, Further and Higher Education, Research, Innovation and Science, 2022) and *Senior Cycle Review: Advisory Report* (NCCA, 2022). Together they present a forward-looking all-encompassing agenda. The NCCA report noted that:

> *There was a recognition that Leaving Certificate examinations, set and administered by the State Examinations Commission, which are seen as enjoying widespread public trust and support, should continue to feature in assessment arrangements.*
>
> (NCCA, 2022)

Reviewing the past fifty years of the examinations highlighted the static nature of the Irish examination format and the high percentage of examination marks assessing the cognitive demands of *remembe*r and *understand*.

The second research question centred on the cognitive demands of international examinations to investigate the possible adaption of questions to enhance the Irish physics and chemistry examinations. The outcome of this second investigation is detailed in Chapter 6.

Chapter 6 Analysis of International 2016 physical sciences examinations

6.1. Introduction

In the early 1960s, the OECD emphasised the role of second-level education, particularly science education, as the pathway to economic stability and prosperity (Blöndal, Field and Girouard, 2002; Bürgi, 2016). At the same time, the International Association for the Evaluation of Educational Achievement (IEA. https://www.iea.nl/) was established to conduct independent studies to compare international education systems. Since the early 1990s, participation in international large-scale assessments (ILSAs) such as the OECD's Programme for International Student Assessment (PISA. https://www.oecd.org/pisa/) and the IEA's Trends in International Mathematics and Science Study (TIMSS. https://www.iea.nl/studies/iea/timss) increased, with the outcomes or findings leading to more significant analysis of knowledge and skills within education systems (Blöndal, Field and Girouard, 2002; Schmidt and Burroughs, 2013; Addey *et al.*, 2017; Braun and Singer, 2019; Verger, Parcerisa and Fontdevila, 2019). However, the remit of the various ILSAs ((Rocher and Hastedt, 2020), the target groups to be assessed, and the nature of the internationally agreed assessment metrics differ. PISA, for example, sets out to measure 15-year-olds' skills and competencies in the areas of reading, mathematics and science knowledge as presented in real-life situations. TIMSS, on the other hand, focuses on the knowledge and skills in mathematics and science as taught in the second year of lower second-level education. Although the assessment metrics for these ILSAs are internationally agreed upon, they are limited by the impossibility of addressing different curricula and specifications of the participating countries. Hence, while there is agreement on what topics/questions are posed in the ILSAs, there may be aspects of questions or even total questions when students in particular countries lack adequate familiarity or knowledge.

In many countries, the end of upper second-level education is marked by public examinations based on specifically drawn-up programmes approved by the relevant education bodies. Dufaux (2012) describes such "high-stakes examinations" as 'assessments for qualification and certification' as they provide access to third-level education, be it academic or vocational, as well as direct entry to the workforce (Kellaghan, 1996; Dufaux, 2012; Kellaghan and Greaney, 2020). While comparing the curricula of different countries can provide insight into the topics and approaches suggested by curricular bodies, comparing the examinations taken at the end of the upper second-level education across countries provides a different insight into the emphasis placed on expected outcomes. As discussed in Chapter 3, the Revised Bloom's taxonomy, as well as providing a framework within which to assess the alignment of the examinations with associated curricula, can facilitate the comparison of the cognitive demand levels of high-stakes examination papers of different education systems (Edwards, 2010; Lee *et al.*, 2017).

Chapter 5 analysed the cognitive demand levels of the Irish Leaving Certificate examination questions in physics and chemistry for 1966-2016. The emphasis on questions coded as *remember*, *understand* and *apply* was notable, with no questions addressing the higher-order demands of *evaluate* or *create*. The focus of Chapter 6 is the second research question, which is

> *Was there a similar range of cognitive demands in selected comparable high-stakes written physics and chemistry examinations in other countries in the Irish Leaving Certificate examinations in these subjects?*

As the last year of the review of the Irish Leaving Certificate physics and chemistry examinations was 2016, it was apt to consider how that year's findings compared to 2016 examination questions in physics and chemistry in other countries. Each of the selected examinations covered a range of topics; comparing the cognitive demand levels as reflected in the examination questions and comparing the cognitive demand levels across examination topics was conducted.

This chapter presents the analysis of this investigation. Section 6.2 gives details of the selection process adopted in choosing the countries. Details of the relevant examination papers selected in each country are also outlined. The analysis of 2016 physics examination papers from the selected countries is detailed in Section 6.3. This section compares cognitive demand levels (i) across the examinations and (ii) across comparable topics in physics. A A similar analysis of the chemistry examinations across the selected countries is presented in Section 6.4, while Section 6.5 discusses the overall findings from these studies.

6.2 Selection of Countries and Examination Papers for Study

As the last year of the analysis of the Irish Leaving Certificate physics and chemistry examinations in Chapter 5 was 2016, it was apt to consider how that year's findings compared to 2016 examination questions in physics and chemistry in other countries. The first task of this study was to decide how to select the appropriate countries for comparison. In *Comparability of Large-Scale International Assessments* (Berman *et al.*, 2020), Perie presents four basic principles for forming a comparability framework, namely.

- Purpose of the intended use of the examination
- The similarity of content upon which the examination is based

- Administration conditions under which the examination is carried out
- The psychometric characteristics of the examinations.

(Perie, 2020)

Based on these principles, the following criteria were applied to select the examination papers from possible countries.

1. The selected examination should be state-wide standardised, designed, administered, and certified by state education authorities.
2. Examination papers and the associated marking schemes should be publicly available. (If the English version is unavailable, a Deepl.com translator will be used).
3. The syllabi upon which the examinations were based are comparable to those of the Irish Leaving Certificate physical (physics and chemistry) sciences syllabi.
4. The examinations should be a written, paper-based assessment, with the examinations independently assessed.
5. Separate examination papers for upper second-level subjects of physics and chemistry.

The following countries fulfilled these criteria: - England, Ireland, the Netherlands, New South Wales (NSW, Australia), Scotland, and South Africa. Including Ireland in this selection facilitated a robust comparison of all six examinations. Meeting the first criterion above, Table 6.1 lists the named high-stakes examination and the relevant body responsible for administrating these examinations on behalf of that state's Department of Education for each selected country.

Table 6.1 High-stakes examination authorises on behalf of each country's Department of Education.

Country	High-stake examination	Examining authority
England	**A-levels**	Office of Qualifications & Examinations Regulation (Ofqual)
Ireland	**L**eaving **C**ertificate (**LC**)	State Examinations Commission
the Netherlands	**H**oger **A**legmeen **V**oortgezet **O**nderwijs (**HAVO**)	Board for Tests and Exams
NSW	New South Wales **H**igher **S**chool **C**ertificate (**HSC**)	Education Standards Authority
Scotland	**Higher** National Qualifications (**Highers**)	Scotland Qualification Authorities
South Africa	**N**ational **S**enior **C**ertificate (**NSC**)	Department of Basic Education

England does not offer a single state-wide standardised examination as did the other countries. Instead, Ofqual regulates syllabi, qualifications, examinations and assessments offered by separate entities called Examining Boards, as shown in Table 6.2. These boards are responsible, to Ofqual, for setting and awarding education qualifications at lower and upper second-levels, such as A-levels and General Certificate of Secondary Education (GCSE). Schools are not restricted to selecting any one board and may select examination papers from any of the examination boards as listed in Table 6.2. The 2016 physics examination papers chosen for this study were set by Edexcel and the chemistry examination papers by AQA, as both the syllabi and the examination papers set by these Examination Boards closely resembled the syllabi and examination papers of the other selected countries.

Table 6.2 Examining Boards in England approved by Ofqual

Examining Board	Weblink for examination papers
Assessment & Qualification Alliance (AQA)	https://www.aqa.org.uk/
Oxford, Cambridge & RSA Examinations (OCR)	https://www.ocr.org.uk/
Edexcel Pearson-London Examinations (Edexcel)	https://qualifications.pearson.com/en/home.html

The examination papers, relevant marking schemes, examination reports and respective syllabi were freely available online for the selected countries satisfying the second and third criteria listed above. The secondary school system in Australia follows a national curriculum framework, with each of the six states setting its own end-of-upper second-level education terminal examinations. The physical sciences syllabi and examination papers from New South Wales (NSW) were considered comparable to those of the Irish Leaving Certificate and the selected countries.

The fourth criterion above focused on the similarity of the administrative conditions set out for the examinations in each of these countries, as shown in Table 6.3. All the examination papers contained advice regarding the maximum time for the examination, the number of questions to be answered, along with the maximum marks available. However, all the papers contained a number of sections, i.e., Section A, Section B, and Section C. The NSW examination papers were unique in including a suggested time-management strategy of 35 minutes to complete Section A, an hour and forty minutes for Section B and 45 minutes for optional sections. The England examination papers advised students that the spaces provided may be more than is required for the expected length of the answer. In contrast, the NSW papers noted that the spaces provided indicated the expected length of answers.

Table 6.3 Administrative conditions of 2016 Physics and Chemistry examination papers in each country

Exam	Time allowed	Number of questions per paper		Required number of questions to answer		Maximum marks possible	
	(hours)	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry
England	3	32	47	32	47	160	160
Ireland	3	12	11	8	8	400	400
the Netherlands	3	27	33	27	33	79	77
NSW	3	35	35	31	31	200	200
Scotland	2.5	24	12	24	12	130	100
South Africa	3	10	10	10	10	150	150

Three examinations, England, NSW and Scotland, required answers in a proforma booklet. Proforma answer booklets were not provided in the other three countries (Ireland, the Netherlands and South Africa). A data and relationships/equations list was included as an integral part of the England, NSW, South Africa and Scotland examination papers. The Netherlands' science reference book, *BiNaS*, used in upper second-level and third-level education, was available for use during all examinations by the students. The title refers to the three sciences- biology (**Bi**ologie), physics (**Na**tuurkunde) and chemistry (**S**cheikunde). Within the Netherlands questions, students were directed to relevant pages in *BiNaS* for relevant data. The booklet *Formulae and Tables* was available in all State Examinations in Ireland. However, there was no internal reference to these data sheets or the booklet in the LC examination questions.

6.3. Analysis of 2016 Physics Examinations across six countries

The syllabus for each country was reviewed using the relevant weblinks in Appendix C. A summary of the topics in each syllabus upon which each country's examination was based is presented in Table 6.4. A number of topics were present in all the syllabi, albeit named differently; for example, the Netherlands topic of *Movement & Energy* focused on Mechanics and *Measure & Control* focused on Electricity; the NSW topic of *Space* included the application of Newtonian physics while the topic *Motors & Generators* focused on the societal impact of electricity. The Ireland option *Applied Electricity* and the NSW *Motors & Generators* contained the same content.

Table 6.4 Summary of physics syllabus in the six countries.

England	Ireland	Netherland	NSW	Scotland	South Africa
Newtonian Mechanics	Mechanics	Movement & Energy	Space	Mechanics	Mechanics
Waves & particle nature of light	Light	Image & Sound	Motors & Generators	Light	Sound & Light
Matter	Vibrations & Sound	Measure & Control	Geophysics – (option)	Waves	Waves
Mechanical properties of matter	Waves	Earth & Universe	Astrophysics-option	Electricity	Electricity & Magnetism
Electric circuits	Electricity	Materials	Motors & Generators	Atom	
Fields	Modern physics	Physics & Technology	Medical physics-(option) Age of Silicon (option)	Nuclear physics	
Quantum & nuclear physics	Particle physics-(option)		Quanta & Quarks-option	Relativity& Universe	
	Applied electricity-(option)		Physics Skills	the Electron	
	Heat & Temperature				

A list of the topics common to the six 2016 physics examination papers is presented in Table 6.5. Each examination paper had questions based on *Mechanics*, *Electricity, Wave motion* and the *Electron*. The Netherlands and Ireland examinations also had questions based on *Heat, Radioactivity and Motors & Generators.* Moreover, these topics covered all questions on the examination papers.

Table 6.5 Topics common to the 2016 physics examinations across the selected countries

Country	Mechanics	Heat	Electricity	Wave motion	Radioactivity	Electron	Motors & Generators
England	✔		✔	✔		✔	
Ireland	✔	✔	✔	✔	✔	✔	✔
the Netherlands	✔	✔	✔	✔	✔	✔	✔
NSW	✔		✔	✔		✔	✔
Scotland	✔		✔	✔		✔	
South Africa	✔		✔	✔		✔	

The syllabi and examination types of a number of countries, including Denmark, Finland, New Zealand, Norway and Sweden, were considered. However, England, the Netherlands, NSW, Scotland and South Africa were deemed most suitable for comparison with Ireland. The following section details the results of analysing the cognitive demands of the physics examination questions across these countries.

6.3.1 Cognitive demand levels across the physics examinations

The six countries' cognitive demand levels of the 2016 examination paper were determined according to the approach presented in Section 4.3.2. The analyse shown as the percentage frequency distribution of the cognitive demand levels, calculated from the total marks per examination paper, are set out in Table 6.6. [As there were no questions (and hence marks) assigned to the cognitive demand *create*, this column is not included]

Table 6.6 Percentage frequency distribution of total marks per cognitive demand levels of physics across countries.

	Remember (%)	***Understand* (%)**	**Apply (%)**	**Analyse (%)**	**Evaluate (%)**
England	9	26	42	16	7
Ireland	**37**	23	36	2	1
the Netherlands	0	5	**70**	11	14
NSW	13	**37**	22	18	11
Scotland	9	15	60	1	**15**
South Africa	18	10	65	7	0

Highlights to note from Table 6.6 are

- the high percentage of marks by Ireland (37%) for questions coding for cognitive demand of *remember* in comparison to the low range of 0-18% for the other five countries
- the high percentage of marks assigned by NSW for *understand* (37%)
- Questions coding for *apply* dominated examination papers of the Netherlands (70%), Scotland (60%) and South Africa (65%)
- The cognitive skill of *analyse* was strongly assessed by NSW (18%), in sharp contrast to the low percentage of Ireland and Scotland at less than 2%.

However, Table 6.6 presents an overview of the percentage frequency distribution of the marks concerning the different cognitive demand levels without referencing how these marks were distributed within the examination questions. Consequently, further analysis of the examination questions was carried out, which focused on aligning question-parts and allocating marks to the respective cognitive demands (as described in Section 4.3.2). This extension allowed for a more in-depth comparison of the distribution of the cognitive demands across the six examinations, as will be seen in the following sections, which will discuss each cognitive demand separately.

Comparison of cognitive demand – *Remember*

The percentage of marks assigned for the cognitive demand *remember* was less th
an that of question-parts coding for the same cognitive demand (Figure 6.1). Excepting Ireland and the Netherlands, the percentage of marks assigned to *remember* varied between 9% and 18% of the total marks available (see Table 6.6). The corresponding percentage of question-parts was somewhat higher, ranging between 13% and 25%.

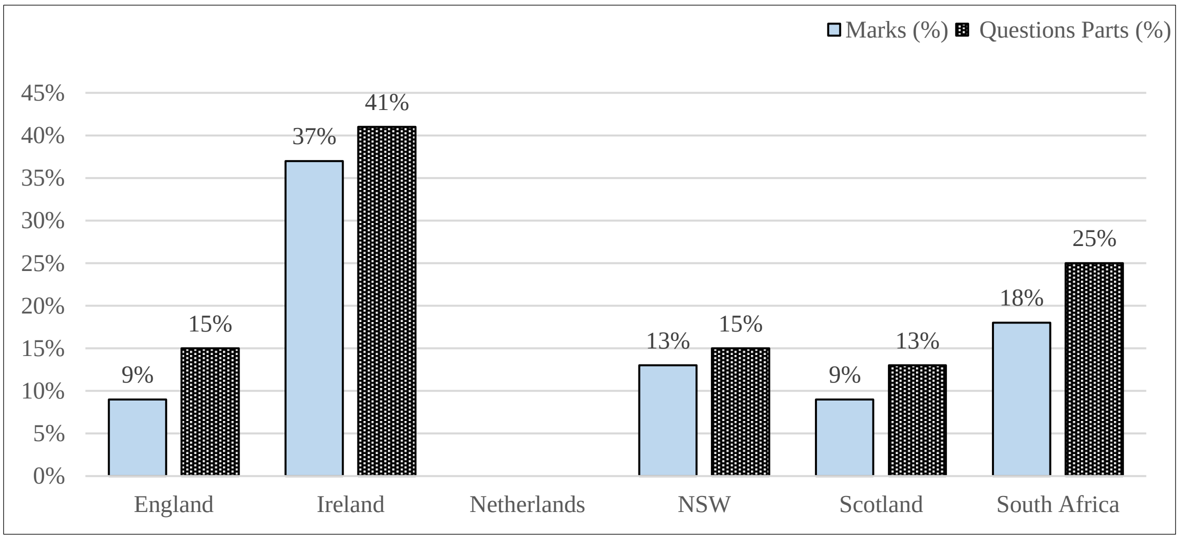


Figure 6.1 Country comparison of marks (%) to question parts (%) to remember

The zero allocation of marks in the Netherlands questions can be explained by examining the supporting documents. The syllabus of the Netherlands, as well as indicating the context of the specifications and targets to be attained included such terms as 'assumed' or 'prior knowledge was', that is, physics knowledge and skills that were considered to have been covered in the lower grades… and therefore do not need to be learned from scratch (Examenblad.nl, 2016). Hence the absence of any data for *remember*. In contrast, Ireland assigned the highest percentage (37%) of the total marks to this cognitive demand. A breakdown of the twelve questions on the LC examination paper (Table 6.7) indicated 45 question-parts coding for *remember* spread across the questions. Nine of the twelve questions consisted of multiple question-parts. For example, the highlighted question 4, was composed of six question-parts, three of which coded for *remember* (3/6); the total marks allocated to that question was 40, of which 21 marks were assigned to these three questions parts resulting in 53% of the marks (21/40) allocated to question-parts coding for *remember*. In addition, Table 6.7 shows an uneven distribution of marks assigned to question-parts coding for *remember*. For example, questions 2 and 4 each had three question-parts, yet the marks allocated were 18 and 21, respectively, despite both questions being allocated the same total mark (40).

Table 6.7. Distribution of percentage of marks per question-parts coding for **remember** *- Ireland*

Question number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
No. question-parts/Total	**0**/7	**3**/6	**1**/5	**3**/6	**6**/11	**2**/9	**4**/9	**6**/11	**4**/7	**1**/7	**5**/8	**10**/23
Marks /Total	**0**/40	**18**/40	**15** /40	**21** /40	**42** /77	**6** /56	**22** /56	**27** /56	**26** /56	**6** /56	**35** /56	**47** /140
Marks (%)	**0**	**45**	**38**	**53**	**55**	**11**	**39**	**48**	**46**	**11**	**63**	**34**

It was noted that these *remember* question-parts sometimes were

(i) At the start of a question,

(ii) mid-way through a question,

(iii) the last part of a question.

For example, the topic of question 7 (Heat) had four question parts which coded for *remember*. The first two were at the start of the question,

- *Distinguish between heat and temperature*
- *State the principle of energy*

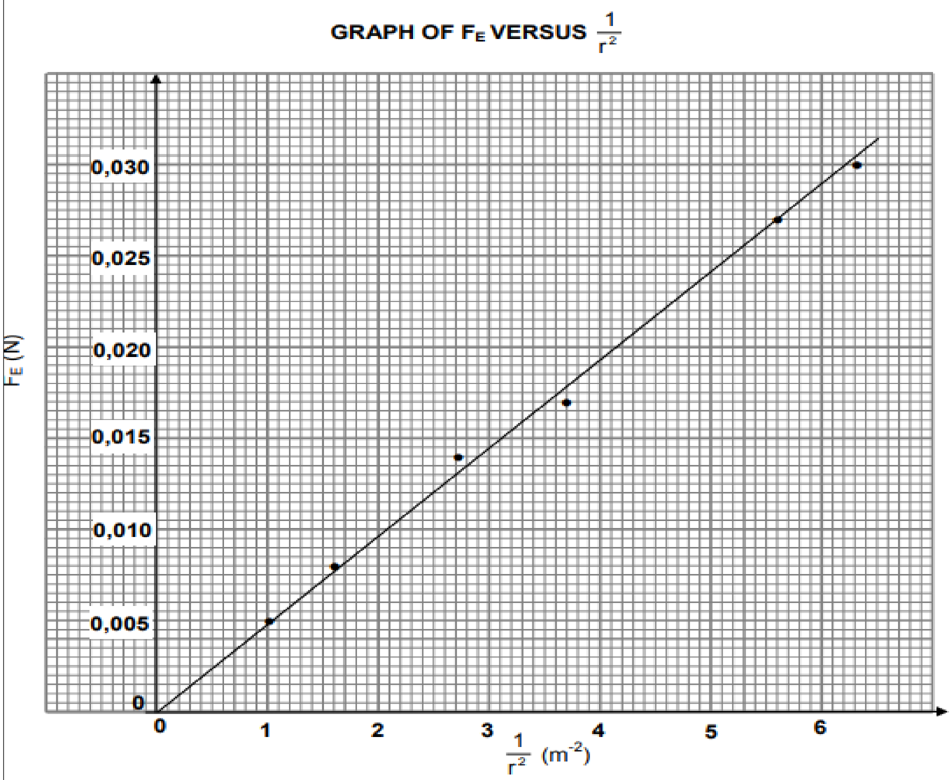
with the following two question-parts mid-way through the question

- *Describe the operation of a heat pump*
- *State two desirable physical properties of the fluid used in a heat pump.*

This was in sharp contrast to the South African examination. This examination allocated less than 20% of the total marks to a quarter of the total number of question-parts coding for *remember*, i.e., fourteen question-parts. Ten were definitions or asking to state a named principle/law. Furthermore, most of the question-parts were the first question-part of a question and so could be regarded as a cue for answering the rest.

Sample question 7 from the South African examination (Figure 6.2) illustrates this. The question presents the context with a brief description of an experiment and an accompanying graph. Both question-parts 7.1.1 (*State Coulomb's law in words*) and 7.1.2 (*Write down the dependent variable of the experiment*) are coded for *remember*. These served as cue prompts which the student should then use to answer question-part 7.1.3. Question-part 7.1.4 challenged the student to apply all this information to calculate the charge on each sphere. It should be noted that this last question-part was assigned the highest mark of the four question-parts (6 marks).

7.1 In an experiment to verify the relationship between the electrostatic force, F_E, and distance, r, between two **identical**, positively charged spheres, the graph below was obtained.



7.1.1	State Coulomb's law in words.	(2)
7.1.2	Write down the dependent variable of the experiment.	(1)
7.1.3	What relationship between the electrostatic force F_E and the square of the distance, r^2, between the charged spheres can be deduced from the graph?	(1)
7.1.4	Use the information in the graph to calculate the charge on each sphere.	(6)

Figure 6.2 Copy of Question 7 - South African 2016 Physics examination paper.

The other three countries (England, NSW and Scotland) followed a similar pattern to South Africa hence the low percentage of marks and question parts coded for *remember*.

Overall, the percentage of marks (less than 18%) and the use of remember type question-parts (less than 25%) reflected the low emphasis placed by countries on this cognitive demand. Typically, such question-parts were used as cue prompts for the remainder of the questions. In contrast, most of the questions on the Irish examination contained multiple *remember*-type question-parts scattered within the questions indicating a high reliance on memory recall skills. Furthermore, this high reliance was supported by allocating a high percentage of marks to a comparably high number of question-parts.

Comparison of cognitive demands – *Understand*

Data for the cognitive demand *understand* for each country is presented in Figure 6.3. Again, the percentage of total marks assigned to this cognitive demand was less than the percentage of question-parts coding for the same cognitive demand for each country (Figure 6.3). The percentage of total marks allocated to question-parts coding for this demand ranged from 5% (the Netherlands) to 26% (England), except for NSW, which allocated over a third of the total marks available (37%) to 45% of the total question-parts.

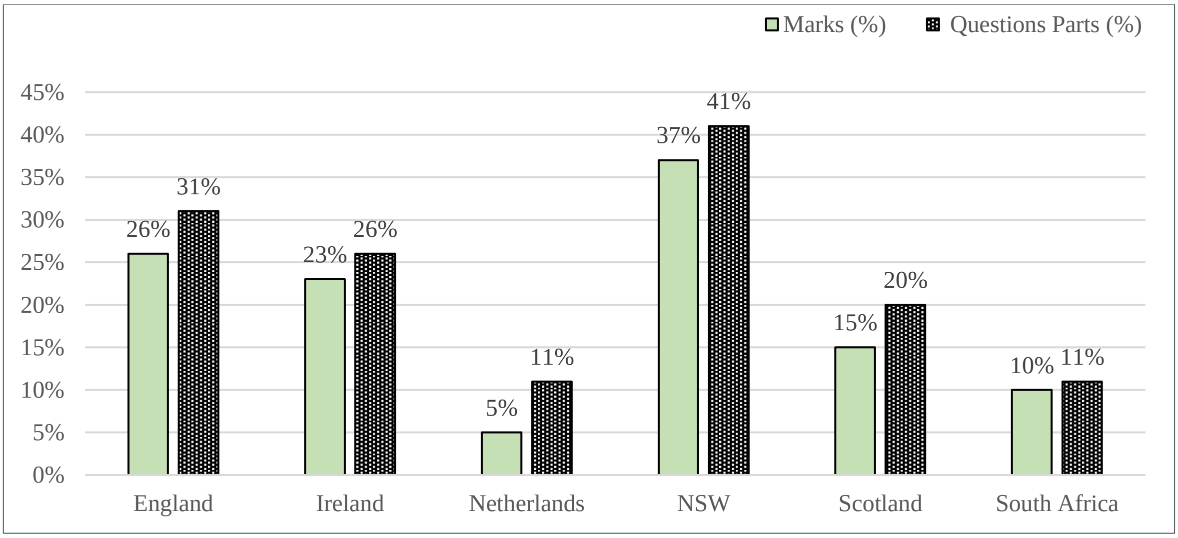


Figure 6.3 Country comparison of marks (%) to question-parts (%) coding for cognitive demand understand

In both the syllabus and the *Marking Feedback* of the NSW 2016 examination, there was an emphasis on understanding. Table 6.8 is a breakdown of all the question-parts and the marks allocated on the examination paper coding for this cognitive demand. The percentage of marks assigned to these ranged from 32% (question 31) to 52% (questions 32 and 34). [Questions 24-29 did not code for *understand*]

Table 6.8 Percentage marks per question in NSW physics assigned to understand

Question No.	**1-20***	**21**	**22**	**23**	**30**	**31**	**32**	**33**	**34**	**35**
Question-parts/ total	**11**/20	**1**/2	**1**/2	**1**/2	**1**/2	**4**/7	**3**/7	**2**/7	**3**/7	**2**/7
Marks/total	**10**/20	**2**/5	**2**/6	**3**/6	**3**/6	**11**/25	**13**/25	**8**/25	**13**/25	**10**/25
Marks %	**50**	**40**	**33**	**50**	**50**	**44**	**52**	**32**	**52**	**40**

* = Multi-choice questions.

At the same time, the *Marking Feedback* highlighted a number of questions which showed the strength of students in the areas of understanding, such as

- *understanding that a voltage or an electric field has an effect on the direction of an electric charge within deflection plates* (as in Q.23a. Explain the role of the deflection plates in displaying voltage changes applied to the input of a cathode ray oscilloscope).

The Netherlands and South Africa examinations allocated low marks to a low percentage of question-parts coding for *remember*. The Netherlands allocated a low percentage of marks to three question-parts coding for *understand.* The question-parts coding for *understand* were based on the diagram Figure 6.4. The context of this question was *Vibrations in a truck* which focused on the damage vibrations of a truck's engine can cause to a truck driver's back. There were five question-parts to this question. Figure 6.4 shows the part coded for *understand.*

Vibrations in a truck

A truck driver often suffers from vibrations caused by the truck's engine. These vibrations are transmitted to the driver through the driver's seat. If the seat sinks too far when the driver sits on it, the seat spring is replaced by a spring when the spring constant (u) increases as the force on the spring increases. Figure below is a (F,u) diagram for three different springs.

Q.3(iv) Which spring (A,B,C) is the most suitable for this driver?

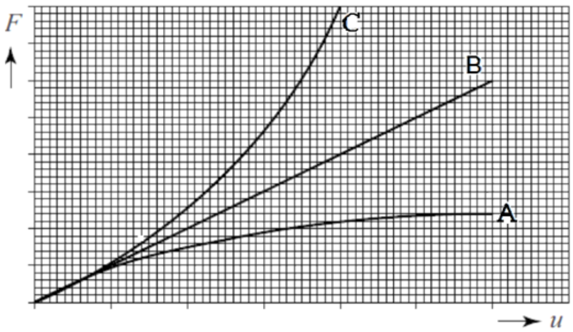


Figure 6.4 Question 3 (iv) The Netherlands 2016

Similarly, the six question-parts coding for understand *in the South African examination centred on a diagram, as in Figure 6.5*

Question 9.1

A generator is shown below. Assume that the coil is in a vertical position.

Is the generator AC or DC? Give a reason for the answer.

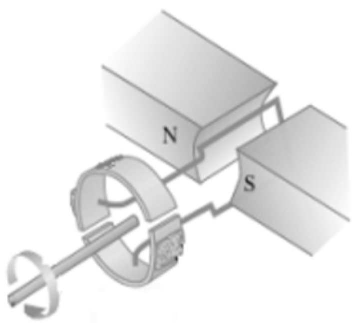


Figure 6.5 Question 9. South Africa 2016 Physics examination.

Compared with the percentage of marks allocated to the cognitive demand, *remember*, there was an increase in the percentage of marks allocated to the cognitive demand *understand*, except for Ireland and South Africa, which showed a decrease. Overall, there was an increase in the number of question-parts coding for these cognitive levels. Consequently, combining questions which coding for *remember* and *understand* accounted for between 20% and 60% of the total marks across all the examinations.

Comparison of cognitive demand – *Apply*

The percentage of total marks coding for the cognitive demand *apply* was somewhat greater than the percentage of question-parts to be answered (Figure 6.6), reversing the trend shown for the previous two cognitive demands. Three countries, the Netherlands, Scotland and South Africa, assigned over 60% of marks to question-parts coding for *apply*. The other three assigned a lower percentage (less than 43%) of the marks to the same cognitive demand.

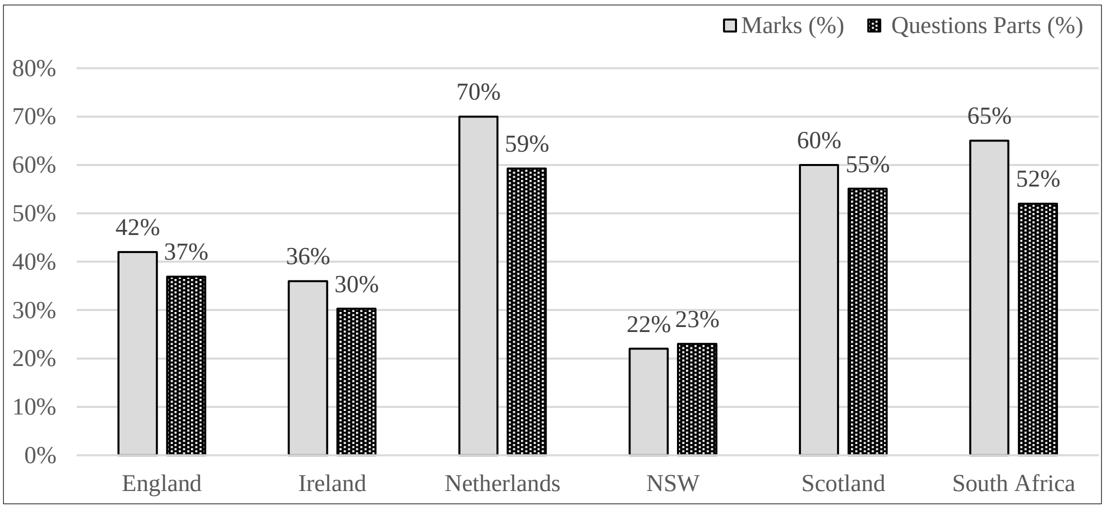


Figure 6.6 Country comparison of marks (%) to question-parts (%) coding for cognitive demand apply

In examining the question parts coding for this demand, three different types of questions were identified, i.e. –

Type 1. Question-parts which were solely based on calculations e.g.

Calculate the resistivity of graphite. (England, paper1,Q.16b)

Type 2. Question-parts which involved graphs/data as a basis for calculations, e.g.

In an experiment to investigate the variation of f, the fundamental frequency of a stretched string, with its length, l, the following data was recorded.

f(Hz)	*256*	*288*	*320*	*341*	*384*	*427*	*480*	*512*
l(cm	*51.3*	*42.6*	*39.2*	*37.7*	*34.5*	*30.3*	*26.0*	*25.0*

Draw a suitable graph and use it to calculate (i) the length of the string at a frequency of 192Hz and (ii) the mass per unit length of the string.

(Ireland, Q. 2)

Type 3. Question-parts in which the principle/concept was to be applied in the answer e.g.

Using Huygens' construction to explain the behaviour of light as it travels past the edge of a ball bearing

(England, Q.11a)

The very high percentage marks (70% of the total available marks) allocated by the Netherlands reflected one of the aims of the specifications in that 'the aim is for 50% of the score points to be obtained from questions where an explicit calculation is required for answering' (Examenblad.nl, 2016). The question parts coding for *apply* then were reanalysed to determine the percentage of these involving the verb 'calculate'. Table 6.9 shows that five of the examinations – Ireland, the Netherlands, NSW, Scotland and South Africa - were dominated by question-parts solely requiring calculations, with England being the outlier.

Table 6.9 Country breakdown of coding results for cognitive demand level-Apply

Country	Number of question-parts	Number of 'calculate' action- verb	% 'calculate' action-verb	% of other action-verbs
England	24	11	46	54
Ireland	32	28	88	12
the Netherlands	17	14	82	18
NSW	14	10	71	29
Scotland	40	33	83	17
South Africa	29	24	83	17

As Table 6.9 indicates, over half of the question-parts on the England examination paper were a mixture of question types 2 and 3, for instance

- *Explain in terms of Newton's laws the actions involved in the tug-of-war.*

(England,10b)

- *With reference to the electrons in the LDR, explain the observation.*

(England, 12a)

- *Show that the maximum energy which can be stored in the battery is about 25kJ.* *(England,14a)*

Overall, the range of percentage of marks (23%-70%) compared to that for question-parts (21%-59%) indicated more marks being allocated to a lesser percentage of question-parts. Although three types of 'apply' questions were identified, most of the question-parts were solely based on 'calculate' type 1 questions. It is worth recalling that all examination papers included data sheets with basic formulae.

Comparison of cognitive demand – *Analyse*

The percentage marks assigned to question-parts coding for *analyse* are shown in Figure 6.7. From the data shown in Figure 6.7, there seemed to be three groups of two with similar data i.e.

- England and NSW - the percentage of marks exceeded the percentage of question-parts, indicating that analyse-type questions merited high-value marks.
- The Netherlands and South Africa - the reverse, the percentage of marks less than the percentage of question parts, indicating a low value (marks) return for these question-parts
- Ireland and Scotland –the percentage of marks and percentage of question-parts were equal and very low values (2% or less)

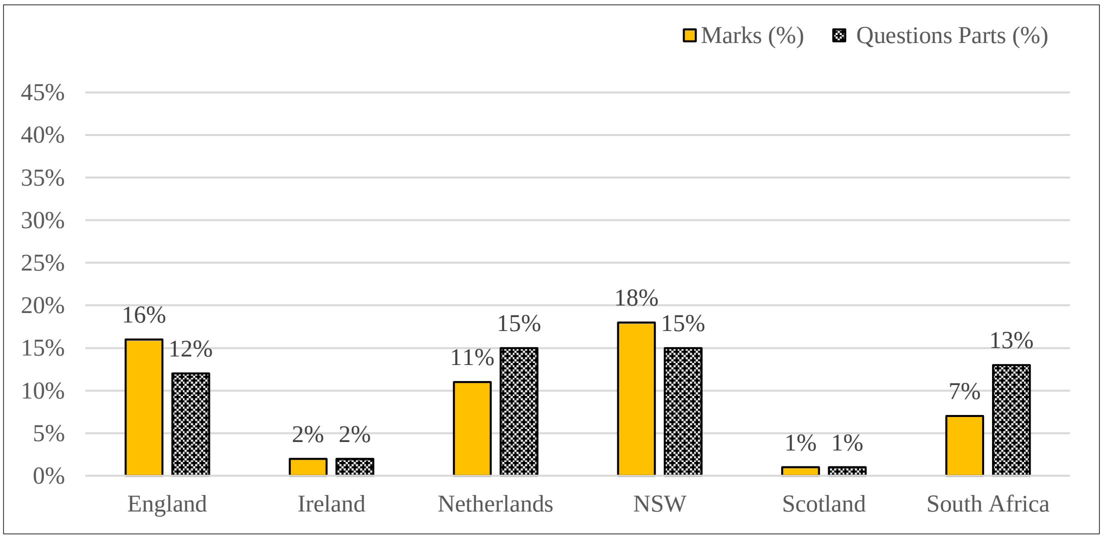


Figure 6.7 Country comparison of marks (%) to question-parts (%) coding for cognitive demand analyse

A survey of the question-parts coding for *analyse* showed they typically fell into one of two types, namely (a) analytic-type essay questions and (b) analysis of graphs. The following question- parts below are an example of an analytic-type essay.

- *One of the students states that the clocks on board the plane run slower when the plane is travelling at relativistic speeds. Explain whether or not this statement is correct.* (Scotland, Q.4)

- *Contrast the use of Doppler ultrasound imaging with the use of computed axial tomography (CAT) imaging. In your answer, include an example of how it is used.* (NSW, Q. 32c)

Examples of graphical analysis question parts are shown in Figure 6.8 (from the Netherlands) and Figure 6.9 (from NSW)

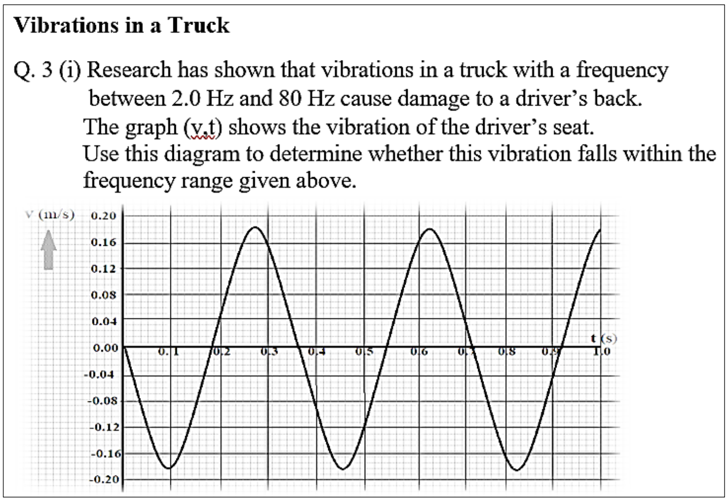


Figure 6.8 Example of question-part coded as Analyse (the Netherlands, Q. 3 i)

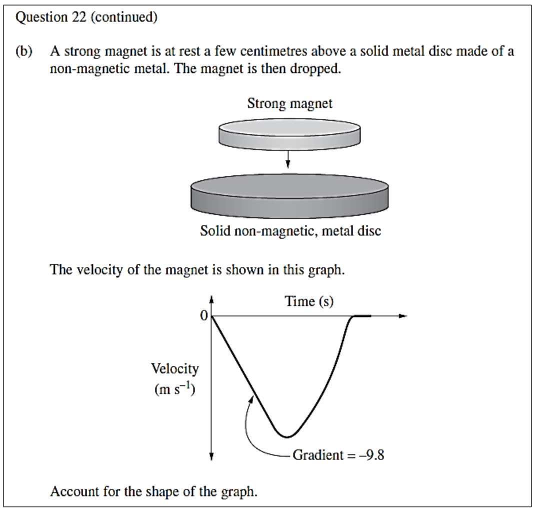


Figure 6.9 Example of question-part coding for analysis (NSW, Q.22 b)

The cognitive demand, *analyse*, is considered higher-order level; hence, question-parts are expected to be more challenging and merit a higher mark than question-parts coding for other levels. For instance, comparing Figures 6.7 (analyse) and 6.1(*remember*), England and NSW allocated a higher percentage mark for *analyse* than for *remember*. However, the percentage of question-parts was comparable for both *remember* and *analyse*. On the other hand, the percentage of marks allocated by South Africa was much less than that for question-parts coding for *remember* and *analyse*. Figure 6.7 shows that the Netherlands allocated less of the mark to more question-parts coding for analysis. This point is further explained in Section 6.3.3.

Comparison of cognitive demand – *Evaluate*

The results of the analysis of question parts coding for *evaluate* are shown in Figure 6.10. Three countries, England, NSW and Scotland, allocated a greater percentage of the total marks to a smaller percentage of question-parts coding for this cognitive demand.

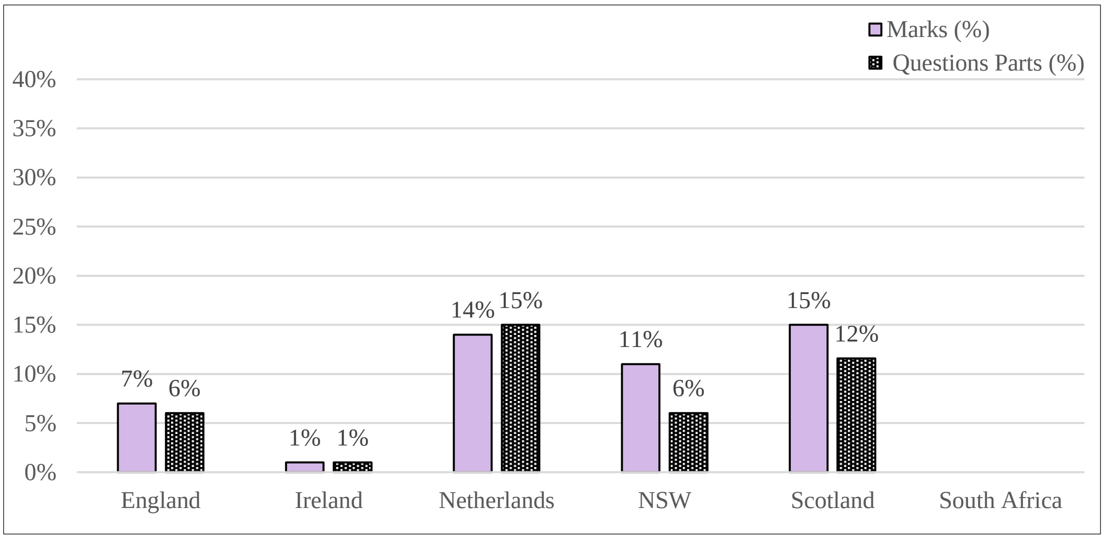


Figure 6.10 Country comparison of marks (%) to question-parts (%) coding for cognitive demand evaluate

The two action-verbs most frequently used in these question parts coding for *evaluate* were assessed and justify. An assess-type question is shown in Figure 6.11, while an example of justify question is

- *Determine which of the quantities, mass m, height h, or mean distance d, has the largest percentage uncertainty. You must justify your answer by calculation.*

(Scotland, Q. 2b)

Two teams carried out independent experiments with the purpose of investigating Newton's Law of Universal Gravitation. Each team use the same procedure to accurately measure the gravitational forces acting between two spherical masses over a range of distances. The following graphs show the data collected. Assess the appropriateness of Team A's data and Team B's data in achieving the purpose of the experiment.

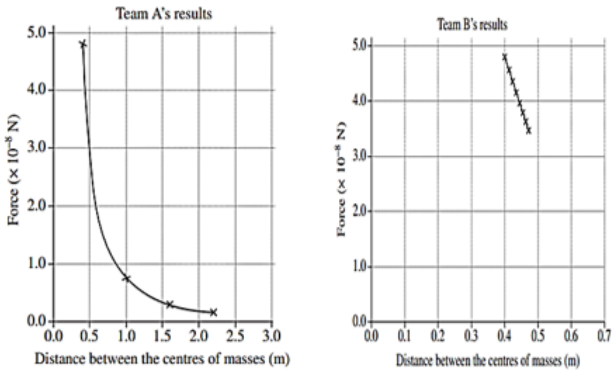


Figure 6.11 Example of question-part coding for evaluate (NSW, Q.25b)

The English examination presented students with a situation where the owner of a mobile phone decided to replace the charging plug (marked 1A, 5V) with one marked 0.5A, 5V. The question asked students

- *by evaluating the information given, discuss the suitability of using the replacement. Include references to possible benefits, disadvantages and risks associated with using the replacement charging plug.* (England, Q.15b)

Of the six countries, the Netherlands and Scotland allocated a greater percentage of marks to these question parts, indicating that these two countries gave this cognitive demand more emphasis. Interestingly, the Netherlands coded the same percentage of question - parts (15%) for both *evaluate* and *analyse* (see Figures 6.7 and 6.10), with a higher percentage of marks assigned to *evaluate* (14%) than to *analyse* (11%).

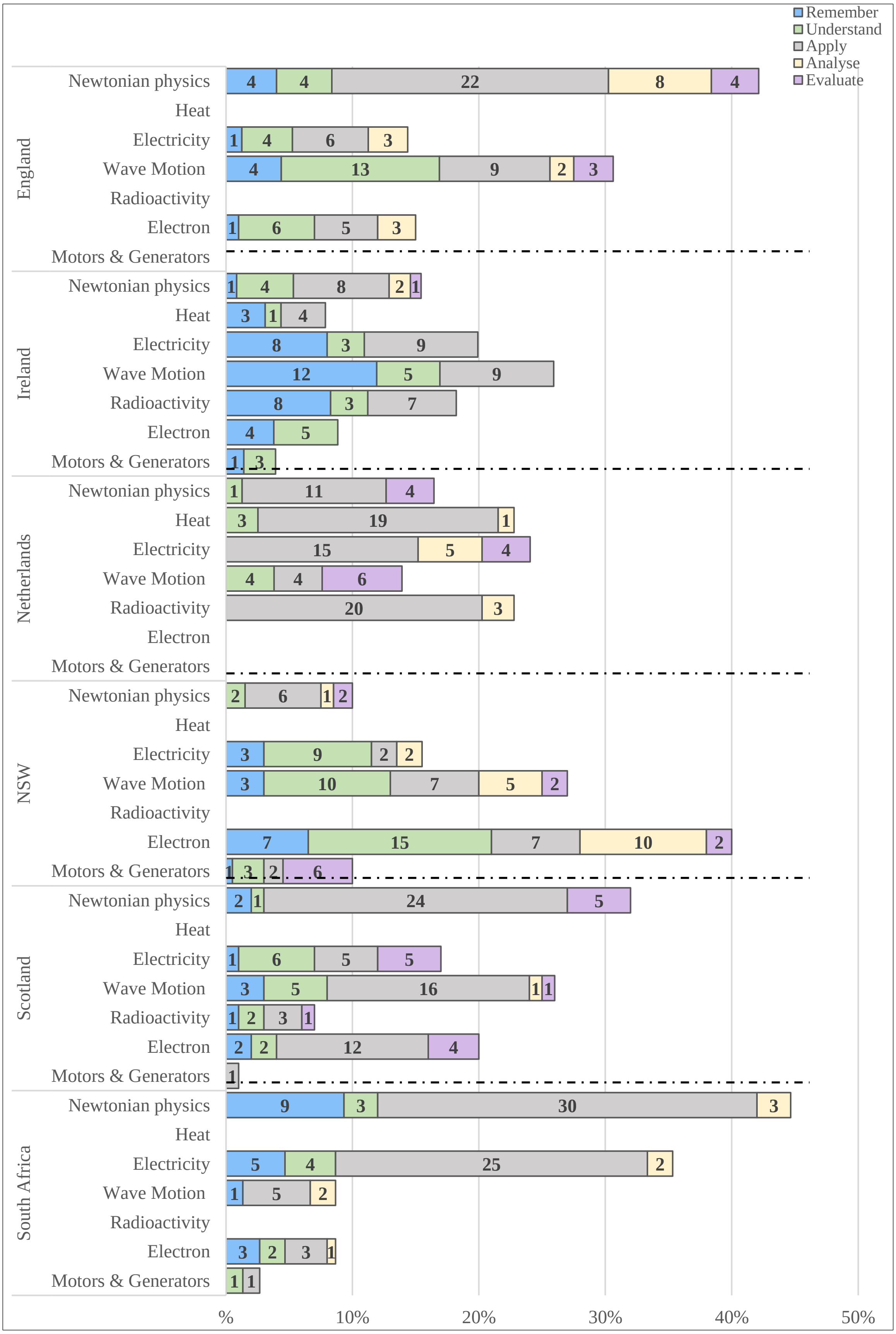
6.3.2. Cognitive demand levels across comparable topics/ concepts in physics

The comparison of the cognitive demands of all examination questions, which led to drawing comparisons between the percentage of marks and the percentage of question-parts coding for these demands, was carried out without reference to the specific topics being examined. These two comparisons prompted the question –

How were these cognitive demands distributed across physics topics, as listed in Table 6.5 in Section 6.3?

As described in Chapter 4, the frequency distribution of the marks per cognitive demands was aligned with the relevant topics from which Figure 6.12 was compiled. This figure presents an overall view of the percentage of marks assigned to the range of cognitive demands across the topics. There are several notable aspects of the data shown in Figure 6.12, as follows.

- Only three of the seven topics - Newtonian physics (England, Ireland), Wave motion (England, NSW, Scotland) and the Electron (NSW) – had marks coded to all five cognitive demands.
- There was a striking similarity between the coding pattern for Ireland and the Netherlands in that the topics assessed no more than three cognitive demands. For Ireland, these were *remember*, *understand* and *apply,* with a high percentage of marks allocated to *remember* and *understand.* In contrast, in the Netherlands, the cognitive demand of *apply* was the greatest, with a low percentage of marks coded for *understand*, *analyse* and *evaluate.*
- In the cases of England, NSW, Scotland and South Africa, all topics had questions coding for at least four of the five cognitive demands, with the percentage spread of marks per cognitive demand varying between topics.
- An exception to this was Ireland; except for Newtonian physics, each topic had question-parts coding for the same three cognitive demands, namely, *remember*, *understand* and *apply*. However, 60% of the total marks were allocated to *remember* and *understand*. Newtonian physics did address the five cognitive demands; however, the low percentage of marks allocated to analys*e* and *evaluate* each represented one question-part.
- In all six examinations, the predominant cognitive demand assessed was *apply*. In many instances, the percentage of marks allocated to question-parts coding for this demand was equal to or greater than the combined percentage for the two lower-order cognitive demands of *remember* and *understand*. This was particularly true of the Netherlands, where the percentage of marks allocated to apply for four of the five topics listed exceeded the sum of the other percentage marks.
- For each country, there was what could be styled a dominant topic, that is, a topic which was allocated an overall high percentage of the total marks; for example, Newtonian Physics was allocated the highest total percentage of marks in England (42%), Scotland (32%) and South Africa (45%). The other dominant topics per country were Wave motion (Ireland, 26%), Electricity (the Netherlands, 24%) and the Electron (NSW, 40%).
- All questions from the exam papers were included in the analysis.
- Across the topics, there was a dearth of questions assessing the more challenging cognitive demands of *analyse* and *evaluate*. The combined percentage of marks allocated to these two demands was always less than 12% across all six examinations.



Note: Due to rounding, not every country's data sums to 100.

Figure 6.12 Comparison of percentage marks per cognitive demands across topics in physics examinations

6.3.3 Key findings of the analysis of the cognitive demands of the six Physics examinations

This study examined the cognitive demands of the high-stakes written physics examinations in one year (2016) across six countries through the analysis of

(a) the percentage frequency distribution of marks with respect to the different cognitive demands of the examination questions
(b) the alignment of the frequency distribution of marks to the percentage of the number of question-parts coding for the different cognitive demands
(c) the distribution of the cognitive demands across the topics examined in the six examinations.

Key points for each of these analyses are noted below.

The initial analysis ((a) above) showed that four of the examinations (England, Ireland, NSW and Scotland) allocated marks to questions which coded for the five cognitive demands of *remember, understand, apply analysis, and evaluate;* The Netherlands had no questions coding for *remember* nor did the South Africa examination have questions coding for the cognitive demand of *evaluate.* None of the countries had questions requiring the cognitive demand of *create.*

The percentage of marks allocated to

- *remember* – ranging from 9% (Scotland, England) to 37 % (Ireland)
- *understand* –ranging from 5% (the Netherlands) to 37% (NSW).
- *apply* – ranged from 23% (NSW) to 70% (the Netherlands)
- *analyse* – ranging from 1% (Scotland) to 18% (NSW)
- *evaluate* – ranging from 1% (Ireland) to 15% (Scotland)

(b) The second analysis ((b) above) focused on the distribution of the cognitive demands of the question-parts of the examination questions and marks allocated to these question-parts. The range of question-parts coding for

- *remember* – ranged from 13% (Scotland) to 41% (Ireland)
- *understand* – ranging from 5% (the Netherlands) to 41% (Scotland)
- *apply* – ranged from 23% (NSW) to 59% (the Netherlands)
- *analyse* – ranging from 1% (Scotland) to 15% (the Netherlands, NSW)
- *evaluate* – ranging from 1% (Ireland) to 15%(the Netherlands)

Across all countries, the percentage of question-parts coding for *remember* and *understand* exceeded the percentage of marks allocated by 1-7 percentage points. This trend was reversed for the cognitive demand *apply* with the percentage of marks greater than the percentage of question-parts. The low percentage of marks allocated to *analyse* and *evaluate* to a correspondingly low percentage of question-parts may reflect a superficial assessment of these cognitive demands.

However, during the alignment of marks with question-parts, it was noticed that the range of marks per cognitive demands did not differentiate between the cognitive demand question–parts. Using the master data sheets for each country, Table 6.10 was compiled. For each cognitive demand, the range of marks was calculated using the lowest and highest marks allocated to question-parts. [Where only one or two question-parts were coding for a specific cognitive demand, the mark is noted (†) instead].

Table 6.10 Comparison of the range of question-parts to cognitive demands of the physics exam

Physics	England	Ireland	the Netherlands	NSW	Scotland	South Africa
Remember	1-4	3-15	n/a	1-3	1-3	1-5
Understand	1-6	3-12	1-2	1-6	1-3	2-3
Apply	1-6	3-15	2-5	1-6	1-4	1-6
Analyse	2-4	3† 12†	1-4	2-6	1†	1-2
Evaluate	2-5	6†	2-3	3-6	1-4	n/a
Total marks per paper	160	400* (797)	79	200	130	150

† = single question-part mark. (* maximum marks to obtain)

Typically, marks within a range of 1-6 were allocated to all question-parts irrespective of the cognitive demand. The two question-parts from the NSW examination illustrate this in Figure 6.9 and Figure 6.11. The action-verb, ***account for***, in Figure 6.5, coded for *analyse* and was allocated four marks; the action-verb, ***assess the appropriateness,*** in Figure 6.6, coded for *evaluate* and was allocated three marks.

On the South African examination, most of these questions followed the same format or lay-out- a diagram/sketch/ graph/ short narrative setting the overall context of the question, the first question-part coding for cognitive demand *remember*, the second question-part coding for *understand*, followed by two or more question-parts coding for *apply*, with the final question-part coding for *analyse*. Similar to Bloom's taxonomy, a hierarchical structure appeared to be applied.

Ireland was an outlier regarding the questions' structure and the range of marks. All questions were composed of six or more question-parts between five to seven question-parts; the range of marks, 3-15, generally were apportioned as multiples of 3.

Concerning the topics examined((c))above, a comparison of the distribution of cognitive demands across the six examinations showed that

- Topics on Newtonian physics (England, Ireland), Wave motion (England, NSW) and the Electron (NSW) assigned a varying percentage of total marks to all five cognitive demands.
- All topics had questions coding for at least four of the five cognitive demands.
- The Netherlands' examination syllabus referenced prior knowledge that students should have, which would not be a feature of the examinations- hence the absence of any question assessing the cognitive demand *remember* and the low percentage of question-parts assessing *understand*. Consequently, there were more question-parts focused on assessing *apply*, *analyse* and *evaluate* across all topics.
- *Apply* was the most dominant demand across England, the Netherlands, Scotland and South Africa, ranging from 42% (England) to 70% (the Netherlands). The majority of question-parts which coded for *apply* used the action-verb 'calculate' with a percentage distribution between 46% (England) and 88% (Ireland)

6.4. Analysis of 2016 Chemistry Examinations across six countries

The presentation of the syllabi content varied across each of the six countries. The Netherlands, NSW, Scotland and South Africa syllabus content was presented within a theme or context which embraced several topics/subtopics (Table 6.11). In contrast, the content for England and Ireland (Table 6.14) was listed as a narrower range of topics without any overall theme of context specifically mentioned.

Table 6.11 Summary of syllabi for Chemistry 2016

	Topics /themes
The Netherlands	1. Knowledge of substances & materials; 2. Knowledge of Chemical Processes & Cycles; 3. Designs & Experiments in Chemistry; 4. Innovative Developments in Chemistry; 5. Processes in Chemical Industry; 6. Society & Chemical Technology.
NSW	1. Production of Materials; 2. Acidic Environment; 3. Chemical Monitoring & Management; **Options- 1**. Industrial Chemistry. **2**. Ship-wrecks Corrosion & Conservation. **3**. Biochemistry of Movement. **4**. Chemistry of Art. **5**. Forensic Chemistry.
Scotland	*1. Chemical Changes & Structure; 2. Nature's Chemistry; 3. Chemistry in Society*
South Africa	1. Matter & Materials; 2. Chemical Systems; 3. Chemical Changes; Skills for Practical Investigations.

Irrespective of the differences in presentation, there was considerable overlap between the content in the various syllabi. For example, *Knowledge of Substances/Fabrics & Materials* (the Netherlands), *Chemical Changes & Structures* (Scotland) and *Matter & Materials* (South Africa) all included topics on atomic structure and modelling, bonding and shapes of molecules. Likewise, *Nature's Chemistry* (Scotland), *Production of Materials* (NSW), and *Matter & Materials* (South Africa) listed similar organic chemistry.

In direct contrast, the syllabi for England and Ireland focussed on a detailed list of each of the chemistry topics, as shown in Table 6.12, without overall themes or contexts mentioned.

Table 6.12 Summary of syllabi for Chemistry 2016 for England and Ireland

Examination	**Content- Topics/themes**
England	Formulae, Equations & Amount of Substances; Atomic Structure; Bonding & Structure; Energetics; Kinetics; Equilibria; Redox; Inorganic Chemistry & Periodic Table; Organic Chemistry; Modern Analytical Techniques.
Ireland	Periodic Table & Atomic Structure; chemical bonding; Stoichiometry, Formulae & Equations; Volumetric analysis; Fuels & Heats of Reactions; Rates of Reactions; Organic Chemistry; Chemical Equilibrium; Environmental Chemistry-Water; Options -1. Additional Industrial Chemistry & Atmospheric Chemistry. 2. Material & Additional Electrochemistry & Extraction of Metals; 28 mandatory experiments

Due to the varied presentation of the six syllabi, an initial list of all the topics/themes featured on the examination papers was drawn up. The eight topics based on this list (Table 6.13) ensured that all examination questions were included in this study.

Table 6.13 Topics common to the six 2016 chemistry examinations.

	England	Ireland	the Netherlands	NSW	Scotland	South Africa
Periodic/Atomic structures	✔	✔	✔	✔	✔	
Chemical bonding	✔	✔	✔	✔	✔	
Chemical equilibrium	✔	✔		✔	✔	✔
Volumetric analysis	✔	✔	✔	✔	✔	✔
Rates of reaction	✔	✔	✔	✔	✔	✔
Organic chemistry	✔	✔	✔	✔	✔	✔
Industrial chemistry	✔	✔	✔	✔	✔	✔
Electrochemistry			✔	✔		✔

The analysis of the chemistry examinations from the six countries was carried out in the same way as that described for physics in Section 6.3, namely, a comparison of cognitive demands across the examination papers, followed by an analysis of the percentage of question-parts vs allocated marks and finally comparison across comparable topics.

6.4.1 Cognitive demand levels across the chemistry examinations

The percentage distribution of the marks per cognitive demand level is set out in Table 6.14. Note that no questions coded for *create*. Highlights from this Table are:

- The range of percentage of marks (25%-38%) assigned by Ireland, the Netherlands and Scotland to questions coding for *remembe*r in contrast to the low range (10%-15%) for the other three countries
- The wide range of percentage of marks (19%-35%) assigned to questions coding for *understand*.
- South Africa assigned the highest percentage of marks (65%) to questions coding for *apply*.

- The low percentage of marks (less than15%) assigned by all countries to questions coding for *analyse* and an even lower percentage of marks for *evaluate* at less than 6%

Table 6.14 Overview of percentage distribution of marks per cognitive demand levels of chemistry

	Remember (%)	Understand (%)	Apply (%)	Analyse (%)	Evaluate (%)
England	14	23	49	9	6
Ireland	38	34	26	2	1
the Netherlands	25	31	27	14	3
NSW	10	33	39	15	3
Scotland	31	27	34	4	4
South Africa	15	19	65	1	n/a

This data is a broad outline of the percentage frequency of the distribution of the marks with respect to the cognitive demand levels. However, as previously stated, it does not provide any insight into how the allocated marks were distributed among the questions or within the various parts of the questions. Each of the examinations differed in the number of questions, question-parts and marks available- as shown in Table 6.15

Table 6.15 Number of questions and question-parts

Chemistry	England	Ireland	the Netherlands	NSW	Scotland	South Africa
Total number of questions	47	11	33	35	12	10
Total number of question-parts	88	107	33	73	80	69
Maximum marks available	160	400	77	200	100	150

The subsequent sections present a more in-depth analysis of the emphasis on the individual cognitive demands through the lens of the percentage of the marks versus the percentage of questions parts coding for the different cognitive demands.

Comparison of cognitive demand - *Remember*

Figure 6.13 shows that, for each country, the percentage of marks allocated to the cognitive demand *remember* was somewhat less than the percentage of question-parts coding for that demand; specifically, Ireland and Scotland assigned the highest percentage of marks (over 30%); for the Netherlands, this was 25% marks, whilst the other countries assigned less than 20%.

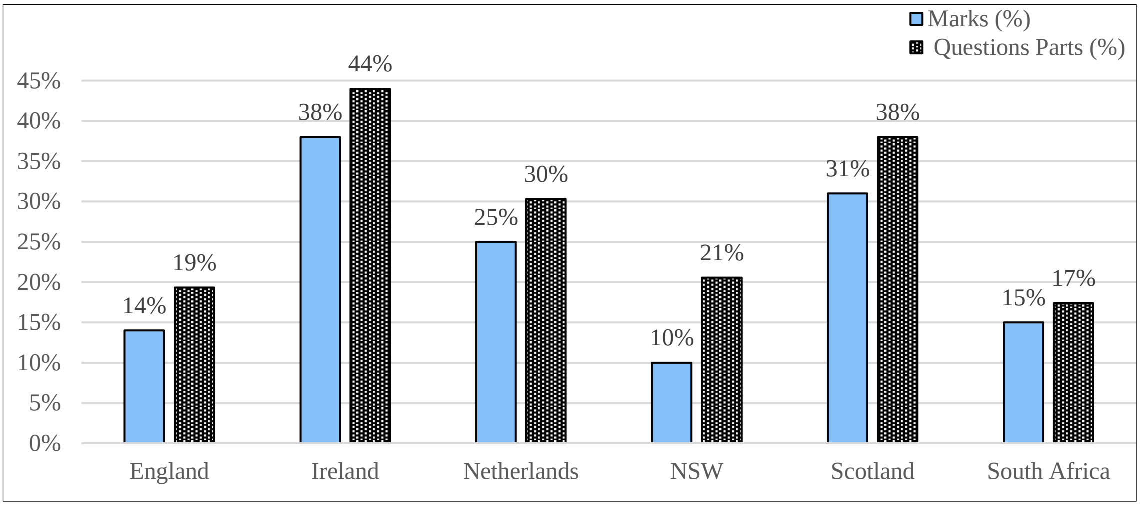


Figure 6.13 Comparison of marks (%) vs question-parts (%) for cognitive demand remember

The majority of these question-parts were at the start of a question serving to give overall context to the subsequent question-parts, for example,

- *Ammonia reacts with aluminium chloride as shown by the equation;*

  $$NH_3 + AlCl_3 \longrightarrow H_3NAlCl_2$$

  7.1 Draw diagrams to illustrate the shapes of NH3 molecules and of AlCl3 molecules (England, Q.7)

- *Hydrogen gas, H2(g), reacts with sulfur powder S(s), according to the following balanced equation:*

  $$H_2(g) + S(s) \longrightarrow H_2S(g) \qquad \Delta H < 0$$

  The system reaches equilibrium at 90^0

  6.1. Define the term chemical equilibrium. (South Africa, Q.6)

Ireland and Scotland both also coded the highest percentage of question-parts for *remember*. Further analysis of these percentages showed that all questions had multiple question-parts coding for *remember*. Table 6.16 highlights the multiplicity of the question-parts per question, coding for *remember* in the Irish LC. Also included in the Table is the percentage of marks assigned per question, which ranged from 12% to 60%.

Table 6.16 Percentage marks per question-part in chemistry (Ireland) exam assigned to remember

Question No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Question parts/ total	**2**/5	**2**/7	**3**/8	**6**/12	**5**/9	**6**/9	**3**/6	**6**/10	**6**/10	**3**/11	**6**/20
Marks /Total	**14/** 50	**6/** 50	**17/** 50	**36/** 75	**19/** 50	**29/** 50	**17/** 50	**26/** 50	**30/** 50	**22/** 75	**29/** 100
Marks (%)	**28**	**12**	**34**	**48**	**38**	**58**	**34**	**52**	**60**	**29**	**26**

Question 5 (c) from the LC chemistry examination below illustrates this multiplicity. The question-parts in italics coded for *remember*. [The bracketed greyed-out part, coding for a different cognitive demand, is included for completeness of this subsection].

Question 5:

(c) Atomic energy levels first described by Bohr are now known to contain energy sublevels and orbitals.

Define an atomic orbital *(6 marks)*

Distinguish between a 2p orbital and a 2p sublevel. *(3 marks)*

Write the s, p electron configuration for a calcium atom. *(4 marks)*

[Explain in terms of energy sublevels why the arrangement of electrons in the main energy levels in a calcium atom is 2, 8, 8, 2 and not 2, 8, 10. (4 marks)]

Like Ireland, many of the questions on Scotland's examination included a number of question-parts coding for *remember* as shown in Table 6.17

Table 6.17 Percentage marks per question-parts in chemistry (Scotland) assigned to remember

Question number	**1***	**1**	**3**	**5**	**6**	**7**	**11**	**12**
Question-parts /Total	**8**/20	**1**/4	**2**/3	**4**/6	**3**/7	**6**/9	**4**/10	**2**/5
Marks/Total	**8**/20	**1**/4	**2**/4	**5**/8	**3**/8	**6**/10	**4**/14	**2**/6
Marks (%)	**40**	**25**	**50**	**63**	**38**	**60**	**29**	**33**

*=multi-choice questions

Typically, the question-parts coding for *remember* showed that numerous question-parts were either questions asking to (i) state a principle or give a definition or (ii) question-parts requiring a single word (name a laboratory technique used to purify impure benzoic acid) or draw/identify molecular structures. In general, a question would have one or two *remember* coded question-parts served to act as a cue prompt for the following parts of a question.

Comparison of cognitive demand – *Understand*

Figure 6.14 shows that, for all six countries, the range of percentage marks (19% to 34%) was almost the same as the percentage of question-parts (22% to 35%) to coding for the cognitive demand *understand*.

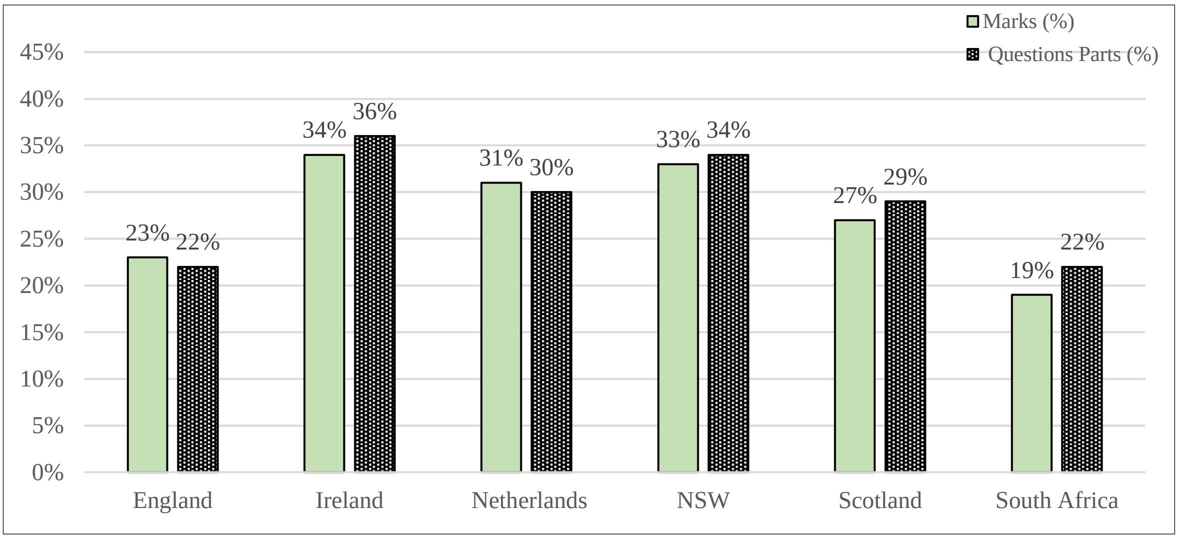


Figure 6.14 Country comparison of marks (%) to question-parts (%) coding for cognitive demand understand

Many of the questions coded for this cognitive demand involved describing procedures, distinguishing between or explaining different states of electrons and types of bonding, and describing or drawing apparatus diagrams. Examples of such question-parts are

- *Describe in detail the procedures involved in measuring a 25.0 cm3 sample of vinegar and diluting it using deionised water to exactly 250 cm3.*

  (Ireland, Q.1a)

- *Explain why the first ionisation energy decreased going down Group 1.*

  (Scotland, Q.2 i)

- *Explain what caused more fragrance per second to dissolve when the ambergris was crushed than if it were not crushed.*

  (the Netherlands, Q.1i)

The Revised Bloom's taxonomy regarded cognitive demands of *remember* and *understand* as lower-order demands. Except for Ireland and Scotland, there was a noticeable increase in both percentages of marks and percentage of question-parts recorded for *understand* compared to *remember*. However, a combination of the data for *remember* and *understand* indicated that for three countries, Ireland, Netherlands and Scotland, more than 50% of the total marks were allocated to these demands.

Comparison of cognitive demand - *Apply*

The cognitive demand *apply* revealed quite a variation between the countries, as shown in Figure 6.15. South Africa assigned a significant percentage of the total marks (65%) to 60% of the question-parts. England was the next highest, with 49% of the total marks assigned to 47% of the questions. In contrast, the percentage of marks assigned to this cognitive demand by Ireland, the Netherlands, NSW, and Scotland ranged from 26% (Ireland) to 39% (NSW).

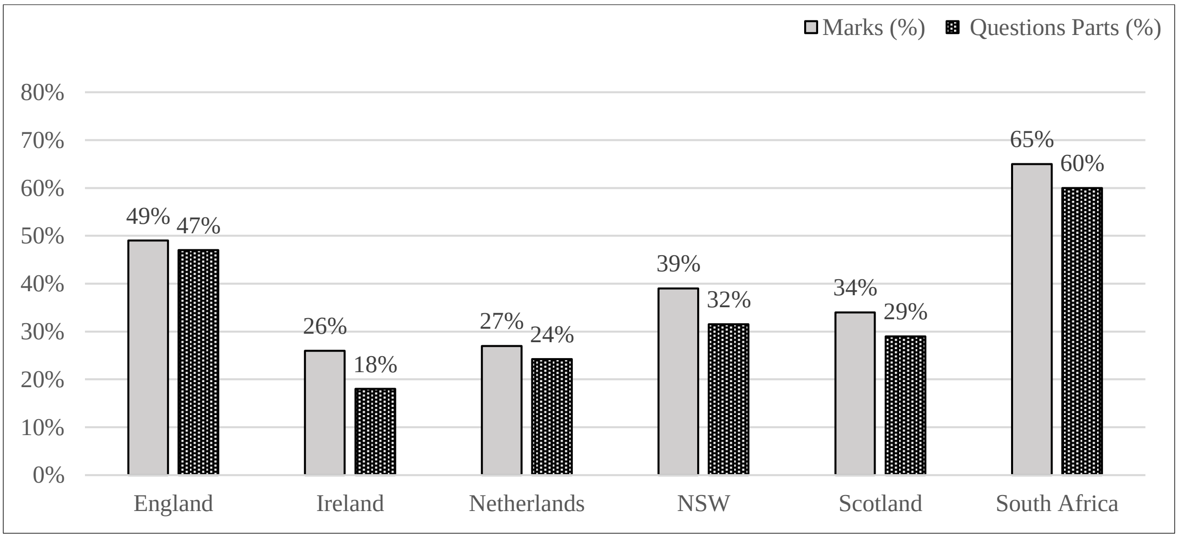


Figure 6.15 Country comparison of marks (%) to question-parts (%) coding for cognitive demand apply

A breakdown of the question-parts coding for this cognitive demand level indicated three different types of questions, similar to those described for this cognitive demand in physics in Section 6.3

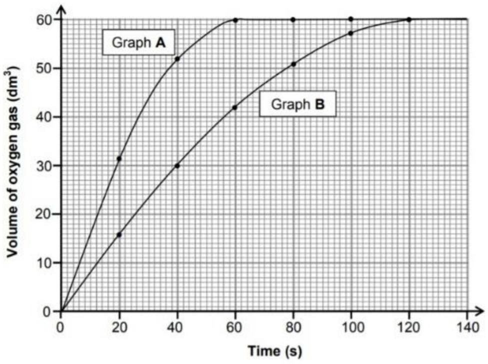
Type 1. Question-parts which solely involved calculations i.*e.*

Calculate the molarity of a sulfuric acid solution that has a pH of 2.0.

(Ireland, Q. 10a)

Type 2. Question-parts which graphs/data as a basis for calculations i.e.

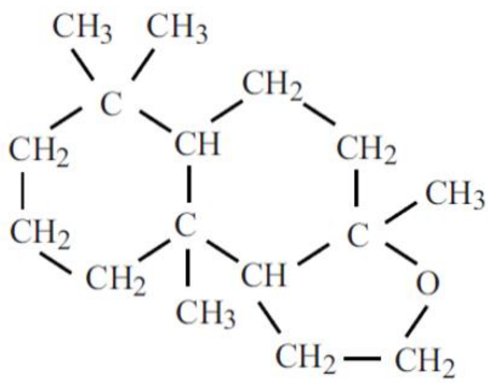
Use the information in Graph A to calculate the mass of hydrogen peroxide used in the reaction.



(South Africa, Q.5.)

Type 3. Question-parts which focused on the application of a theory or principle i.e.

> *Using the structural formula shown here, explain whether the fragrance ambrox is a hydrophobic substance.*



.

The structural formula of ambrox fragrance

(the Netherlands Q.2.)

Table 6.18 shows the breakdown of eight of the eleven questions on the Irish Leaving Certificate examination, which had question-parts coding for *apply*. Of the twenty question-parts coded for *apply*, twelve were solely calculations, with four based on graphic representation and the remaining four of type 3 above. Questions 10 and 11 contained internal choices, hence the high number of question-parts, each of which was calculations.

Table 6.18 Percentage of marks per question in chemistry (Ireland) assigned to apply

Question No.	1	2	3	4	6	7	10	11
Question parts/total	**2**/5	**1**/7	**2**/8	**1**/12	**1**/9	**2**/6	**6**/11	**5**/20
Marks/total	**21**/50	**6**/50	**24**/50	**6**/75	**9**/50	**30**/50	**38**/75	**33**/100
Marks (%)	**42**	**12**	**48**	**8**	**18**	**60**	**51**	**33**

By contrast, each of the questions on the England examination (Table 6.19) had numerous question-parts coding for the cognitive demand *apply.* An inspection of the type of questions showed that the majority were calculations (type 1) with a limit number based on graphic/data representation (type 2) and application of principle or theory (type 3).

Table 6.19 Percentage of marks per question assigned to apply in the English examination.

Question No.	1	2	3	4	5	6	7	8	9	10*
Question-parts/total	**1**/5	**4**/8	**4**/11	**2**/4	**5**/8	**5**/10	**1**/5	**6**/6	**1**/1	**12**/30
Marks /total	**2**/8	**9**/17	**8**/26	**7**/15	**12**/15	**11**/19	**2**/15	**11**/11	**4**/4	**12**/30
Marks (%)	**25**	**53**	**30**	**46**	**80**	**57**	**13**	**100**	**100**	**40**

* = Multi-choice questions.

Coincidently, England and South Africa (Table 6.20) had the same number of questions and question-parts (41) coding for *apply*.

Table 6.20 Percentage of marks per question assigned to apply in the South Africa examination

Question No.	1*	2	3	4	5	6	7	8	9	10
Question-parts/total	**0**/29	**9**/9	**1**/5	**7**/8	**5**/9	**3**/5	**2**/4	**5**/7	**3**/6	**6**/6
Marks/total	**0**/29	**13**/13	**3**/11	**9**/13	**15**/20	**15**/18	**11**/16	**13**/16	**4**/9	**14**/14
Marks (%)	**0**	**100**	**27**	**69**	**75**	**83**	**17**	**69**	**44**	**100**

* = Multi-choice questions.

However, there was a limited number of calculation type (type 1) question-parts in the South African examination compared to England (Table 6.21). Most question-parts centred on applying principles (type 3) and interpreting data in various forms.

Table 6.21 Country comparisons of question types,

Country	Number of question-parts	% 'calculate' type 1	% based on data type 2	% based on concepts type 3
England	41	44	27	29
South Africa	39	15	15	70

For instance, question 3 (South Africa) is an example of applying inferred principles (structure, intermolecular forces and energy).

Q.3 The boiling points of three isomers are given in the Table below. Explain the trend in the boiling points from compound A to compound C.

Isomers	*Boiling Point (^{0}C)*
A. 2,2-dimethylpropane	*9*
B. 2-methybutane	*28*
C. pentane	*36*

(South Africa, Q. 3)

There were two notable aspects of this comparison. Firstly, the contrast between the data for England and South Africa compared with the other four countries, with the former placing greater emphasis on *apply* type of questions. Secondly, the data for both Ireland and the Netherlands showed a decrease in both percentages of marks (and question-parts) for *apply* relative to data for *understand*. However, as neither of these countries issued post-examination reports, it was impossible to draw any conclusion.

Comparison of cognitive demand – *Analyse*

England, the Netherlands and NSW assigned between 9% and 15% of the marks to cognitive demand analyse, while the other three countries assigned marks less than 4% (Figure 6.16).

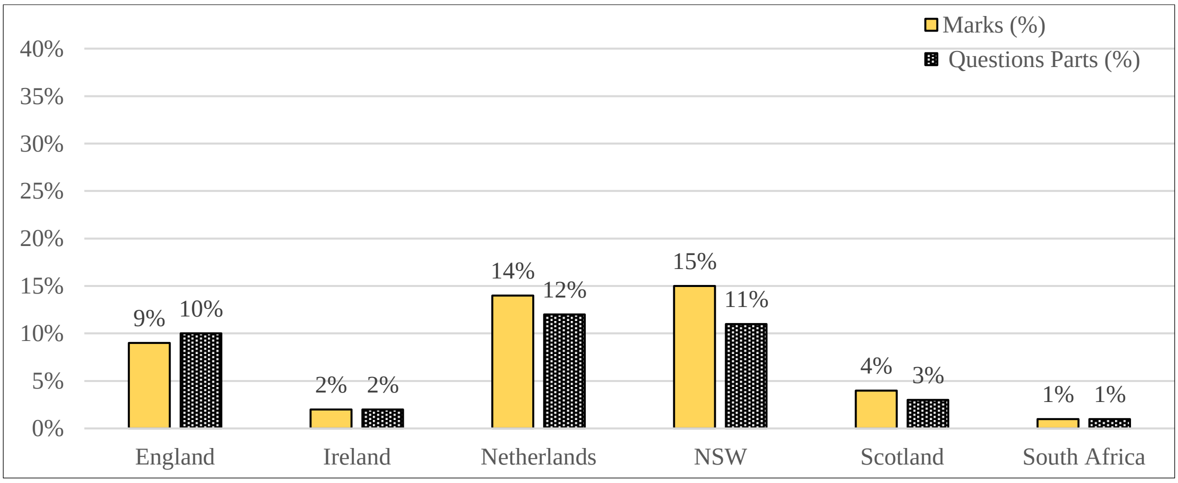


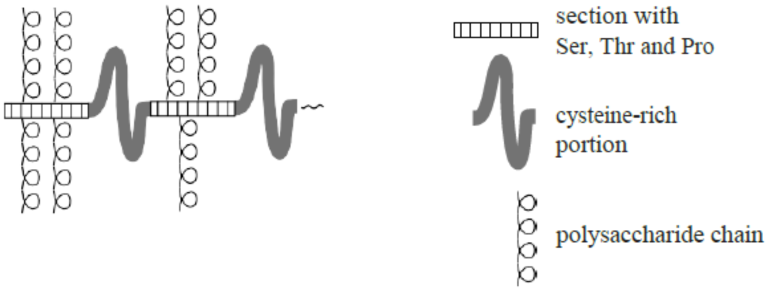
Figure 6.16 Country comparison of marks (%) to question-parts (%) coding for cognitive demand analyse.

The following is a sample of the question-parts with action-verbs (in bold) which coded for *analyse*

- ***Deduce*** *which of Na^{+} and Mg^{2+} is the smaller ion. Explain your answer.*

(England, Q. 2)

- *(The eye is protected by a thin fluid-filled film. This film consists of three layers a mucus layer, a water layer and a fat layer.) The mucus layer contains mucins. Mucin molecules consist of protein chains to which polysaccharide chains are bound. These polysaccharide chains give mucin molecules a high water-binding capacity. The figure below shows a fragment of a mucin molecule schematically.*



*Using micro-level concepts, **explain why** the polysaccharide chains impart high water-binding capacity to mucin molecules.*

(the Netherlands, Q. 30)

- *Methane and water vapour react to form carbon monoxide and hydrogen in a closed container, as shown,*

$$CH_4(g) + H_2(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = + 206kJ$$

***Compare** the impact on the equilibrium system of a decrease in the volume of the container to the impact of a decrease in temperature. Refer to the equilibrium constant in your answer.*

(NSW, Q. 31)

The marking guidance for these three countries showed that England and the Netherlands each allocated two marks to the above question-parts while NSW allocated three marks. Comparing the marking guidance showed that marks were apportioned as follows; for England, it was sufficient to name the correct ion and briefly refer to proton numbers and electron shielding; the Netherlands lists two expected answers; NSW listed criteria to obtain 1-3 marks and included a sample comparison table. Neither England nor the Netherlands provided a review or marking feedback information on students' responses. In contrast, NSW's marking feedback on this question-part (Q.31) stated that students showed strength in understanding how changes in temperature and volume alter equilibrium but needed to clarify the role of Le Châtelier's principle in these changes.

Comparison of cognitive demand – *Evaluate*

The very low percentage values for both marks and question-parts coding for the cognitive demand *evaluate* are shown in Figure 6.17. The percentage of question-parts represents either one (Ireland) or two question-parts for the other four countries.

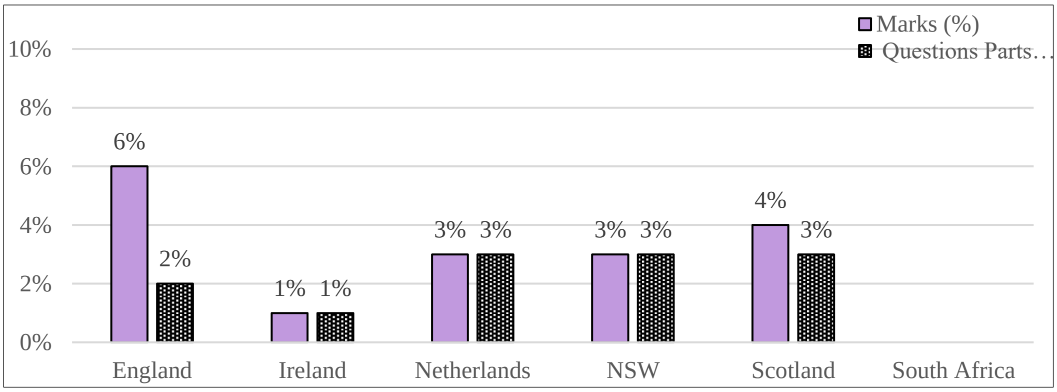
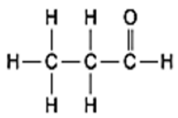
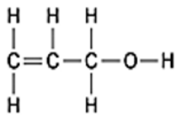
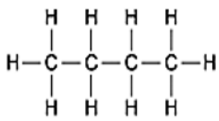


Figure 6.17 Country comparison of marks (%) to question-parts (%) coding for cognitive demand evaluate

Coding question-parts for this cognitive demand generally were of the type containing key action-verbs such as predict, determine, justify, and comment, as highlighted in the following

Name	Propanal	Prop-2-en-1-ol	Butane
Structure			

The compounds in the above Table all have a relative molecular mass of 58.0. Predict the relative boiling points of these three compounds from the highest to the lowest boiling points. Justify this order in terms of intermolecular forces. (England Q.4, Paper 2)

Consider the three gaseous hydrides, NH_3, PH_3 and AsH_3.

Molecular formula	*Common name*	*IUPAC name*	*Boiling point (°C)*
NH_3	*Ammonia*	*azane*	*-33.3*
PH_3	*Phosphine*	*phosphate*	*-87.7*
AsH_3	*Arsine*	*arsane*	*-62.5*

Using data in the Formulae and Tables booklet, determine the type of bonding arsine is expected to have. (Ireland, Q. 11)

The chemical industry creates an immense variety of products which impact on virtually every aspect of our lives. Industrial chemists, including chemical engineers, production chemists and environmental chemists, carry out different roles to maximise the efficiency of industrial processes. Using your knowledge of chemistry, comment on what industrial scientists can do to maximise profit from industrial processes and minimise the impact on the environment.

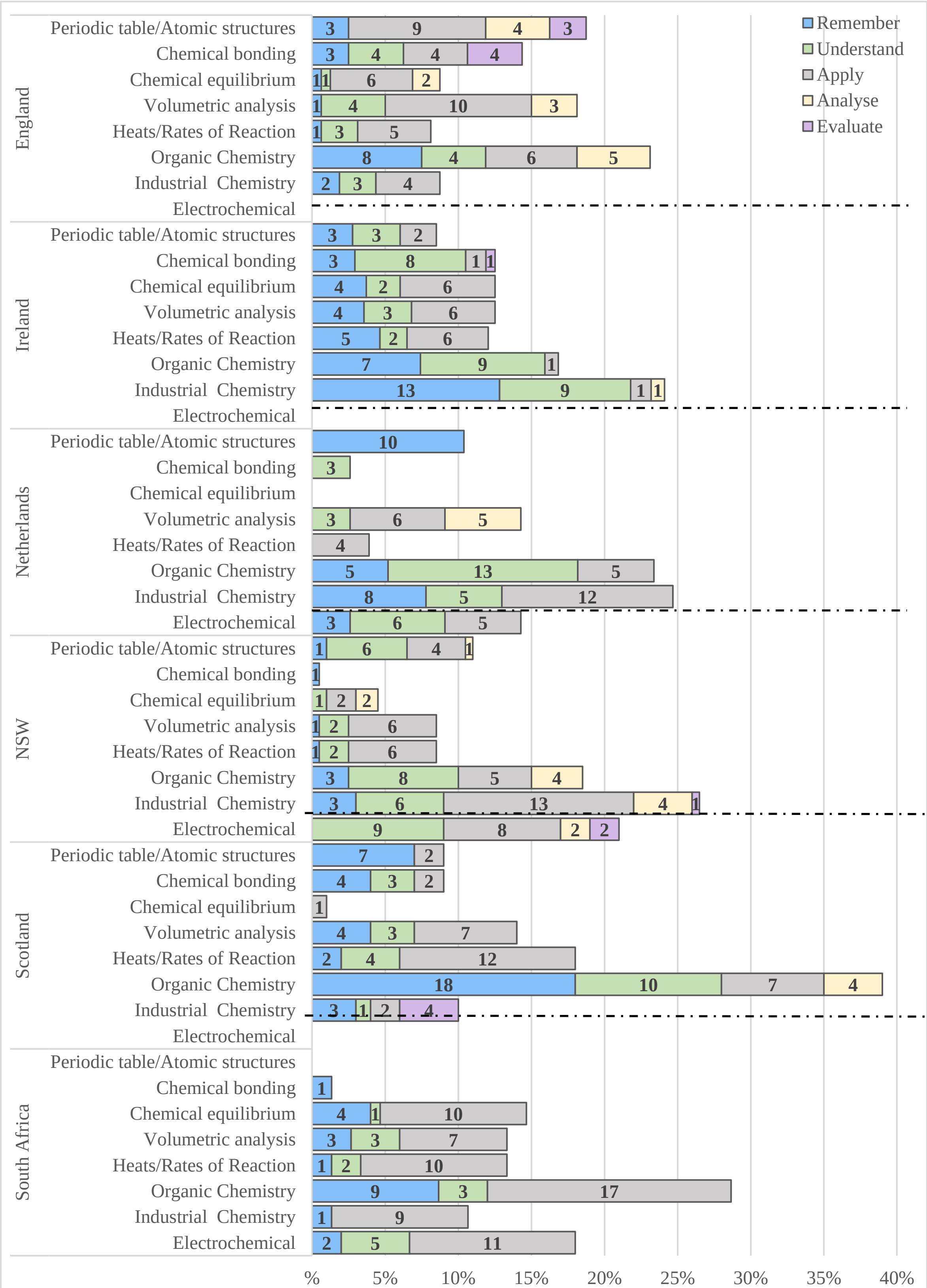
(Scotland, Q. 10)

Like the cognitive demand analysis, the cognitive demand evaluation would be considered higher-order level and such -parts coded as more challenging. However, the marks allocated were not reflective of this challenge. For instance, the above three sample question-parts were allocated between 1% and 3% of the total marks per paper.

6.4.2 Cognitive demand levels across comparable topics/concepts in chemistry

As previously stated, the focus of the comparisons of the chemistry questions was solely on the action-verbs used in the questions. Similar to physics (Section 6.3.2), the frequency distribution of marks per cognitive demands of chemistry was aligned with the topics to compile Figure 6.18. Among the notable aspects of Figure 6.18

- Of the topics shown in Figure 6.18, three topics (The Periodic Table/Atomic Structure (England), Organic Chemistry (the Netherlands) and Industrial Chemistry (NSW) assigned a varying percentage of marks for all five cognitive demands.
- NSW was the only country with questions on all eight chemistry topics. The range of cognitive demands assessed varied from topic to topic.
- Ireland was the only country for which question-parts coding for *remember*, *understand* and *apply* were presented in all the topics on the examination papers. In addition, the percentage of marks allocated to *remember* and *understand* was the highest of all the six countries. Moreover, it was the only country for which the combined marks allocated to *remember* and *understand* ranged from 50% (Chemical equilibrium) to 90% (Industrial chemistry) of the total marks per individual topic. Consequently, the combined percentage of marks for *apply*, *analyse* and *evaluate* ranged from 1% to 6%. This was the lowest range of all the six countries,
- Both the Netherlands and Scotland presented quite similar data for Organic chemistry. Interestingly, both countries allocated 70% of the combined marks allocated to *remember* and *understand*, the same percentage as Ireland.
- On the other hand, these countries allocated more marks to *apply* and *analyse* than Ireland.
- Assessing the more challenging cognitive demands of *analyse* and *evaluate*. The combined percentage of marks allocated to these two demands of analyse and evaluate was always less than 12% across all six examinations.



Note. Due to rounding, not every country's data sums to 100.

Figure 6.18 Comparison of percentage marks per cognitive demands across topics in chemistry examinations

6.4.3 Key findings of the analysis of the cognitive demands of the six Chemistry examinations

The presentation of the analysis of the chemistry examinations across the six countries used the process as described in Section 6.3.3.

In relation to the percentage distribution of marks with respect to the different cognitive demands of the examination questions, five of the countries, England, Ireland, the Netherlands, NSW and Scotland, assigned marks to questions which coded for the five cognitive demands of *remember*, *understand*, *apply*, *analysis*, and *evaluate.* The South Africa examination did not have any questions coding for *evaluate.* The percentage of marks allocated for the five cognitive demands varied across all six countries:

- *remember* – ranged from 10% (NSW) to 38% (Ireland)
- *understand* - ranged from 19% (South Africa) to 34% (Ireland)
- *apply* - ranged from 26% (Ireland) to 65% (South Africa)
- *analyse* – ranging from 1% (South Africa) to 15% (NSW)
- *evaluate* - 1% (Ireland) to 6% (England).

Like physics, the subsequent analysis examined the percentage of marks allocated to the question-parts coding for the different cognitive demands. The percentage of question-parts coding for the five cognitive demands varied across all six countries:

- *remember* – ranged from 17% (South Africa) to 44% (Ireland)
- *understand* – ranged from 22% (England, South Africa) to 36% (Ireland)
- *apply* – ranged from 18%(Ireland) to 60% (South Africa)
- *analyse* – ranging from 1% (South Africa) to 12% (the Netherlands)
- *evaluate* – ranging from 1% (Ireland) to 3% (the Netherlands, NSW, Scotland)

Overall, across all countries, the percentage of question-parts coding for *remember* and *understand* was greater than the percentage of marks allocated. However, the gap between the percentage marks and corresponding question-parts coding for *remember* was noticeably greater than for *understand.* This trend was reversed for the cognitive demand *apply,* with the percentage of marks exceeding the percentage of question-parts so coded. However, Ireland and the Netherlands allocated a lower percentage of marks than for *understand.* The percentage of marks allocated to cognitive demand *analyse* and *evaluate* was low (less than 15%), as was the percentage of question-parts (less than 12%) in all countries. The range of marks allocated by many countries to *analyse* (and *evaluate)* question-parts was comparable to those allocated to *remember* and *understand*.

Using the master coding sheet for chemistry, the range of marks for each cognitive demand was compiled (Table 6.22). [Where there were only one or two question-parts coding, the mark is noted (†) instead].

Table 6.22 Comparison of the range of question-parts to cognitive demands of the chemistry exam

Chemistry	England	Ireland	the Netherlands	NSW	Scotland	South Africa
Remember	1-3	2 -13	1-2	1-3	1-2	1-2
Understand	1-7	3-15	2-4	1-4	1-2	1-4
Apply	1-4	3-18	2-4	1-7	1-3	1-9
Analyse	1-3	3-6	2-4	1-6	1-3	2†
Evaluate	4† 6†	4†	2†	1† 4†	1- 3	n/a
Total marks per paper	160	400*(647)	77	200	100	150

† = single question mark. (* = maximum marks attainable)

Similar to physics, marks within the overall range of 1-7 were allocated to question-parts irrespective of the cognitive demand. Consequently, there were instances where question-part coding for *understand* was assigned the same mark as question-parts coding for *apply* or *analyse*. Ireland and South Africa retained a similar structure for the chemistry examinations as previously described for physics.

A comparison of the distribution of cognitive demands across the six examinations in the selected topics showed that

- The Periodic Table/atomic structure (England), Organic Chemistry (the Netherlands) and Industrial Chemistry (NSW) assigned a varying percentage of marks for all five cognitive demands.
- Organic chemistry was the dominant topic for England, the Netherlands, Scotland and South Africa; Industrial chemistry was the dominant topic for Ireland and NSW.
- Across many countries, the emphasis was on question-parts coding for *remember* and *understand*.
- Ireland was the only country for which the combined marks allocated to *remember* and *understand* demands ranged from 50% (Chemical equilibrium) to 90% (Industrial chemistry), with a combined percentage of marks for *apply, analyse* and *evaluate* between 1% and 6% - the lowest of all the countries.

6.5. Discussion

The analysis of 2016 high-stakes examinations using action verbs associated with Bloom's Revised Taxonomy highlighted the differences and similarities in the cognitive demand levels of physics and chemistry examinations across these six countries. Sections 6.3.1 and 6.4.1 investigated the cognitive demands of the physics and chemistry examinations separately, respectively. What information might be gleaned if comparisons were drawn between the cognitive demands of physics and chemistry? For example, Figure 6.17 shows the overall combined data for the percentage of marks allocated to each country's cognitive demand of physics and chemistry, as in Table 6.6 (physics) and Table 6.16 (chemistry).

Key observations compare physics and chemistry examinations for each cognitive demand.

- *Remember –*

Of the six countries, Ireland had the highest percentage of question-parts in both subjects, coding for *remember* every topic on the physics and chemistry examination allocating marks for this cognitive level ranging between 1% - 12 % for physics and 3%-13% for chemistry. In the cases of the Netherlands and Scotland, both countries allocated high percentage marks for *remember* in the topic of Organic Chemistry – 13% (Netherlands) and 16% (Scotland). In comparison, England, NSW and South Africa had question parts on most if not all topics on their examination papers coding for *remember* but allocated a narrower range of marks varying between 1% to 9% for physics and chemistry question-parts.

As previously discussed in Section 6.3.1. the zero allocation of marks in the 2016 Netherlands physics examination to *remember* reflected their physics specifications and the role of prior knowledge. In contrast, 25% of the total marks on the Netherlands' chemistry were allocated to question-parts coding for *remember*. The Netherlands' chemistry specifications included a five-stage proficiency level, which used action verbs in determining the relative level of mastery expected of the students. The specifications noted that higher-level questions should always include lower-level questions. Hence four of the six topics on the Netherlands' chemistry examination paper had a range of percentage of marks allocated to *remember* in contrast to zero for physics. Overall for England, Ireland, NSW and South Africa, there were marginal differences in this cognitive demand in both subjects.

- ***Understand –***

In physics, the overall level of cognitive demand *understand* was comparable for England (26%) and Ireland (23%) but varied in chemistry (England, 23%, Ireland, 34%). For the Netherlands, there was a pronounced difference between the percentage of marks allocated to *understand* in physics and chemistry, with three of the five physics topics allocating between 1% and 3% of total marks to cognitive demand *understand*, whilst five of the six chemistry topics allocated from 3% to 14% of the total marks to *understand*. Of the 31% marks in chemistry the Netherlands allocated to *understand,* 14% were based on Organic Chemistry. The difference in percentage marks allocated by NSW to physics and chemistry was marginal (37% to 33%, respectively). Nevertheless, these high percentages indicated the emphasis on *understand* in both syllabi objectives and the *Marking Feedback* of the NSW 2016 examination. Each of the six countries emphasised the cognitive demand *understand* in chemistry more than in physics, as shown in Figure 6.35. Moreover, there was a degree of similarity in the range of the percentage of marks allocated by all countries to this cognitive demand that is between 20% and 35%, which was not evident in physics. Although a core feature of all the examinations (except for the Netherlands) was the concentration of both *remember* and *understand* question-parts, it was particularly noticeable in chemistry with a marked focus on *understand,* indicating some difference between the natures of physics and chemistry.

- ***Apply –***

The dominant cognitive demand in the physics and chemistry examinations was *apply.* For England, the percentage of question-parts in physics and chemistry coding for *apply* was comparable, between 40% of physics question-parts and 50% of chemistry question-parts. For South Africa, physics and chemistry had the same percentage (65%) of question-parts coding for *apply,* indicating a similar questioning approach for both subjects. The Netherlands and Scotland allocated more than double the percentage of marks to physics question-parts than to chemistry question-parts. As noted in Section 6.3.2, the Netherlands' specifications for physics stipulated that 50% of marks be allocated to questions explicitly based on calculations (Examenblad.nl, 2016). None of the other five countries had such an addition in their syllabi. On the other hand, the percentage of marks (22%) allocated to NSW physics question-parts was almost half the percentage of marks (40%) allocated to chemistry.

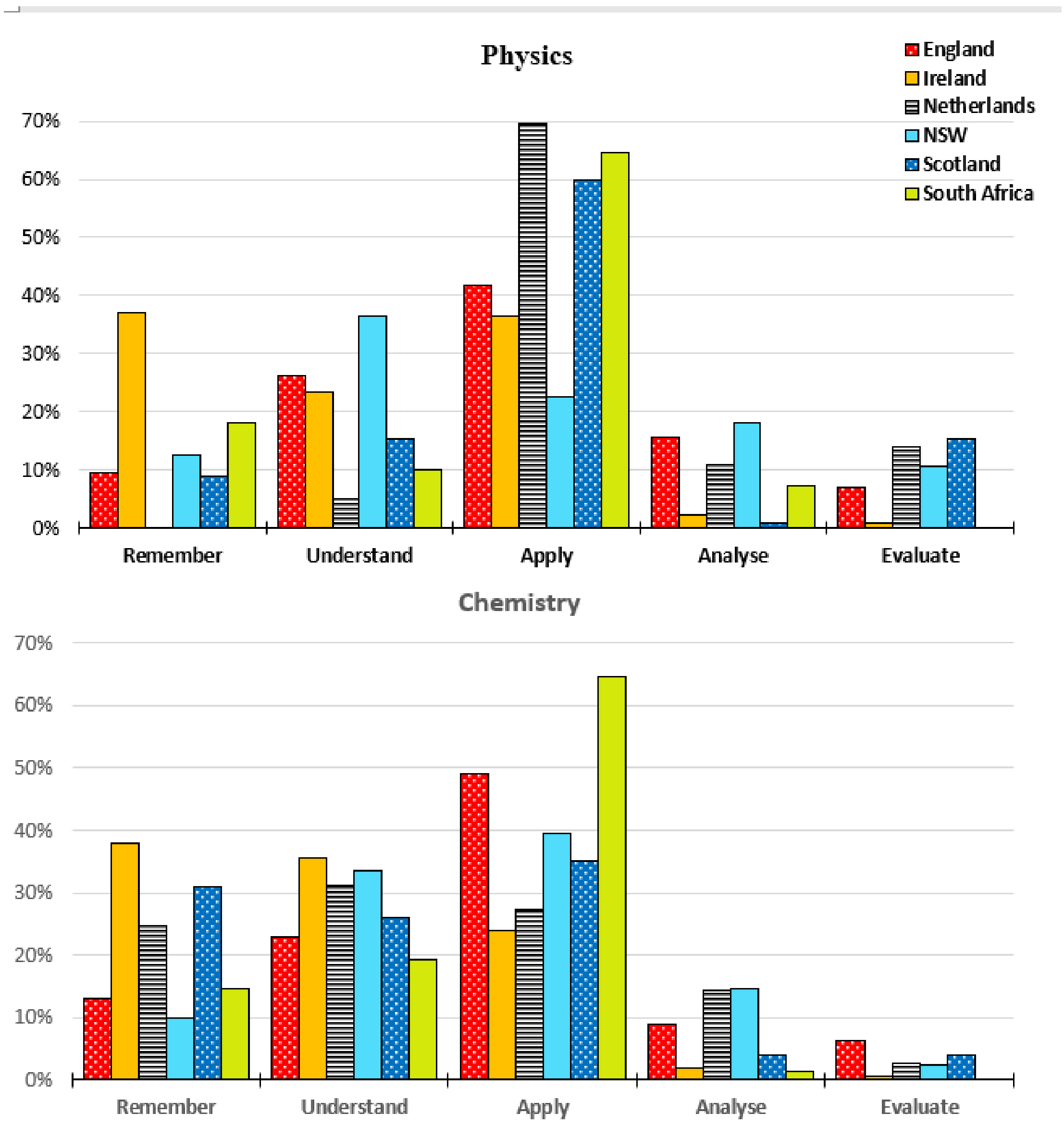


Figure 6.19 Comparison of cognitive demands of physics and chemistry (based on marks(%) for each cognitive demand)

As described previously in Sections 6.3.1 and 6.4.1, all the questions which coded for *apply* were one of three types, namely:

Type 1: Question-part based solely on calculations

Type 2: Question-part with graphs/data as a basis for calculations

Type 3: Question-part based on the application of principle/concept.

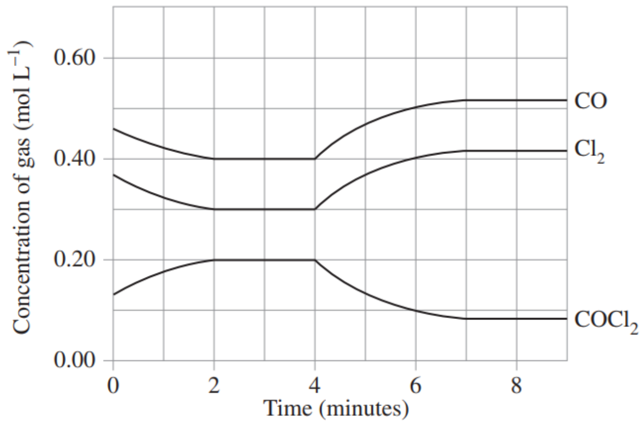
Table 6.23 summarises the question types coded for the cognitive demand applied in the 2016 physics and chemistry examinations. Except for England, over 70% of the physics question-parts were Type 1, with the remaining percentages of Types 2 or 3. In contrast, there was more of a balance of all three Types in chemistry with the exceptions of the Netherlands and South Africa, which had over 80% of Type 2 and 3 questions.

Table 6.23 Country breakdown of the percentage of question-type for cognitive level apply.

	Number of question-parts		**% 'type 1(%)**		**type 2 / 3(%)**	
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry
England	24	41	46	44	54	56
Ireland	32	20	88	60	12	40
the Netherlands	17	23	82	13	18	87
NSW	14	23	71	35	29	65
Scotland	40	24	83	54	17	46
South Africa	29	39	83	17	17	83

The following is an example of a Type 3 question-part from NSW. Answering this question required applying Le Châtelier's principle to interpret the graph.

A mixture of carbon monoxide, chlorine and phosgene ($COCl_2$) gases is placed in a closed container. The concentrations of the gases were monitored over time.



b) At four minutes, the temperature of the container was increased.

Explain, with reference to the graph, whether the decomposition of $COCl_2$ into CO and Cl_2 is exothermic or endothermic.

(NSW, Q.28)

- ***Analyse –***

Overall, there was a noticeable reduction in the percentage of marks allocation and the number of topics with question-parts coding for analysis across both subjects. Six of the seven physics topics had questions coding for *analyse*, namely

a) Newtonian physics (England, Ireland, NSW, South Africa),

b) Heat (the Netherlands)

c) Electricity (England, the Netherlands, NSW, South Africa),

d) Radioactivity (the Netherlands)

e) Wave motion (England, NSW, Scotland, South Africa)

f) Electron (England, NSW, South Africa)

(Note: The two underlined countries each had a single topic coding for *analyse*)

Interestingly, there was a similar reduction in chemistry of both percentage of marks and the number of topics with question-parts coding for *analyse*. Six of the eight topics in chemistry had question-parts coding for analyse that is:

a) Period table/Atomic structure (England, NSW)

b) Chemical equilibrium (England, NSW)

c) Volumetric analysis (England, the Netherlands, South Africa)

d) Organic chemistry (England, the Netherlands, NSW, Scotland)

e) Industrial chemistry (Ireland, the Netherlands, NSW)

f) Electrochemical (NSW)

(Note: the underlined countries had one question-part coding for *analyse*).

- ***Evaluate-***

Five of the seven physics topics had question-part coding for the cognitive demand *evaluate*, which were

a) Newtonian physics (England, Ireland, the Netherlands, NSW, Scotland)

b) Wave motion (England, the Netherlands, NSW, Scotland)

c) Electricity (the Netherlands, Scotland)

d) Electron (NSW)

e) Motors/generators (NSW)

In chemistry, five of the eight topics had question-parts coding for *evaluate*, with just five countries assigning marks to this demand -

a) Periodic Table/Atomic structures (England)

b) Chemical bonding (England, Ireland)

c) Organic chemistry (the Netherlands)

d) Rates of reaction (NSW)

e) Industrial chemistry (Scotland)

Generally, there was more emphasis on the cognitive demand *evaluate* in physics than in chemistry. There were two exceptions. England allocated the same percentage of marks to evaluate in physics and chemistry; South Africa had no question-parts in either physics or chemistry, which coded for *evaluate.* Another comparison could be drawn between the overall cognitive demands of each country's examination in physics and chemistry. The rearrangement of the data from Figure 6.17 facilitates the comparison of the overall cognitive demands between physics and chemistry of each country (Figure 6.18).

Some observations:

- England's chemistry examination was slightly more cognitively demanding (than physics) due to the emphasis on *apply,* yet the overall cognitive profile for physics and chemistry was similar.
- Ireland's physics and chemistry examinations were cognitively challenging due to a) the percentage of marks assigned to *remember* and *apply* in physics and b) the percentage of marks assigned to *remember* and *understand* in chemistry.
- The dominant emphasis on the Netherlands' physics was *apply* with the other cognitive demands at a low level of emphasis. On the other hand, the chemistry examination presents a more balanced distribution of all the cognitive demands.
- NSW's physics and chemistry examination favoured a balanced distribution of all the cognitive demands.

- Scotland's physics examination cognitive load broadly resembled those of the Netherlands and South Africa, with a high level of cognitive demand *apply* and a low distribution of the other cognitive demands. In contrast, Scotland's chemistry examination was similar, with an overall balanced distribution of cognitive demands to that of the Netherlands' chemistry.
- South Africa's physics and chemistry examinations closely resembled each other, particularly with a high percentage level of emphasis on *apply.*

Except for Ireland, the dominant cognitive demand in physics for England, the Netherlands, NSW, Scotland, and South Africa was *apply.* However, it is notable that in chemistry, except for England, and South Africa, the combined percentage of marks assigned to *remember* and *understand* was more than the percentage of marks assigned to *apply (Table 6.23).*

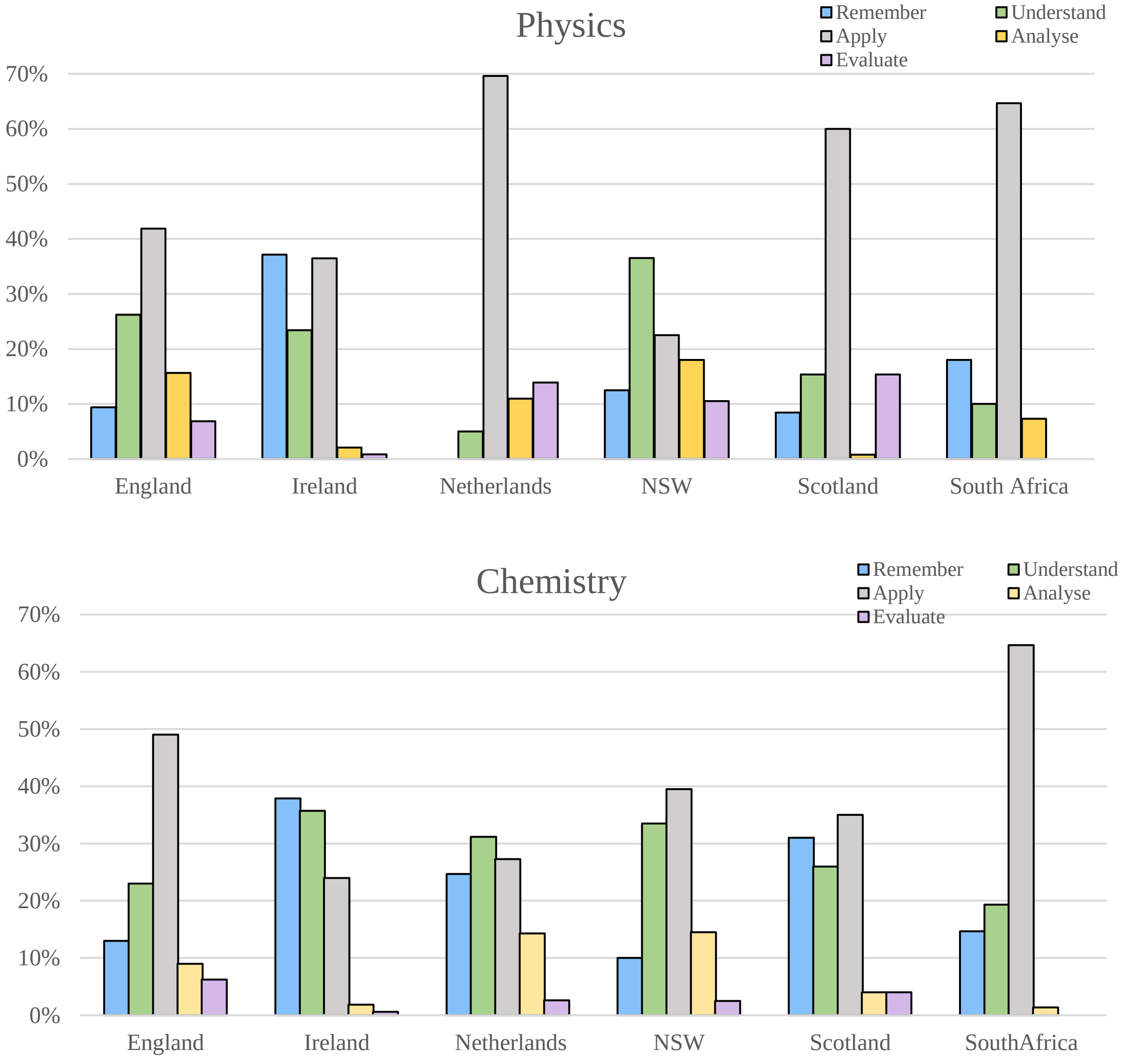


Figure 6.21 Comparison of cognitive demands across the six countries

From a subjective view, both of these observations, emphasis in the physics examinations across the countries of *apply*, and the emphasis on *remember* and *understand* in chemistry speaks to the differing natures of physics and chemistry. Originally called natural philosophy, physics has its origins in the philosophies of ancient times, particularly of the Greek schools of Aristotle, Socrates and Plato. These ancient philosophers reflected on their observations and then offered what seemed logical explanations.

This approach changed when Francis Bacon (1561-1626) and Galileo (1564-1642) looked for answers to the 'how' rather than solely accepting a logical answer to the 'why' question. Gradually the philosophically 'why' questions were replaced by the experimental 'how'. By the twentieth century, experimental physics had replaced natural philosophy. Thus, the nature of physics could be said to have as the starting point – 'how' to be answered experimentally and then work backwards to the 'why' that starts from the concrete and works towards understanding concepts of 'why'. This is a simplistic view, but one which could explain the relatively strong emphasis on cognitive demand of *apply* and the comparatively low level of the cognitive demand *understand* as shown in the physics examinations.

The nature of chemistry is more conceptual and abstract. It also has its origins in ancient philosophies, introducing the concepts of atoms forming the structures of matter, the concepts of elements and how they combine to form other substances. However, at the heart of chemistry is understanding why an interaction occurs and how it can be improved. Concepts such as bonding proposed by Lewis – why certain substances will interact and why others will not; the nebulous called an orbit, electrons rotating around a nucleus, and energy levels of electrons conceived by Bohr, eventually leading to quantum physics, all of which are invisible to the naked eye, yet their effects are visible. This simplistic subjective view of chemistry, where the results of interactions are visible but not what determines the interactions, underscores the role understanding plays in chemistry. This may explain the emphasis on the cognitive demand *understand* in the chemistry examinations.

Comparing the results from the analysis carried out of the 2016 Irish LC physics and chemistry examinations to the analysis carried on the 2016 physics and chemistry examinations in England, the Netherlands, NSW, Scotland and South Africa highlighted a number of differences, for instance:

- The range of the five cognitive demands (*remember, understand, apply, analyse* and *evaluate*) addressed in the 2016 international examinations compared to the narrow range of *remember, understand* and *apply* addressed in the Irish 2016 LC physics and chemistry examinations.
- The use and appropriateness of context-based questions in 2016 physics and chemistry examinations.
- The range of question types in the 2016 physics and chemistry examinations.
- The availability of detailed annual Examiners' Reports indicating strengths and weaknesses of responses to the examination questions (available in England, Scotland, and NSW).

From this researcher's perspective and experience of teaching LC physics and chemistry, the format and question presentation of Irish LC physics and chemistry have remained mainly unchanged from 1966 to the present. The analysis of the 2016 physics and chemistry examination papers from England, the Netherlands, NSW, Scotland and South Africa presented many alternatives which could be usefully adopted into the Irish LC physics and chemistry examinations. These alternatives will be discussed in Chapter 7.

Chapter 7 Findings and Recommendations

7.1 Introduction

Between 1966 and 2016, three syllabi for LC physics and chemistry were implemented. Despite the importance placed on the role of science in the Irish State's economy (Fitzgerald, 1965; Department of Education, 1966; Loxley, Seery and Walsh, 2014), research shows just three studies focused on the cognitive demands of these subjects: 1970 study by Madaus and Macnamara; 2009 study by McCrudden and Finlayson and 2019 study by Burns et al. All three studies arrived at the same conclusion- these examinations were more a test of memory reliance rather than an assessment of the analytical or evaluation skills of the students. As the time lapse between the first study and the other two studies was between forty and fifty years, it was impossible to establish a trend that might merit monitoring (Patrick, 1996); or perhaps the conclusions were coincidences.

This first longitudinal analysis of the LC physics and chemistry examinations from 1966 to 2016 was carried out to address this lacuna. The following two research questions guided the analysis -

- *What were the cognitive demands of the higher-level physics and chemistry Leaving Certificate examination questions in Ireland from 1966 to 2016?*

- *Were there similar ranges of cognitive demands in selected comparable high-stakes written physics and chemistry examinations in other countries, as in the Irish Leaving Certificate examinations in these subjects in 2016?*

One of the many criticisms of the Leaving Certificate examinations was its apparent reliance on rote learning and memorising capabilities to obtain high grades. The introduction of an international dimension, in the form of a second research question, was to investigate the possible adaption of examination questions from other countries to enhance the cognitive demands of the LC physics and chemistry examinations.

This chapter presents the findings and recommendations based on these findings. Section 7.1 details the finding of the two research questions. Recommendations based on these findings are presented in Section 7.2. Section 7.3 focused on the overall limitations of the research. Further studies are suggested in Section 7.4.

7.2 Findings

These findings are based on the analysis of two sources of data -

(a) the higher-level LC physics and chemistry examinations for the period 1966-2016 comprising 102 papers;

(b) six physics and six chemistry examinations, for the examination year 2016, from England, Ireland, the Netherlands, New South Wales (NSW), Scotland and South Africa.

Using the Revised Bloom's taxonomy use of action-verbs, the cognitive demands of the 114 examination papers were determined year-to-year rather than according to topics. Chapter 4 details the process followed in determining the cognitive demands of the LC and the six international examinations.

7.2.1 Cognitive Demands of LC Physics and Chemistry Examinations

The Department of Education presented the three syllabi as revised ones; that is, most of the previous syllabi content was retained and supplemented with additional topics replacing deleted topics. The analysis of the examinations based on these revised syllabi allowed consideration as to whether the revisions resulted in more or fewer questions coding to higher-order cognitive demands or whether there was a resulting change in emphasis on cognitive demands in the examinations.

Throughout the fifty years, both the physics and chemistry examination questions coded for four of the six cognitive demands – *remember*, *understand*, *apply* and *analyse*. There were no questions assessing the two higher cognitive demands of *evaluate* and *create* on either physics or chemistry examinations.

- **Physics examinations.**

Figure 7.1 is a graphic representation of the cognitive demands of the higher-level physics examinations from 1966 to 2016. This cognitive profile shows that the examinations assessed just four cognitive demands – *remember, understand, apply* and *analyse.* No questions assessed the two higher cognitive demands of *evaluate* and *create*.

- There was a marked imbalance between the percentage of marks allocated to questions coding for these demands. Between 55-80% of the total marks were assigned to two cognitive demands of *remember* and *understand.* Irrespective of which syllabus the examination was based on, the dominance of these two lower-level cognitive demands persisted. Interestingly, over the years, when the percentage of marks allocated to *remembe*r increased, there was a decrease in marks allocated to *understand*.

- There were always questions which coded for *apply*. However, the percentage of marks allocated varied considerably, between 6-33% of the total marks. It was noted that most of these questions were computational, requiring students to remember the relevant formula and then apply it. From 2010 onwards, students had access to the booklet *Formulae and Tables*, which contained all necessary formulae. On the other hand, the percentage of marks allocated to *apply* gradually decreased, as shown in Figure 7.1. In sharp contrast, there was a noticeable decrease in questions assessing *analyse,* with some years not coding any question-parts for this cognitive demand.

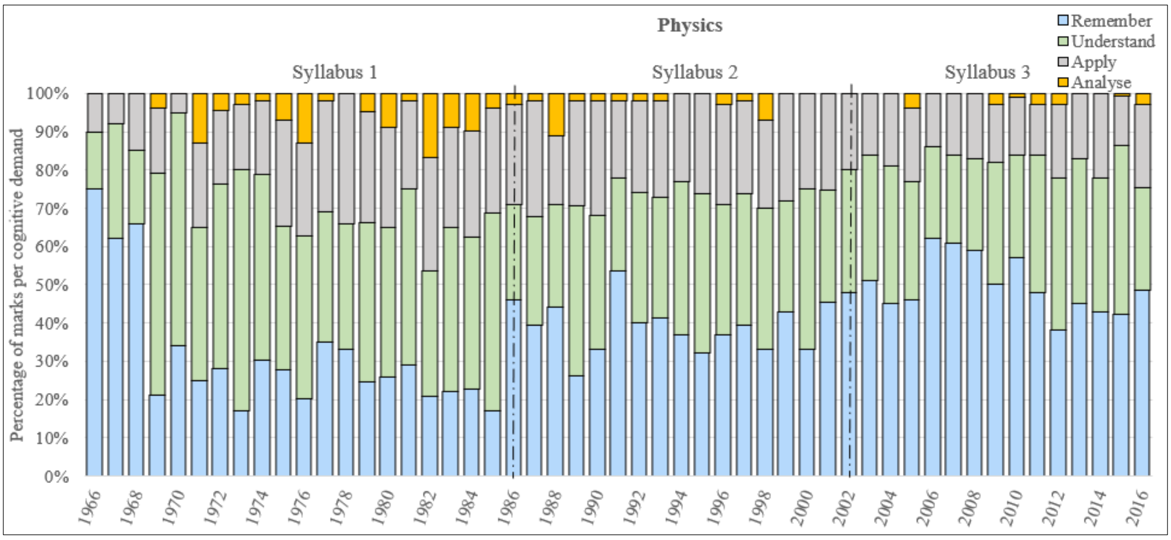


Figure 7.1 Graphic representation of the cognitive demands of physics examinations 1966-2016

- Comparing the cognitive profile of the three syllabi, there was little change in the dominance of questions coding for the two lower cognitive demands – *remember* and *understand.* Conversely, introducing Syllabus 3 resulted in a noticeable decrease in the percentage of marks allocated to cognitive demand *apply*. There were two reasons for this: fewer questions were coded for *apply*; second, fewer marks were allocated to such questions. Examinations based on Syllabus 2 allocated less percentage of marks to questions coding for *analyse.* Moreover, this decrease in questions coding for *analyse* continued through the examinations based on Syllabus 3 when seven of the fourteen years had no questions coding for *analyse*.

- **Chemistry examinations**

Likewise, Figure 7.2 is the graphic representation of the cognitive demands of chemistry for the same fifty-year period.

- Although the overall combined percentage of marks allocated to *remember* and *understand* was approximately 55-85% (similar to physics), the data showed the percentage for *understand* decreased from 65% in the 1970 to 27+% in the 2000s.

- Unlike physics, there was an increase in the percentage of marks allocated to *apply* across the three syllabi, with the most significant increase in the examinations based on Syllabus 3.

- There was also a noticeable decrease in questions coding for *analysis;* for example, between 1988 and 2004, just one year (1993) had a question-part assessing this demand.

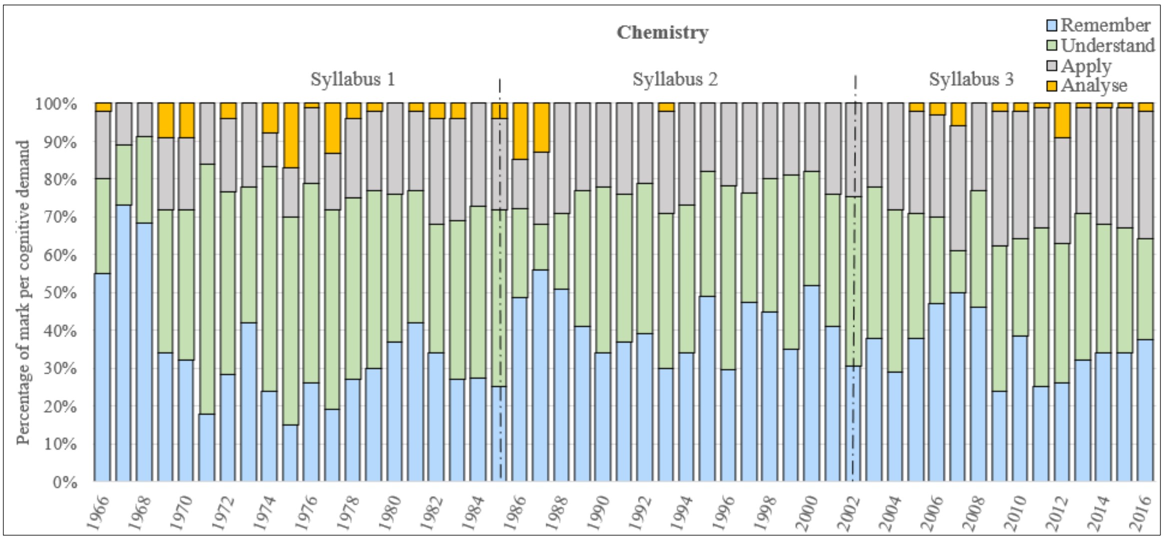


Figure 7.2 Graphic representation of the cognitive demands of chemistry examinations 1966-2016

Although physics and chemistry are different subjects, using different pedagogical approaches, the cognitive profiles of each, as represented by Figure 7.1 (physics) and Figure 7.2 (chemistry), were quite similar-

- for both the dominant cognitive demands were *remember* and *understand*

- in general, there were more questions coding for *apply* in chemistry than in physics

- there was a distinct decrease in questions coding for *analysis in* physics and chemistry examinations

- neither had any questions coding for *evaluate* or *create*

7.2.2 Cognitive Demands of the International Examinations.

The same process to determine the cognitive demands of the Irish LC physics and chemistry examinations was also applied to the six International examinations.

Figure 7.3 shows the range of cognitive demands of each country's examination – *remember*, *understand*, *apply*, *analyse* and *evaluate*. None of the examinations assessed the cognitive demand *create*.

- Except for Ireland, the overall cognitive profile for physics and chemistry were quite different- For physics, the overall emphasis was on questions coding for *apply*; for chemistry, the emphasis was on the cognitive demand *understand*.
- Several countries had questions assessing *analyse* and *evaluate* of the physics and chemistry examination papers.

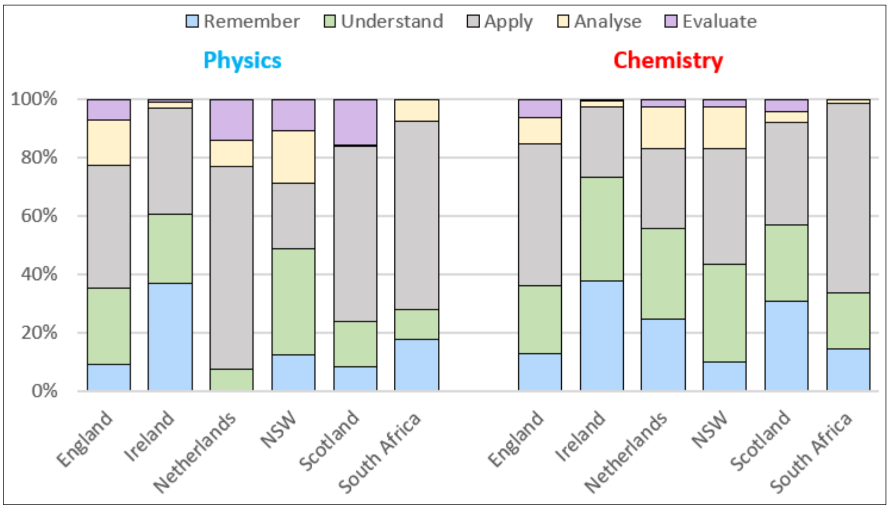


Figure 7.3 Cognitive demands of International physics examinations -2016

However, Figure 7.3 presents a broad overview of the percentage marks allocated to these demands without reference to how these marks were distributed within the examination questions. Mindful of the high number of question-part per question on the Irish LC examinations, further analysis of the examination questions focussed on question-parts and marks allocated.

- Apart from Ireland, the ratio of the total number of question-parts to the total number of questions ranged from 1:1 to 1: 5 (physics) and for chemistry, 1:1 to 1:7 (Table 7.1).

Table 7.1 Number of questions vs number of question-parts for International examinations

		England	Ireland	the Netherlands	NSW	Scotland	South Africa
Physics	Total number of questions	32	12	27	35	24	10
	Total number of question-parts	65	109	27	71	69	56
	Maximum marks per exams	160	400	79	200	130	150
Chemistry	Total number of questions	47	11	33	35	12	10
	Total number of question-parts	88	107	33	73	80	69
	Maximum marks per exams	160	400	77	200	100	150

- Despite having the highest number of question-parts and the second lowest number of questions, Ireland allocated between 60-75% of the marks to the two lower cognitive demands. This finding is in keeping with the similar pattern found across the fifty-year review, although two different lists of action -verbs were used in both analyses.

As the rationale for the analysis of the International examinations was to investigate the possible adaptation of practices, presentation of questions as well as the cognitive load of these questions, a third analysis was carried out – this time of the distribution of the cognitive demands within the various topics as illustrated in Figure 7.3 (physics) and Figure 7.4 (chemistry).

Physics

- Although all the named topics were listed on the respective country's syllabus, a limited number of these topics featured in the 2016 examinations (hence the gaps in Figure 7.4)
- The range of cognitive demands assessed varied significantly across all examinations, with an overall emphasis on questions coding for cognitive demand *apply*.
- The range of cognitive demands per topic assessed varied within each examination except for Ireland.
- Each topic examined in Ireland assessed the same three cognitive demands, remember, understand and apply.
- Except for Ireland, all questions on the other examinations were compulsory.

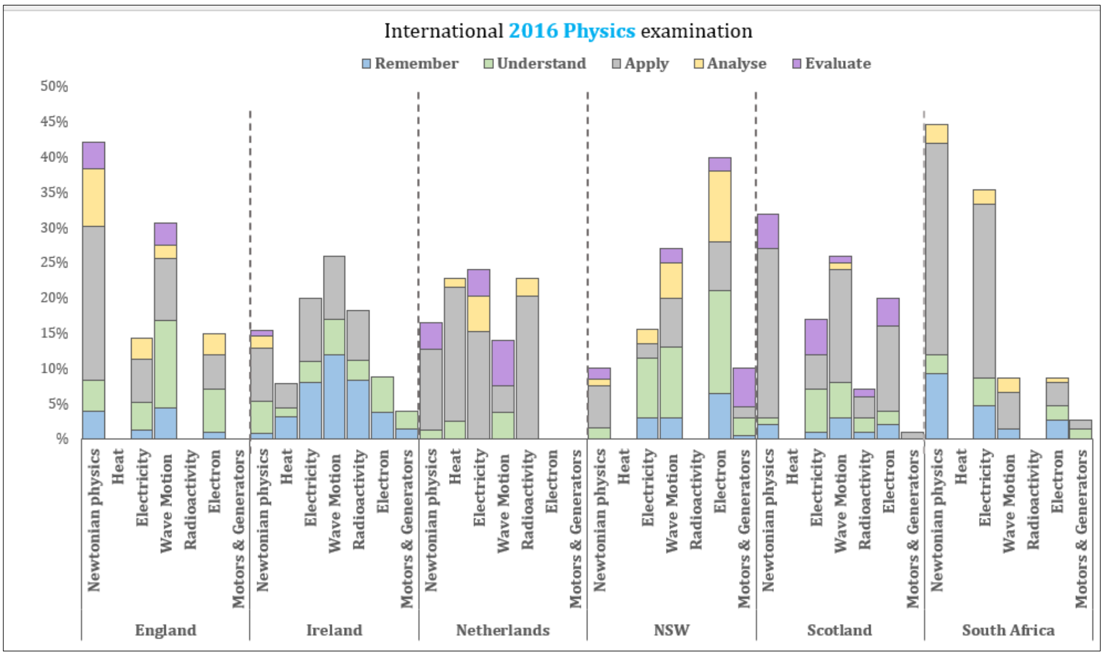


Figure 7.4 Comparison of cognitive demands across similar topics

Chemistry

- Compared to physics, seven of the listed chemistry topics featured on each country's examination.
- Overall, questions based on Organic Chemistry accounted for 24-42% of an examination's total mark.
- Across all six examinations, there was a marked emphasis on questions coding for *remember* and *understand.*
- The percentage of marks allocated to questions coding for *analyse* was in the low digit bracket, a limited number of questions coded for *evaluate*.

There was a noticeable difference between the cognitive profiles of physics and chemistry across all the countries. Physics emphasised the cognitive demand *apply* whilst the focus of chemistry was *understand.*

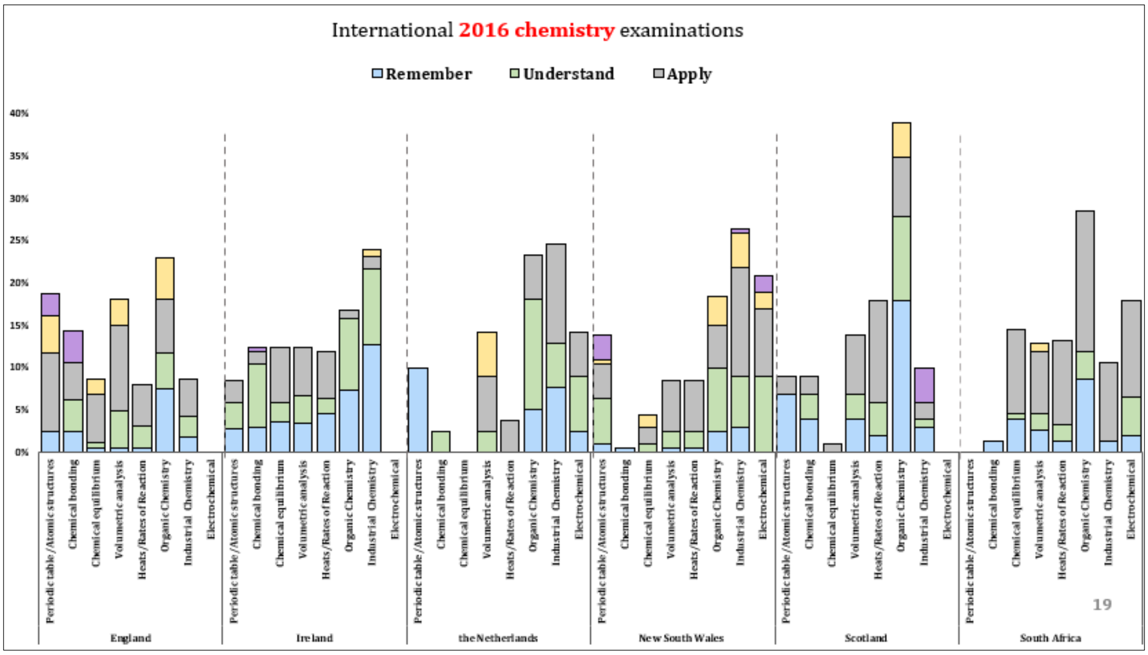


Figure 7.5 Comparison of Cognitive demands across similar topics

7.3 Recommendations

The analysis of the LC physics and chemistry examinations between 1966-2016, as detailed in Chapter 5, showed that consistently, two-thirds of the questions were in the *remember* and *understand* cognitive demand categories. Questions coded for *apply* were based solely on 'calculate' questions. In addition, there was a limited number of questions in the *analyse* categories, with no questions in *evaluate* category.

One of the criteria for selecting these countries was that the physics and chemistry syllabi were comparable to those of Ireland. The analysis of the 2016 physics and chemistry examinations from six countries, as described in Chapter 6, highlighted the range of cognitive demand categories being assessed across comparable topics within each of the six examinations in both subjects. Compared to Ireland, this range included five categories: *remember*, *understand*, *apply*, *analyse* and *evaluate.* This analysis of the international examinations provides the basis for the following recommendations.

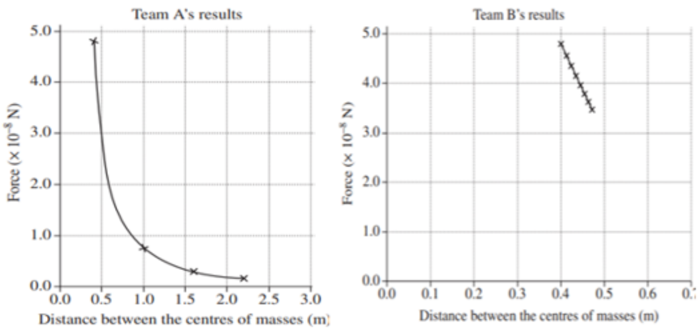
Recommendation 1. To enhance the cognitive demands of questions

Over 65+% of the LC physics and chemistry examinations reviewed were questions assessing both *remember* and *understand.* In comparison, the International examinations allocation focused on cognitive demands of *apply*, *analyse* and *evaluate* as shown by questions in Figure 7.6 (*analyse* and *evaluate*) and Figure 7.7 (three different treatments of the same experiment)

The following question (Figure 7.6), based on Newtonian Mechanics, is from 2016 NSW,

Two teams carried out independent experiments to verify Newton's Law of Universal Gravitation. Each team used the same procedure to accurately measure the gravitational forces acting between two spherical masses over a range of distances.

The following graphs show the data collected by each team:



(a) Compare, qualitatively the relationship between force and distance in the graphs.

(b) Assess the appropriateness of Team A's data and Team B's data in achieving the purpose of the experiments

Figure 7.6 Question from NSW, 2016, Q.25

The Marking Feedback[8] presented by the NSW examination standards for this question highlighted

- students' strength in recognising that force decreases as distance increases (Q, 25a)
- Realising that the broader range produced a more comprehensive view of the curve (Q.25b)

at the same time, highlighting areas for improvement

- comparing the actual curves presented rather than theoretical ones (Q.25a)
- using correct mathematical terms to compare the graphs (Q.25a)
- understanding that a sufficient number of measurements over a sufficient range of distances is required to deduce a valid relationship (Q25b)
- understanding the terms 'accurate', 'valid' and 'reliable' (Q25b).

[8]https://educationstandards.nsw.edu.au/wps/portal/nesa/resources-archive/hsc-exam-papers-archive/physics/physics-2016-hsc-exam-pack-archive

The following marking criteria were applied:

Criteria for Question 25 (a)	Marks
• Provided valid comparison between forces and distances in the graphs	2
• Identified a relationship between force and distance in one of the graphs	1
Criteria for Question 25 (b)	
• Makes an informed judgment of the appropriateness of each data set	3
• Identifies strengths and weaknesses of the data set(s)	2
• Provides some relevant information	1

Essentially, this question tests the student's depth of understanding

- comparing (offering at least two comparisons),
- that 'qualitatively' refers to a description rather than a mathematical statement and
- understanding the appropriateness of data to establish a relationship is a number of data points within a given range.

The SEC did not issue a 2016 LC physics and chemistry examination report. The most recent report is for 2013. Looking at one of the questions on this paper coupled with the marking criteria will indicate the reporting process:

Question 1 on the paper centred around one of the mandatory experiments – measuring the dissolved oxygen content of a water sample. The final question -part was as follows:

> *Kits, designed for use in the field, allow the dissolved oxygen concentration to be measured immediately on the collection of the sample. Why is the **immediate** determination of dissolved oxygen considered best practice?* *(3)*

Chief Examiners' Report on this particular question –

> *This question required critical assessment based on prior knowledge. This question, based on scenario candidates were unlikely to have previously considered, tested candidates' ability to explain an unfamiliar, to understand how chemistry is used to solve problems in society and how chemistry is related to everyday life. Good answering required generalisation to a context new to the candidates. This is a challenging skill, and many answers were unsatisfactory. This type of question serves as a discriminator for achievement in higher-order cognitive skills.*
>
> (State Examinations Commission, 2013, p. 15)

The marking criteria for this question consisted of two possible answers in the form of a list, i.e. biochemical (biological) reactions (photosynthesis, respiration, metabolism) occur; alternatively, the action of microorganisms (bacteria, algae, diatoms) (State Examinations Commission, n.d.). A question based on the decomposition of hydrogen peroxide featured in the 2016 chemistry examination in Ireland, Scotland and South Africa. Figure 7.7 shows all three together. However, the range of questions based on the investigation varies across the three examinations, as follows:

Ireland:

Based on the experiment mandatory experiment *Monitoring the rate of production of oxygen from hydrogen peroxide, using manganese dioxide as a catalyst* (Department of Education & Science/NCCA, 1998c, p. 53)) questions asked the students to recall

- the diagram of the apparatus used,
- plot a graph from the data given
- carry out calculations based on the graph involving drawing the tangent at 4.0 minutes and calculating the slope. [This particular calculation is in the syllabus (Department of Education & Science/NCCA, 1998c, p. 57)].

The question-parts on catalysis and catalyse could allow students to apply their analytic skills. On the other hand, this question based on one of the mandatory experiments was, in reality, a laboratory account of the experimental procedures repurposed as a series of questions.

Scotland:

Each of the four questions posed was precise (state, complete, calculate), with each question allocated just one mark. Completing the diagram was a standard type of question. The first calculation required knowledge of the reaction equation and the reaction's stoichiometry. The second calculation depended on the student recognising that the time on the graph was in unit $s^{-1,}$ yet the calculated time was to be in seconds.

South Africa

Notably, the necessary data was presented in two labelled sections, 5.1 and 5.2. The questions associated with each section were likewise labelled, such as 5.1.1 and 5.2.1.

i. Inserting a graph profile based on the information given,
ii. Applying the collision theory to explain the role of manganese dioxide in the decomposition of hydrogen peroxide,
iii. Using the graph to calculate the average rate of reaction,
iv. Interpreting the graph to determine the volume of H_2O_2 decomposed and then converting this volume to grams.

Overall, the South African question-parts were quite demanding but gave the students a greater opportunity to use and show their chemical knowledge about what is happening, e.g. using the collision theory as the basis for explanation.

Ireland Q.

In an investigation into the decomposition of a hydrogen peroxide solution, using a manganese (IV) oxide catalyst, the volume of oxygen produced was monitored over time. Two runs were conducted under the same conditions of temperature and pressure, using the same initial volume of the same hydrogen peroxide solution, and the same mass of catalyst from two different suppliers, A and B. The volumes of oxygen collected at a set of times common to both runs are recorded in the Table below

	Time (mins)	0.0	1.0	2.0	3.0	5.0	6.5	8.0	9.5	11.0	12.0
Run A	Volume (cm^3)	0	25	41	54	72	78	81	82	82	82
Run B	Volume (cm^3)	0	16	28	39	57	68	76	80	82	82

Questions to be answered.

a) Draw a labelled diagram of apparatus used.

b) Plot a graph of volume of oxygen vs. time for each run.

c) Calculate the instantaneous rate of reaction (in cm^3 O_2 per minute) for Run A at 4.0 minutes.

d) Which run, A or B
   a) reached completion first,
   b) had the slower rate?

e) What type of catalysis was involved in the reaction?

f) Suggest how the catalyst used in run A may have differed from that used in run B to account for your answers to parts (i) and (ii).

Scotland Q. 1

Hydrogen peroxide gradually decomposed into water and oxygen according to the following balanced equation

$$2H_2O_2(l) \longrightarrow 2H_2\,(l) + O_2\,(g)$$

(a) At room temperature the reaction is very slow. It can be speeded up by heating the reaction mixture.

(b) i. The reaction can also be speeded up by adding a catalyst, such as manganese dioxide. To determine the rate of reaction, the volume of gas produced in a given time can be measured. Complete the diagram (Figure A) to show how the gas produced can be collected and measured.

(b) ii. The concentration of hydrogen peroxide is often described as a volume of strength. This related to the volume of oxygen that can be produced from a hydrogen peroxide solution.

Volume of oxygen produced = volume strength + volume of hydrogen peroxide

In an experiment 74 cm^3 of oxygen was produced from 20 cm^3 of hydrogen peroxide solution.

(c) Hydrogen peroxide can react with potassium iodide to produce water and iodine. A student carried out an experiment to investigate the effect of changing the concentration of potassium on reaction. The result are shown in Figure B.

Figure A

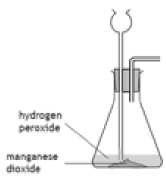
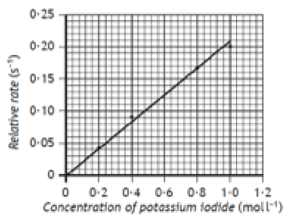


Figure B



Questions to be answered.

(a) State why increasing the temperature causes an increase in reaction rate.

(b) i. Complete the diagram to show how the gas produced can be collected and measured.

(b) ii. Calculate the volume strength of the hydrogen peroxide.

(c) Calculate the time, in s, for the reaction when the concentration of potassium iodide used was 0.6 mol l^{-1}

South Africa, Q. 5.

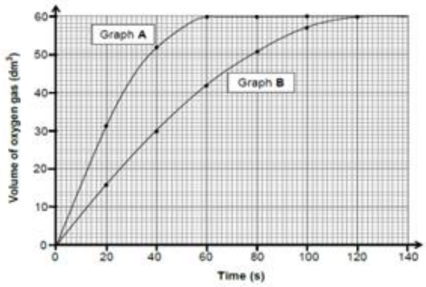
Hydrogen peroxide gradually decomposed into water and oxygen according to the following equation

$$2H_2O_2(l) \longrightarrow 2H_2\,(l) + O_2\,(g).$$

5.1. The activation energy (EA) for this reaction is 75kJ and the heat of reaction is -196 kJ.

When powdered manganese dioxide is added to the reaction mixture, the reaction increases.

5.2. .Graphs A and B were obtained for the volume of oxygen produced over time under different conditions. The results are shown below.

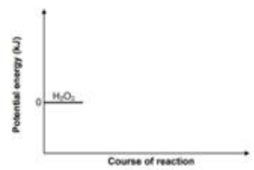


Questions to be answered.

5.1.1. Define the term activation energy.

5.1.2. Redraw the set of axes below and complete the potential energy diagram of this reaction. Indicate the value of the potential energy of the following on the y-axis:-

(i) Activation complex (ii) Products.



5.1.3. On the above graph, use broken lines to show the path of the reaction when manganese dioxide is added.

5.1.4. Use the collision theory to explain how manganese dioxide influences the rate of decomposition of hydrogen peroxide

5.2.1. Calculate the average rate of the reaction (in dm3 s-1) between t = 10s and t = 40 s for graph A.

5.2.2. Use the information in Graph A to calculate the mass of hydrogen peroxide used in the reaction. Assume that all the hydrogen peroxide decomposed. Use 24 dm^3 mol^{-1} as molar volume of oxygen

Figure 7.7 Question on decomposition hydrogen peroxide (Ireland, NSW, South Africa)

Recommendation 2 – Reduce the number of question-parts per question in the physics and chemistry examinations

Syllabus 3 for physics consists of eight topics, and for chemistry consists of nine topics; both subjects also have 24 mandatory experiments and two options (Department of Education and Science, 1999a; Department of Education & Science/NCCA, 1998c). All content of both syllabi is examinable. Hence, physics and chemistry examination papers contain eleven to thirteen questions (often a question per page) to encompass all topics. Each question, in turn, comprises several question-parts, usually between five and twelve. Consequently, answering eight questions means answering between 55 and 65 question-parts. As part of their examination strategy, many students draw up a ‘timetable’ allocating a time length to answer each question before moving on to the next question. This strategy involves assigning twenty minutes per question and the remaining twenty minutes to review all answers. However, before applying this strategy, students must read all questions to decide which eight to answer. One would not usually apply a ‘time and motion’ analysis to examination questions. However, Table 7.2 shows how long it took this researcher to read each of the 2016 Leaving Certificate physical sciences examination questions. According to this simple experiment, between twelve and thirteen minutes would need to be deducted from that overall time of three hours allowed for answering. Thus, time-induced pressure starts building up within ten minutes of the examination time starting. Having read through all the questions, students then self-select which eight questions to answer.

Table 7.2 Comparing time length to read all questions on the 2016 Leaving Certificate physical sciences examination papers

	Time per question /sec.	No. question.-parts /per question	2016 Chemistry Question	Time per question /sec.	No. question-parts /per question
1	45	7	**1**	60	5
2	43	6	**2**	104	7
3	40	5	**3**	90	8
4	38	6	**4**	54	12
5	80	11	**5**	48	9
6	71	9	**6**	60	9
7	80	9	**7**	56	6
8	58	11	**8**	52	10
9	56	7	**9**	51	10
10	49	7	**10**	82	11
11	101	8	**11**	88	20
12	100	23			
Total time/s 761 sec.		(109)	Total time/s 745 sec.		(107)
Total time: 13 minutes			Total time: 12 minutes		

One immediate proposal for modifying the Leaving Certificate physics and chemistry examinations is to reduce question-parts. Of all the examination question papers analysed in Chapters Five (Ireland) and Six (International), Ireland is the only country where every question had several questions–parts coding for the cognitive demands of remembering and understanding. This preponderance of *remember* and *understand* questions was evident in the findings presented in Chapter 6 from the comparative analysis of the physics examination papers, as shown in Table 6.6 and Figure 6.12 and chemistry examination papers, in Table 6.15 and Figure 6.18. Reducing the reading time of Leaving Certificate examination papers by reducing the number of question parts would provide time and capacity for more *apply* and *analyse* questions.

Recommendation 3 – A detailed annual Examiners' Report for physics and chemistry

One of the limitations of this study was the inadequacy of feedback on the examinations from the SEC compared to the nature of the feedback provided by other international countries. In Ireland, between 2002 and 2010, there were four Chief Examiners' Reports (CER)[9] on the physics and chemistry examinations of 2002, 2005, 2008 and 2013. As well as providing statistics on participation and performance trends, these reports focused on the quality of answers provided by the students and recommendations for teachers and students. The 2013 reports for physics and chemistry were the only ones which referenced the subject objectives. However, reports on both subjects present different approaches – the physics report primarily focused on the objectives with passing reference to higher cognitive skills. On the other hand, the chemistry report focused on cognitive levels with objectives referenced where pertinent.

In contrast, the **NSW's annual report** highlight physics question-parts in which students

(i) showed strength; for example, in the 2016 examination:

- identifying the increased lattice vibrations with increasing temperature
- articulating the multiple steps required to achieve the correct calculation

and (ii) areas in which to improve, such as

- interpreting velocity-time graphs, especially when the gradient is acceleration.

In chemistry, using the same format,

(i) areas in which strength is shown include –

[9] : https://www.examinations.ie/?l=en&mc=en&sc=cr

- writing half equations for an anode and a cathode
- identifying equilibrium on a graph

and

(ii) areas to improve, such as

- completing all parts of a question
- linking cause and effect

In England, the examining board, Edexcel, is responsible for the physics examinations. The Examiners' Reports, as well as giving explanations of the questions, also included samples of good responses highlighting why the response merited full marks. AQA (England) was responsible for the chemistry examination but did not publish a report.

Scotland: The annual report was in the form of a checklist (Table 7.3)

Table 7.3 Sample Report from Scotland 2016

Question	Part	Content topic	Skills assessed	Maximum mark
9	(a)	Refraction of light	K2	1
10	b(ii)	Electrical sources and internal resistance	S2	1

Where K2 = providing descriptions and explanations and integrating knowledge
S2 = Selecting information from a variety of sources

Recommendation 4 - Raise the level of expectation for the students

The revised biology syllabus was first examined in 2002. Acknowledging the biochemical nature of biology, the *Guidelines for Teachers* (NCCA, 2002) considered '*prior knowledge of basic chemistry and knowledge of the topics* listed below to be *useful in the study of biology*

1. *Composition of matter, atoms and ions*
2. *Isotopes and radioisotopes*
3. *Electronic configuration of atoms and ions*
4. *Bonding- ionic, covalent and hydrogen bond*
5. *Acids, bases, pH and neutralisation*
6. *Oxidation and reduction*
7. *Water as a solvent and its role in hydration, dehydration reactions and hydrolysis*

8. The notion of hydrophilic substances and hydrophobic substances. The nature of lipids as hydrophobic substances. The hydrophilic and hydrophobic nature of proteins
9. For higher students, an appreciation of the peptide bond, the three-dimensional nature of proteins – a linear molecule folded up to give very different three-dimensional shapes.

(NCCA, 2002, p. 3)

Neither the physics nor the chemistry guidelines contain a comparable list. However, not every student who elects to study either or both subjects at the upper-second level would have studied science at the lower-second level. On the other hand, both subjects refer to the mathematical aspects but in a different tone of language and with different objectives. Comparing the mathematical requirements listed in both syllabi shows the sole difference is the inclusion of *Geometry & Trigonometry* and the elementary treatment of *Vectors* in Physics. Furthermore, the *Physics: Guidelines for Physics* highlighted mathematics positively for both higher and ordinary levels and considered that

skills in arithmetic, algebra, geometry, trigonometry, and drawing and interpreting graphs are required. The mathematics required is well within the demands of Leaving Certificate in Ordinary level mathematics.
A positive attitude to mathematics in physics classes is important. There is a fine balance between doing sufficient mathematical work for students to become competent and deterring them with too much mathematics.

(Department of Education & Science/NCCA, 1999b, p. 16)

By contrast, the *Chemistry: Guidelines for Teachers* observed that

The number of types of mathematical problems at the Ordinary level has been reduced, and a number of more difficult topics have been eliminated. These measures, along with an increased emphasis on practical work and the social and applied aspects, should help to attract more Ordinary level students. (Department of Education & Science/NCCA, 1999d, p. 3.)

Recommendation 5 - Consider the cognitive demands of syllabi objectives

In the *Manual for Drafters, Setters and Assistant Setters* (State Examinations Commission, 2007), several references are made to Bloom's Taxonomy. On page 33, referring to constructing the assessment grid template drawn up to identify content vs assessment objective, the *Manual* relates the assessment objectives to *a taxonomy of educational objectives such as Bloom's Taxonomy or some other taxonomy appropriate to the subject. On pages 49-50, more details about educational objectives indicate that both terms of the* objectives and descriptors were similar to those of the 1956 Bloom's Taxonomy. Furthermore, Appendix 5: *Question Cues and Bloom's Taxonomy (Cognitive Domain)* in the *Manual* uses the 1956 cognitive demand terms, knowledge, comprehension, application, analysis, synthesis and evaluation (State Examinations Commission, 2007, pp. 98–99). This raises an interesting observation – the analysis of the Leaving Certificate examinations detailed in Chapter 5, carried out based on the Revised Bloom Taxonomy (RBT), showed a high reliance on questions in the *remember* and *understand* cognitive demand categories.

The syllabi objectives for physics and chemistry are listed under the headings – Knowledge, Understanding, Skills and Competences. The research in this thesis focussed on the cognitive demands of the questions without reference to the syllabi objectives. This prompts the question – what are the cognitive demands of the syllabi objectives themselves?

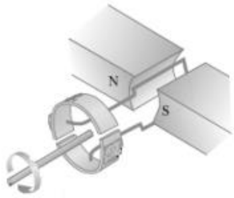
Recommendations 6 - Upgrade the standard of examination questions

There is a visual lack of uniformity concerning the layout of the questions. That is to say, each question is presented differently, e.g., one question consisting of a set of items labelled (a), (b), (c), (d); another question consisting of a series of questions based on a given context; or two topics treated within one question.

In contrast, in South Africa, all the questions on both physics and chemistry follow a definite pattern, as shown in the following example from the 2016 physics paper. This examination consisted of 16 pages, with ten questions (all mandatory). The overall appearance of the paper was one of orderliness and clarity of purpose, with the mark allocation for each question part indicated. Each question was presented with a simple context, usually accompanied by a diagram or sketch, as shown in Figure 7.8.

QUESTION 9 (Start on a new page.)

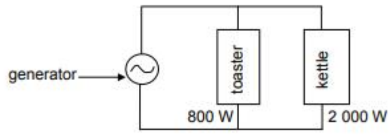
9.1 A generator is shown below. Assume that the coil is in a vertical position.



9.1.1 Is the generator above AC or DC? Give a reason for the answer. (2)

9.1.2 Sketch an induced emf versus time graph for ONE complete rotation of the coil. (The coil starts turning from the vertical position.) (2)

9.2 An AC generator is operating at a maximum emf of 340 V. It is connected across a toaster and a kettle, as shown in the diagram below.



The toaster is rated at 800 W, while the kettle is rated at 2 000 W. Both are working under optimal conditions.

Calculate the:

9.2.1 rms current passing through the toaster (3)

9.2.2 Total rms current delivered by the generator (4)
[11]

Figure 7.8 Question 6, South Africa, 2016 physics examination

Contrast this to the 2011 Leaving Certificate physics Q. 10 (b) Figure 7.9: there were 11 question-parts, none labelled nor allocated individual marks. However, adding the marks (18+12+15+5) gives 56; thus, this question could be one of the eight selected by the student.

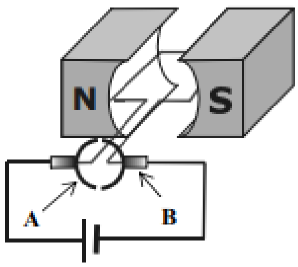
(*b*) State the principle of operation of an electric motor. (6)

The diagram shows a simple d.c. motor.

Name each of the parts labelled **A** and **B** on the diagram and state the function of each.

What material is normally used in part **B**? Give two properties of this material that make it suitable for use in a motor.

List three factors that affect the torque (couple) acting on the coil. (18)



If the motor jammed, a larger current than normal would flow through the motor.

Explain why.

What would be the effect on the motor if this happened? (12)

What changes can be made to a d.c. motor to convert it to an a.c. generator?

Draw a sketch of the output voltage from an a.c. generator. (15)

Give two ways in which the output voltage from an a.c. generator can be increased. (5)

Figure 7.9 Question 10, Ireland physics, 2011

7.4 Limitations of the research

- **Personal bias**

This research used the Revised Bloom's taxonomy and action-verbs as the metric for determining the cognitive demands of both the LC and international examinations. The LC physics and chemistry examinations (1966-2016) were one of the source data for the research. Having taught these subjects for many years, the researcher was familiar with the syllabi and the examination system. In order to maintain an objective stance, a list of action-verbs to use in categorising the questions was compiled from online sources. When a particular action-verb was not listed, the researcher looked at the context of the question.

- **Selection of topics for international examinations**

The second data source was the six international examinations. Due to the varied presentation of the six chemistry syllabi, the researcher drew up an initial list of all topics on the examination papers; in consultation with other experienced second-level Irish teachers, eight topics emerged from this list, which ensured all examination questions were included in this research. The formation of these eight topics was influenced by the teachers more familiar with the Irish syllabi than by the syllabi of other countries.

- **Lack of data information**

Between 1966-1986, the allocation of marks per question-parts was not indicated. As no marking scheme was available for these years, the researcher, in consultation with other experienced teachers, applied a marking scheme based on those used from 2002 onwards.

According to the SEC website

> *the Chief Examiners' Reports provide a review of the performance of candidates in the examinations and a detailed analysis of the standards for answering.*

Established in 2001, the SEC published four CER for both subjects, 2002, 2005,2008 and 2015. This paucity of reports resulted in no baseline for comparison or reference points.

7.5 Further studies

Although this research focused on the past, it has highlighted several areas for further investigation.

(a) Few studies have compared the Leaving Certificate syllabus in physics and chemistry with first-year university physics and chemistry examinations. Nor are there many studies comparing the cognitive demands of the Leaving Certificate physics and chemistry examinations to those of first-year university examinations in these subjects. Such studies would prove fruitful in understanding the depth or lack of the Leaving Certificate students' grasp of science concepts.

(b) The intrusion of Covid-19 has highlighted the usefulness of digital tools for remote learning. It also highlighted the inequity that can arise. It is interesting to note that the 2022 report *Leaving Certificate Reform: the Need for a New Senior Cycle* (Joint Committee on Education, Further and Higher Education, Research, Innovation and Science, 2022) considered the role of digital learning within the context of primary and second-level education. What is not mentioned is how physics and chemistry syllabi would incorporate this form of learning. A study examining this aspect of digital learning within the confines of experimental subjects has not been carried out so far.

(c) One of the findings of analysing the cognitive demands of the Leaving Certificate examinations in physics and chemistry had been the dearth of questions assessing the cognitive domains of *evaluate* and *create* and the small percentage of questions assessing the cognitive domain of *analyse*. To adequately assess these cognitive demands, the questions should present unfamiliar information/data for *analysing* and *evaluating*. Generally, each question on the Leaving Certification physics and chemistry examinations is topic specific. In the late 1990s, synoptic assessment was introduced in the UK to test students' understanding and use of different aspects of a course (Patrick, 2005; Constantinou, 2020). Synoptic Assessment was defined as

> *A form of assessment which tests candidates' understanding of the connections between different elements of a subject*
>
> *(QCA, CCEA & ACCEC, 1999, p.43)*

The interdisciplinary nature of this type of assessment lends itself to physics and, in particular, chemistry. Although presented as a means of testing understanding across a subject, this multi-topic question could allow students to use their analytical skills. A feasibility study to explore and draw up these specific questions could provide a novel way of assessing the analytic and evaluative cognitive domains.

(d) Bloom’s taxonomy as a metric tool.

Including action-verbs in the revised Bloom’s taxonomy provided a means of assessing the cognitive demands of examinations. In Chapter 5, the action-verbs list used was primarily based on the SEC list in the *Manual for Setters*, with an additional list should an action-verb not be on the SEC list. This list was used in determining the cognitive demands of the LC physics and chemistry examination from 1966 to 2016. In Chapter 6, another list, based on two independent sources- Stanny and Newton et al.- was used to determine the cognitive demands of the 2016 examinations of six countries. Table 7.4 shows the percentage distribution of the cognitive demands of the 2016 LC physics and chemistry examinations as determined by both lists.

Table 7.4 Determining the cognitive demands of the 2016 physics and chemistry examination using different action-verb lists.

	Physics 2016		**Chemistry 2016**	
	SEC list	Stanny/Newton et al. list	SEC list	Stanny/Newton et al list
Remember	38%	37%	49%	38%
Understand	27%	23%	27%	34%
Apply	34%	36%	22%	26%
Analyse	2%	2%	3%	2%
Evaluate	n.a	1%	n.a	1%

The SEC list contains fewer action-verbs than the Stanny/Newton list, which may contribute to the marginal differences between the two sets of cognitive demands of the 2016 physics examination. However, the marked difference between the cognitive demands of chemistry may be attributed to applying the same list to chemistry – a different subject to physics. At third-level education, based on Bloom’s cognitive demands categories, a number of subject-specific taxonomies have been developed, for example, in computer science (Fuller *et al.*, 2007), physics (Buick, 2011; Shakhman and Barak, 2019), biology (Crowe, Dirks and Wenderoth, 2017), Medical Education (Tuma and Nassar, 2021). However, there are no subject-specific taxonomies suitable for use at upper second- level assessment. This is an area that merits investigation rather than applying a generic taxonomy across all subjects.

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Appendices

Appendix **A: Number of Students sitting a science examination 1964-2016**

	Physics	Chemistry	Biology	Ag. Science	Total LC
1966	17%	17%		4%	12573
1967	17%	17%		3%	13590
1968	16%	18%		4%	14757
1969	21%	21%	Introduced in 1969-first exam in 1971	4%	16986
1970	14%	19%		4%	18975
1971	13%	17%	18%	4%	20780
1972	11%	17%	20%	3%	24163
1973	11%	18%	25%	2%	25280
1974	11%	19%	33%	2%	26892
1975	12%	18%	34%	2%	29206
1976	12%	19%	39%	2%	32559
1977	13%	31%	45%	2%	35268
1978	13%	19%	48%	0%	35804
1979	14%	18%	51%	3%	35510
1980	14%	19%	53%	2%	36539
1981	0%	0%	0%	0%	38336
1982	0%	0%	0%	0%	41428
1983	19%	19%	54%	3%	43858
1984	16%	16%	42%	0%	55466
1985	0%	0%	0%	0%	47736
1986	0%	0%	0%	0%	47857
1987	20%	19%	52%	4%	50446
1988	20%	18%	51%	0%	51159
1989	19%	17%	51%	0%	54038
1990	19%	16%	49%	4%	55146
1991	19%	15%	47%	4%	55641
1992	16%	9%	28%	4%	55179
1993	19%	13%	21%	4%	57230
1994	22%	15%	56%	4%	51810
1995	21%	16%	58%	5%	53843
1996	20%	16%	59%	5%	46564
1997	17%	13%	54%	5%	53904
1998	18%	15%	56%	5%	54297
1999	17%	13%	54%	6%	53349
2000	16%	13%	51%	6%	52190
2001	17%	13%	48%	6%	49392
2002	15%	3%	26%	6%	46900
2003	18%	14%	47%	6%	47900
2004	17%	15%	39%	7%	47498
2005	17%	16%	54%	8%	46958
2006	17%	16%	56%	9%	44411
2007	16%	16%	58%	10%	44523
2008	16%	16%	59%	10%	45394
2009	15%	16%	60%	11%	46728
2010	14%	16%	63%	12%	46791
2011	14%	16%	65%	14%	46699
2012	14%	17%	66%	15%	46236
2013	14%	17%	67%	15%	47040
2014	15%	18%	67%	16%	48875
2015	15%	18%	68%	15%	50044
2016	15%	18%	67%	16%	50766

Appendix B: Physics and Chemistry syllabi 1966-1969

Physics syllabus (Pa) (1964-1969) Pass and Honours

Mechanics

1. Displacement. Vectors and scalars. Addition and resolution of vectors. Velocity and acceleration.
2. Newton's laws. Force. Mass. Weight. Conservation of momentum.
3. Force as a vector. Moments. Gravitation.

Heat

1. Concept of temperature. Gas thermometer. Definition of gas scale. Absolute scale. Gas laws. Centigrade scale. The mercury thermometer.
2. Concept of quantity of heat. Specific heat.
3. Work. Energy. Mechanical equivalent of heat. Conservation of energy.
4. Kinetic theory. Pressure and temperature on the kinetic theory. Avogadro's number. Brownian movement.

Light

Laws of reflection and refraction. Velocity. Formation of images by mirrors and lenses. Simple telescope. Dispersion by prism. Formation of spectra.

Wave Motion

1. Transverse and longitudinal waves. Meaning of frequency, wavelength, amplitude, velocity.
2. Diffraction patterns of waves, suggesting dependence of diffraction on ratio of wavelength to width of aperture.
3. Interference patterns of waves.

Sound

Wave theory. Interference. Young's experiment. Diffraction. Spectral lines and wavelengths. Ultraviolet and infrared light. Propagation of energy by waves, heat radiation. Electromagnetic spectrum.

Electrostatics.

Charges. Conductors and insulators. Electroscopes. Induction. Coulomb's law. Electric fields. Field strength and potential. Condensers. Energy of system of charges.

Magnetism

Magnets. Notion of magnetic pole. Magnetic field. Dipole moment. Couple on dipole in uniform field. Terrestrial magnetism.

Current Electricity and Modern Physics

1. Voltaic cells. Electric current as a flow of charge. Magnetic effect of current. Definition of unit current. Potential difference. Heating effect.
2. Methods of producing magnetic fields. Force on current-carrying conductor in magnetic field. Moving coil meters and galvanometers.
3. Descriptive account of atomic structure. Electrolysis and ionic conduction. Faraday's laws. Charge/mass for hydrogen ion.
4. Thermionic and photoelectric effects. Charge/ mass for electron by deflection in electric and magnetic fields. Production of x-rays by retardation of fast electrons. Ionisation of gases by X-rays.
5. Relation between potential difference and current for various kinds of conduction. Saturation. Ohm's law. Resistance. Moving coil voltmeter.
6. Electromagnetic induction. Alternating currents.
7. Descriptive account of nuclear structure. Isotopes. Radioactivity. Emission of alpha, beta and gamma rays. Radioactive decay. Discovery of neutron. Examples of nuclear reactions. Artificial radioactivity. Mass-energy conservation nuclear reactions. Photoelectric effect and photons. Gamma rays as photons. Compton effect and pair production.

(An Roinn Oideachais, 1963, pp. 81–82)

Chemistry syllabus (Ca) (1964-1969)

Pass

1. The properties of gases, liquids and solids; elements, compounds and mixtures.
2. Atomic theory: the structure of the atom, electrons, protons, neutrons, atomic number, isotopes.
3. Structure of simple molecules; covalent, electrovalent and metallic bonds; crystal structure as exemplified by the sodium chloride lattice; electronegativity.
4. The structure and valence of elements as exemplified by the first twenty elements of the Periodic Table.
5. The Kinetic Theory of Gases; its use in explaining the Gas Laws, Diffusion.
6. Determination of equivalent, atomic and molecular weights. Vapour density. Simple volumetric and gravimetric analysis. Formulae and equations.
7. (a) Study of the following elements and compounds: -
   Hydrogen, ammonia, ammonium salts, nitrogen oxides, nitric acid, nitrates;
   Carbon, carbon dioxide, carbonates, hydrogen carbonates, carbon monoxide;
   Sulphur, hydrogen sulphide, sulphur dioxide, sulphurous acid, sulphur trioxide, sulphuric acid, sulphates;
   The halogens, halogen hydrides;
   Phosphorus, phosphorus oxides, phosphoric acids.

   (b) Study of the following elements and their more important compounds:
   sodium, potassium, copper, silver, magnesium, calcium, zinc, aluminium, lead, iron.

   Suitable reference should be made to the Electrochemical Series and the periodic Table in dealing with the above elements and compounds.
8. Study of the chemistry of methane, ethylene, acetylene, ethyl alcohol, acetaldehyde, acetic acid, benzene, nitrobenzene.
9. Heats of formation and heats of reaction.
10. Modern concepts of acid-base reactions, oxidation-reduction processes.

Honours

As for the Leaving Certificate Pass Course and in addition: -

11. Concepts of energy levels, ionisation potential and electron affinity.
12. The shape of simple symmetrical molecules (organic and inorganic; tetrahedral, planar and linear), reference to orbitals and hybridisation.
13. The Periodic Table in relation to Atomic Structure.
14. Study of the chemistry of methyl alcohol, ethylene (polymerisation of), chloroform, diethyl ether, glycerol, formaldehyde, formic acid, lactic acid (optical isomerism), fumaric and maleic acids (geometrical isomerism), ethyl acetate, acetone, glucose, cane sugar, aniline.
15. First Law of Thermodynamics.
16. The Law of Mass Action and electrolyte solutions; strong and weak acids, hydrolysis of salts; pH and indicators.
17. Oxidation and reduction as electron transfer. Oxidation number.
18. The study of the following reactions as examples of reaction mechanisms: - chlorine and hydrogen, chlorine and methane, bromine and ethylene, sodium hydroxide and ethyl bromide. Catalysis.
19. Radioactive isotopes and their uses (elementary treatment only).
20. The identification of the ions of the chief salts of the metals in par. 7 (b) by micro or semi-micro methods. Volumetric analysis using silver nitrate, potassium permanganate.

Appendix C: Websites accessed for examination material

Education authorities

Country	Examining authorities	Website
England	Office of Qualifications & Examinations Regulation (Ofqual)	https.//www.gov.uk/government/organisations/ofqual
Ireland	State Examinations Commission	https.//www.examinations.ie/about-us/
The Netherlands	Board for Tests and Exams	https.//www.examenblad.nl/
New South Wales	Education Standards Authority	https.//educationstandards.nsw.edu.au/wps/portal/nesa/home
Scotland	Scottish Qualification Authorities	https.//www.sqa.org.uk/sqa/70972.html
South Africa	Department of Basic Education	https.//www.education.gov.za/

Examining Boards approved to set A-levels by Ofqual

Examining Board	Examination papers	Weblink for examination papers
Assessment & Qualification Alliance	AQA -	https.//www.aqa.org.uk/
Oxford, Cambridge & RSA Examinations	OCR -	https.//www.ocr.org.uk/
Edexcel Pearson- London Examinations	Edexcel -	https.//qualifications.pearson.com/en/home.html

Website links for examination papers analysed

England	**https.//www.gov.uk/government/publications/gce-as-and-a-level-for-science**
	9781449781446910719_GCE_Lin_Physics_Issue_6.pdf6910719_GCE_Lin_Physics_Issue_6.pdf
	https.//secondaryscience4all.files.wordpress.com/2014/06/aqa-as-and-a-level-specification-june-2014-to-june-2015.pdf
	https.//www.aqa.org.uk/find-past-papers-and-mark-schemes
Ireland	https.//www.examinations.ie/exammaterialarchive/
Nether-lands	https.//www.examenblad.nl/item/havo/2016/havo translations by. https.//www.deepl.com/translator
NSW	https.//educationstandards.nsw.edu.au/wps/portal/nesa/resources-archive/hsc-exam-papers-archive/physics
	https.//educationstandards.nsw.edu.au/wps/portal/nesa/resources-archive/hsc-exam-papers-archive/chemistry
	https.//lakemacqua-h.schools.nsw.gov.au/content/dam/doe/sws/schools/l/lakemacqua-h/localcontent/physics-st6-syl.pdf
	https.//lakemacqua-h.schools.nsw.gov.au/content/dam/doe/sws/schools/l/lakemacqua-h/localcontent/chemistry-st6-syl.pdf
Scotland	https.//www.sqa.org.uk/sqa/files_ccc/NH_Physics_all_2016.pdf-DQP-Spellcheckon.pdf
	https.//www.sqa.org.uk/sqa/files_ccc/NH_Chemistry_all_2016-DQP-Spellcheckon.pdf
South Africa	https.//wcedonline.westerncape.gov.za/november-2016-nsc-examinations
	https.//wcedeportal.co.za/eresource/106356

Appendix D: Sample of coding sheet used to analysis physics and chemistry examinations 1966-2016

	All Qs	**Qt. parts**	**Marks**	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
1	1	_i	12	12					
2		_ii	6		6				
3		_iii	6	6					
4		_iv	9			9			
5		_v(i)	9			9			
6		_v(ii)	9			9			
7		_v(iii)	9			9			
8		_vi	6		6				
9	2	_i	9	9					
10		(i)	12			12			
11		(ii)	12			12			
12		(iii)	12			12			
13		_ii	21				21		
14	3	_i	6	6					
15		_ii	12	6	6				
16		_iii	6	6					
17		_iv	9			9			
18		_v(a)	12			12			
19		_v(b)	12			12			
20		_vi	15	6	9				
21	4	(i)-i	6	6					
22		(i)-ii	18		18				
23		(i)-iii	21			21			
24		(ii)-i	6	9					
25		(ii)-ii	15		15				
26	5	_i(i)	12				12		
27		_i(ii)	12		12				
28		_ii	18		18				
29		_iii	24		24				
30	6	_i	6	6					
31		_i(i)	6	6					
32		_i(ii)	6	6					

33		_ii	6	6					
34		_iii	6	6					
35		(a)	6	6					
36		(b)	6	6					
37		_iv-i	12		12				
38		_iv-ii	12		12				
39	7	(a)_i	30		30				
40		(a)-ii	12	12					
41		(b)-i	7	7					
42		(b)-ii	18		18				
43	8	(i)_i	6	6					
44		(i)-ii	15		15				
45		(i)-iii	7	7					
46		(ii)-i	9	9					
47		(ii)-ii	12		12				
48		(ii)-iii	6	6					
49		(ii)-iv	12	12					
50	9	_i	7	7					
51		_ii	15		15				
52		_iii	9		9				
53		_iv	15			15			
54		_v	15	6	9				
55		_vi	6	6					
56	10	(i)	22		22				
57		(ii)	22				22		
58		(iii)	22				22		
59		(iv)-i	9		9				
60		(iv)-ii	24			24			
61		(v)-i	3						
62		(v)-ii	15		15				
63		(v)-iii	18				18		
Total marks			738	186	292	165	95	0	0
Percentage of total marks				25%	40%	22%	13%	0%	0%

Appendix E: Data used in the analysis of physics examinations 1966-2016

Physics	Year	Total marks per examination	*Remember*	*Understand*	*Apply*	*Analyse*	Question-parts per examination
Syllabus 1	1966	994	55%	25%	18%	2%	68
	1967	730	73%	16%	11%	0%	49
	1968	730	69%	23%	9%	0%	51
	1969	729	34%	38%	19%	9%	54
	1970	726	32%	40%	19%	9%	52
	1971	819	18%	66%	16%	0%	56
	1972	756	28%	48%	19%	4%	57
	1973	750	42%	36%	22%	0%	57
	1974	756	24%	60%	9%	8%	60
	1975	756	15%	55%	13%	17%	57
	1976	756	26%	53%	20%	1%	67
	1977	756	19%	52%	15%	13%	57
	1978	756	27%	48%	21%	4%	63
	1979	756	30%	47%	21%	2%	64
	1980	756	37%	39%	24%	0%	62
	1981	789	42%	35%	21%	2%	65
	1982	756	34%	34%	28%	4%	69
	1983	792	27%	42%	27%	4%	72
	1984	789	27%	45%	27%	0%	72
	1985	756	25%	47%	24%	4%	75
Syllabus 2	1986	723	49%	24%	13%	15%	72
	1987	723	56%	12%	19%	13%	65
	1988	723	51%	20%	29%	0%	80
	1989	726	41%	36%	23%	0%	80
	1990	723	34%	44%	22%	0%	76
	1991	723	37%	39%	24%	0%	74
	1992	729	39%	40%	21%	0%	79
	1993	723	30%	41%	27%	2%	76
	1994	672	34%	39%	27%	0%	65

Syllabus 3	1995	723	49%	33%	18%	0%	85
	1996	723	30%	49%	22%	0%	74
	1997	732	48%	29%	24%	0%	94
	1998	726	45%	35%	20%	0%	89
	1999	726	35%	46%	19%	0%	75
	2000	726	52%	30%	18%	0%	93
	2001	729	41%	35%	24%	0%	82
	2002	734	31%	45%	25%	0%	89
	2003	743	38%	40%	22%	0%	86
	2004	754	29%	43%	28%	0%	82
	2005	685	38%	33%	27%	2%	73
	2006	741	47%	23%	27%	3%	82
	2007	741	50%	11%	33%	6%	73
	2008	810	46%	31%	23%	0%	114
	2009	741	24%	39%	36%	2%	74
	2010	741	39%	26%	34%	2%	78
	2011	741	25%	42%	32%	1%	67
	2012	741	26%	37%	28%	9%	76
	2013	741	32%	39%	28%	1%	115
	2014	763	34%	34%	31%	1%	98
	2015	685	34%	33%	32%	1%	92
	2016	797	38%	27%	34%	2%	110
Mean %		719.10	37%	37%	23%	3%	74
Standard deviation (%)		63	12%	11%	6%	4%	15

Appendix F: Data used in the analysis of chemistry examinations 1966-2016

Chemistry	Year	Total marks per examination	*Remember*	*Understand*	*Apply*	*Analyse*	Question-parts per examination
Syllabus 1	1966	995	75%	15%	10%	0%	51
	1967	797	62%	29%	8%	0%	47
	1968	644	66%	19%	15%	0%	34
	1969	655	21%	58%	17%	4%	58
	1970	669	34%	61%	5%	0%	49
	1971	738	25%	40%	22%	13%	63
	1972	664	28%	48%	19%	4%	72
	1973	717	16%	63%	17%	3%	53
	1974	768	30%	48%	19%	2%	75
	1975	748	27%	38%	28%	7%	81
	1976	732	20%	42%	24%	13%	66
	1977	744	35%	34%	29%	2%	85
	1978	744	33%	33%	34%	0%	82
	1979	744	25%	42%	29%	5%	92
	1980	741	26%	39%	26%	9%	72
	1981	744	29%	46%	23%	2%	78
	1982	744	21%	33%	30%	17%	72
	1983	774	22%	43%	26%	9%	92
	1984	744	23%	40%	28%	10%	85
Syllabus 2	1985	747	17%	51%	27%	4%	83
	1986	750	46%	25%	26%	3%	85
	1987	753	39%	28%	30%	2%	89
	1988	750	44%	27%	18%	11%	72
	1989	750	26%	44%	27%	2%	80
	1990	741	33%	35%	30%	2%	78
	1991	748	53%	24%	20%	2%	75
	1992	750	40%	34%	24%	2%	72

	1993	753	41%	31%	25%	2%	74
	1994	609	37%	40%	23%	0%	62
	1995	750	32%	41%	26%	0%	73
	1996	750	37%	34%	26%	3%	111
	1997	750	39%	34%	24%	2%	82
	1998	741	33%	37%	23%	7%	72
	1999	750	43%	29%	28%	0%	73
	2000	750	33%	42%	25%	0%	76
	2001	753	45%	29%	25%	0%	80
Syllabus 3	2002	646	48%	32%	20%	0%	73
	2003	641	51%	33%	16%	0%	76
	2004	647	45%	36%	19%	0&	82
	2005	647	46%	31%	19%	4%	80
	2006	741	62%	24%	14%	0%	88
	2007	741	61%	23%	16%	0%	88
	2008	741	59%	24%	17%	0%	83
	2009	647	50%	32%	15%	3%	77
	2010	647	57%	27%	15%	1%	84
	2011	647	48%	36%	13%	3%	76
	2012	647	38%	40%	19%	3%	80
	2013	647	45%	38%	17%	0%	82
	2014	640	43%	35%	22%	0%	84
	2015	647	42%	44%	13%	1%	120
	2016	647	49%	27%	22%	3%	70
Mean %		719	39%	36%	21%	3%	76
Standard deviation (%0		63	14%	10%	6%	4%	14

Appendix G: Data used in the analysis of 2016 international physics examinations

England. Edexcel 2016 physics examination - Paper 1 -

England	All Qs	Qn-pts	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*	*Create*
1	1		1	Newton P.		1				
2	2		1	Newton P.			1			
3	3		1	Electricity		1				
4	4		1	Newton P.	1					
5	5		1	Newton P.	1					
6	6		1	Newton P.	1					
7	7		1	Newton P.		1				
8	8		1	Electricity		1				
9	9		3	Newton P.			3			
10	10	(a)	3	Newton P.	3					
11		(b)	6	Newton P			6			
12	11	(a)	2	Newton P.			2			
13		(b)	5	Newton P.			5			
14		(c)	3	Newton P.				3		
15	12	(a)	5	Electron			5			
16		(b)	3	Electron			3			
17		(c)	3	Electron		3				
18	13	(a)	3	Newton P.			3			
19		(b)	3	Newton P.			3			
20		(c)	3	Newton P.				3		
21	14	(a)i	1	Electricity			1			
22		(a)ii	2	Electricity			2			
23		(a)iii	3	Electricity			3			
24		(b)	4	Electricity		4				
25	15	(a)	3	Newton P.		3				
26		(b)	4	Newton P.				4		
27		(c)	4	Newton P.					4	
28	16	(a)	2	Electricity				2		
29		(b)	4	Electricity			4			
30		(c)	3	Electricity				3		
Total marks			80		6	14	41	15	4	0
Total percentage			80		8%	18%	51%	19%	5 %	0%

England Edexcel 2016 physics examination -paper 2

	All Qs	Qnt.pt	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*	*Create*
1	1		1	Wave m.	1					
2	2		1	Wave m.	1					
3	3		1	Newton P.		1				
4	4		1	Newton P.		1				
5	5		1	Newton P.			1			
6	6		1	Wave m.		1				
7	7		1	Wave m.		1				
8	8		1	Wave m.		1				
9	9	(a)	3	Wave m.			3			
10		(b)	3	Wave m.	3					
11	10	(a)i	3	Newton P.			3			
12		(a)ii	2	Newton P.		2				
13		(b)	3	Newton P.				3		
14	11	(a)	2	Wave m.			2			
15		(b)	3	Wave m.		3				
16		(c)	3	Wave m.		3				
17		(d)	2	Wave m.		2				
18	12	(a)	2	Wave m.		2				
19		(b)	3	Wave m.			3			
20		(c)	5	Wave m.					5	
21	13	(a)	6	Electron		6				
22		(b)i	2	Electron			2			
23		(b)ii	1	Electron		1				
24	14	(a)	2	Wave m.			2			
25		(b)i	2	Wave m.			2			
26		(b)ii	2	Wave m.	2					
27		(c)	3	Wave m.				3		
28	15	(a)	3	Electron		3				
29		(b)i	3	Electron		3				
30		(b)ii	1	Electron	1					
31		(c)	4	Electron		4				
32	16	(a)	3	Newton P.			3			
33		(b)i	3	Newton P.			3			

34	(b)ii	2	Newton P.			2			
35	(b)iii	1	Newton P.	1					
Total marks		80		9	34	26	6	5	0
Percentage of total marks		80		11%	43%	33%	8%	6%	0

Final coding results of merging results from paper 1 and paper 2

	Marks	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
Edexcel 1	80	6	14	41	15	4	0
	80	8%	18%	51%	19%	7%	0%
Edexcel 2	80	9	34	26	6	5	0
	80	11%	43%	33%	8%	6%	0%
Total Marks	160	15	48	67	21	9	0
Total Percentage		**9%**	**30%**	**42%**	**13%**	**6%**	0%

Ireland 2016 Physics examination

Ireland	**All Qs**	**Qt.-pt**	**Marks**	**Topic/s**	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
1	1	(i)	3	Newton P		3				
2		(ii)	3	Newton P		3				
3		(iii)	6	Newton P		6				
4		iv	4	Newton P		4				
5		(i)	6	Newton P			6			
6		(ii)	12	Newton P			12			
7		iii	6	Newton P		6				
8	2	2.i	9	Wave m.	9					
9		2.ii	3	Wave m.	3					
10		2.iii	12	Wave m.		12				
11		2.iv	6	Wave m.	6					
12		(i)	4	Wave m.			4			
13		(ii)	6	Wave m.			6			

14	3	3.i	15	Wave m.	15			
15		(i)	12	Wave m.			12	
16		(ii)	6	Wave m.			6	
17		(i)	4	Wave m.			4	
18		(ii)	3	Wave m			3	
19	4	4.i	9	Electricity	9			
20		4.ii	3	Electricity	3			
21		4.iii	10	Electricity			10	
22		4.iv	9	Electricity	9			
23		4.v	6	Electricity		6		
24		4.vi	3	Electricity		3		
25	5	(a)	7	Newton P			7	
26		(b)	7	Newton P		7		
27		(c)	7	Wave m.		7		
28		(d)	7	Wave m.	7			
29		(e)	7	Wave m.			7	
30		(f)	7	Electricity	7			
31		(g)	7	Electricity		7		
32		(h)	7	Electron	7			
33		(i)	7	Electron	7			
34		(j)	7	Electron	7			
35		(j-i)	7	Electron	7			
36	6	6.i	3	Newton P	3			
37		6.ii	3	Newton P	3			
38		6.iii	8	Newton P		8		
39		(i)	6	Newton P			6	
40		(ii)	9	Newton P			9	
41		6.iv	6	Newton P		6		
42		6.v	6	Newton P			6	
43		6.vi	3	Newton P	3			
44		6.vii	12	Newton P				12
45	7	7.i	6	Heat	6			
46		7.ii	4	Heat	4			
47		7.iii	9	Heat			9	
48		7.iv	3	Heat		3		

49		7.v	6	Heat	6		
50		7.vi	6	Heat		6	
51		7.vii	6	Heat	6		
52		(i)	6	Heat			6
53		(ii)	10	Heat			10
54	8	8.i	6	Electron	6		
55		8.ii	6	Electron		6	
56		8.iii	6	Electron		6	
57		8.iv	8	Electron		8	
58		8.v	3	Electron	3		
59		8.vi	9	Electron	9		
60		8.vii	6	Electron		6	
61		8.viii	3	Electron	3		
62		8.ix	3	Electron		3	
63		8.x	3	Electron	3		
64		8.xi	3	Electron	3		
65	9	9.i	12	Radioact.	12		
66		9.ii	15	Radioact.			15
67		9.iii	3	Radioact.	3		
68		9.iv	3	Radioact.		3	
69		9.v	3	Radioact.	3		
70		9.vi	8	Radioact.	8		
71		9.vii	12	Radioact.			12
72	10	10.i	6	M & G	6		
73		10.ii	9	M & G		9	
74		10.iii	11	M & G			11
75		(i)	12	M & G			12
76		(ii)	3	M & G			3
77		(i)	9	M & G			9
78		(ii)	6	M & G			6
79	11	(a)	7	Wave m.	7		
80		(b)	7	Wave m.	7		
81		(c)	7	Wave m.	7		
82		(d)	7	Wave m.	7		
83		(e)	7	Wave m.		7	

84		(f)	7	Wave m.			7			
85		(g)	7	Wave m.		7				
86		(h)	7	Wave m.	7					
87	12	(a).i	6	Radioact.	6					
88		.ii	7	Radioact.		7				
89		.iii	9	Radioact.			9			
90		.iv	6	Radioact.			6			
91		(b).i	6	Electricity	6					
92		.ii	4	Electricity			4			
93		.iii	6	Electricity	6					
94		.iv	9	Electricity			9			
95		.v	3	Electricity	3					
96		(c).i	6	Wave m.	6					
97		.ii	4	Wave m.	4					
98		.iii	12	Wave m.			12			
99		.iv	6	Wave m.			6			
100		(d).i.i	3	Electron	3					
101		i.ii	3	Electron	3					
102		i.iii	8	Electron		8				
103		i.iv	8	Electron			8			
104		i.v	3	Electron				3		
105		i.vi	3	Electron		3				
106		(d).ii.i	6	M & G	6					
107		ii.ii	9	M & G		9				
108		ii.iii	9	M & G		9				
109		ii.iv	4	M & G	4					
Total Marks			713		268	178	252	15	0	0
Total Percentage			713		38%	25%	35%	2%	0%	0%

The Netherlands 2016 physics examination

The Netherlands	**All Qs**	**Qt-pt**	**Marks**	**Topic/s**	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
1	1	(a)	3	Radioact.			3			
2		(b)	4	Radioact.			4			
3		(c)	4	Radioact.			4			
4		(d)	5	Radioact.			5			

5		(e)	2	Radioact.				2		
6	2	(a)	3	Newton P.			3			
7		(b)	3	Newton P.			3			
8		(c)	3	Newton P.			3			
9		(d)	3	Newton P.			3			
10		(e)	1	Newton P.		1				
11	3	(a)	2	Wave m.				2		
12		(b)	3	Wave m.				3		
13		(c)	2	Wave m.		2				
14		(d)	3	Wave m.			3			
15		(e)	1	Wave m.		1				
16	4	(a)	3	Electricity			3			
17		(b)	4	Electricity				4		
18		(c)	4	Electricity			4			
19		(d)	2	Electricity			2			
20		(e)	3	M & G			3			
21		(f)	3	M & G				3		
22	5	(a)	3	Heat			3			
23		(b)	1	Electricity		1				
24		(c)	4	Heat			4			
25		(d)	2	Heat	2					
26		(e)	4	Heat			4			
27		(f)	4	Heat			4			
Total marks			79		2	4	58	15	0	0
Total percentage			79		3%	5%	73%	19%	0%	0%

New South Wales (NSW)- 2016 physics examination

NSW	All Qs	Qt.-pt.	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*	*Create*
1	Part A	1	1	M & G	1					
2		2	1	Electricity	1					
3		3	1	Electron	1					
4		4	1	Electron	1					
5		5	1	Electricity			1			
6		6	1	Newton P.			1			

7		7	1	Electricity	1			
8		8	1	M & G	1			
9		9	1	M & G	1			
10		10	1	Newton P.	1			
11		11	1	Electron		1		
12		12	1	Electron	1			
13		13	1	Electron	1			
14		14	1	Newton P.		1		
15		15	1	Electron	1			
16		16	1	Electricity.	1			
17		17	1	Newton P.		1		
18		18	1	Newton P.		1		
19		19	1	Electron	1			
20		20	1	M & G	1			
21	21	(a)	2	Newton P.	2			
22		(b)	3	Newton P.		3		
23	22	(a)	2	Electricity	2			
24		(b)	4	Electricity(M)			4	
25	23	(a)	3	Electron	3			
26		(b)	3	Electron		3		
27	24	-	4	Electron		4		
28	25	(a)	2	Newton P.			2	
29		(b)	3	Newton P.				3
30	26		5	M & G				5
31	27	(a)	3	Electron	3			
32		(b)	4	Electron	4			
33	28		5	Newton P.		5		
34	29		6	M & G			6	
35	30	(a)	3	M & G		3		
36		(b)	3	M & G	3			
37	31	(a)i	2	Wave m.	2			
38		ii	3	Wave m.	3			
39		(b)i	3	Wave m.	3			
40		ii	3	Wave m.	3			
41		(c)	4	Wave m.	4			
42		(d)	4	Wave m.				4
43		(e)	6	Wave m.	6			

44	32	(a)i	2	Electron	2					
45		ii	3	Electron	3					
46		(b)i	3	Electron	3					
47		ii	3	Electron			3			
48		(c)	4	Electron				4		
49		(d)	4	Electron		4				
50		(e)	6	Electron		6				
51	33	(a)i	2	Wave m.	2					
52		ii	3	Wave m.				3		
53		(b)i	3	Wave m.		3				
54		ii	3	Wave m.					3	
55		(c)	4	Wave m.		4				
56		(d)	4	Wave m.		4				
57		(e)	6	Wave m.		6				
58	34	(a)i	2	Electron	2					
59		ii	3	Electron		3				
60		(b)i	3	Electron	3					
61		ii	3	Electron			3			
62		(c)	4	Electron		4				
63		(d)	4	Radioactivity		4				
64		(e)	6	Radioactivity				6		
65	35	(a)i	2	Electron			2			
66		ii	3	Electron	3					
67		(b)i	3	Electron				3		
68		ii	3	Electron	3					
69		(c)	4	Electron				4		
70		(d)	4	Electron		4				
71		(e)	6	Electron		6				
Total marks			200		25	96	32	26	21	0
Total percentage			200		13%	48%	16%	13%	11%	0%

Scotland – 2016 physics examination

Scotland	**All Qs**		**Marks**	**Topic/s**	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	*Create*
1	Section 1	1	1	Newton P.			1			
2		2	1	Newton P.	1					
3		3	1	Newton P.			1			
4		4	1	Newton P.			1			

5		5	1	Newton P.			1		
6		6	1	Wave m.			1		
7		7	1	Wave m.		1			
8		8	1	Electron	1				
9		9	1	Electron		1			
10		10	1	Electron	1				
11		11	1	Electron	1				
12		12	1	Electron			1		
13		13	1	Wave m.			1		
14		14	1	Wave m.		1			
15		15	1	Electron			1		
16		16	1	M & G		1			
17		17	1	Electricity			1		
18		18	1	Electricity			1		
19		19	1	Electricity			1		
20		20	1	Electricity			1		
21	Section 2								
22	1	(a) i	1	Newton P.			1		
23		(a)ii	1	Newton P.			1		
24		(b)	2	Newton P.			2		
25		(c)	3	Newton P.			3		
26		(d)	2	Newton P.			2		
27	2	(a) i	1	Newton P.			1		
28		(a)ii	2	Newton P.			2		
29		(b)	4	Newton P.					4
30		(c)i	3	Newton P.			3		
31		(c)ii	3	Newton P.			3		
32		(c)iii	1	Newton P.	1				
33	3	(a)	1	Newton P.	1				
34		(b)	3	Newton P.			3		
35		(c)	4	Newton P.			4		
36	4	(a)	2	Newton P.					2
37		(b)i	2	Newton P.		2			
38		(b)ii	3	Newton P.			3		
39		(b)iii	1	Newton P.				1	
40	5	(a)i	2	Newton P.			2		
41		(a)ii	1	Newton P.		1			

42		(b)	3	Wave m.			3			
43	6		3	Electron		3				
44	7	(a)	3	Electron			3			
45		(b)	4	Electron			4			
46		(c)	1	Electron			1			
47	8	(a)	1	Radioact.		1				
48		(b)	4	Radioact.			4			
49		(c)	1	Radioact.		1				
50		(d)	1	Radioact.			1			
51	9	(a)	1	Wave m.	1					
52		(b)	1	Wave m.		1				
53		(c)	3	Wave m.			3			
54		(d)	2	Wave m.		2				
55	10	(a)	3	Wave m.			3			
56		(b)	3	Wave m.			3			
57		(c)	1	Wave m.			1			
58	11		3	Electricity		3				
59	12	(a)i	4	Electricity			4			
60		(a)ii	3	Electricity		3				
61		(b)i	3	Electron			3			
62		(b)ii_A	4	Electron			4			
63		(b)ii_B	1	Electron		1				
64	13	(a)i	1	Electricity	1					
65		(a)ii	3	Electricity			3			
66		(b)	3	Electricity			3			
67		(c)	2	Electricity		2				
68	14	(a)	2	Wave m.			2			
69		(b)i	3	Wave m.	3					
70		(b)ii	1	Wave m.			1			
Total marks			130		11	24	88	1	6	0
Total percentages			130		8%	18%	68%	1%	5%	0%

South Africa – 2016 physics examination

South Africa	**All Qs**	**Qt.pt**	**Marks**	**Topic/s**	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
1	1	1.1	2	Newton P.	2					
2		1.2	2	Newton P.			2			

3		1.3	2	Newton P.		2		
4		1.4	2	Newton P.				2
5		1.5	2	Newton P.				2
6		1.6	2	Newton P.		2		
7		1.7	2	Electricity		2		
8		1.8	2	Electricity				2
9		1.9	2	Electricity		2		
10		1.10	2	Electricity		2		
11	2	2.1	2	Newton P.	2			
12		2.2	3	Newton P.			3	
13		2.3	5	Newton P.	5			
14		2.4.1	3	Newton P.			3	
15		2.4.2	5	Newton P.			5	
16	3	3.1	2	Newton P.	2			
17		3.2.1	4	Newton P.			4	
18		3.2.2	3	Newton P.			3	
19		3.3	2	Newton P.			2	
20	4	4.1	1	Newton P.	1			
21		4.2.1	3	Newton P.			3	
22		4.2.2	5	Newton P.			5	
23		4.2.3	4	Newton P.			4	
24	5	5.1.1	3	Newton P.			3	
25		5.1.2	4	Newton P.			4	
26		5.2	2	Newton P.	2			
27		5.3	4	Newton P.			4	
28	6	6.1.1	2	Wave m.	2			
29		6.1.2	3	Wave m.			3	
30		6.1.3	5	Wave m.			5	
31		6.1.4	1	Wave m.				1
32		6.2	2	Wave m.			2	
33	7	7.1.1	2	Electricity	2			
34		7.1.2	1	Electricity	1			
35		7.1.3	1	Electricity				1
36		7.1.4	6	Electricity			6	
37		7.2.1	2	Electricity	2			

38		7.2.2	5	Electricity			5			
39	8	8.1.1	2	Electricity	2					
40		8.1.2	1	Electricity			1			
41		8.1.3	1	Electricity			1			
42		8.1.4	3	Electricity			3			
43		8.1.5	2	Electricity			2			
44		8.1.6	4	Electricity			4			
45		8.2.1	3	Electricity			3			
46		8.2.2	5	Electricity			5			
47	9	9.1.1	2	M & G		2				
48		9.1.2	2	M & G			2			
49		9.2.1	3	M & G			3			
50		9.2.2	4	M & G			4			
51	10	10.1.1	2	Electron	2					
52		10.1.2	3	Electron		3				
53		10.1.3	1	Electron	1					
54		10.1.4	1	Electron				1		
55		10.2.1	5	Electron			5			
56		10.2.2	1	Electron	1					
Total marks			150		27	15	97	11	0	0
Percentage of total marks			150		18%	10%	65%	7%	0%	0%

Appendix H: Data used in the analysis of the 2016 international chemistry examinations

England AQA – 2016 chemistry examination, Paper 1

England	All questions	Q-p	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
Section A	1	1.1	2	Period/At	2				
2		1.2	1	Period/At				1	
3		1.3	1	Period/At				1	
4	2	2.1	2	Period/At				2	
5		2.2	1	Period/At			1		
6		2.3	4	Period/At					
7	3	3.1	3	Vol.an.			3		
8		3.2	3	Vol.an.			3		4
9		3.3	2	Vol.an.				2	
10		3.4	6	Vol.an.		6			
11	4	4.1	5	Period/At			5		
12	5	5.1	3	Chem.Eq			3		
13		5.2	3	Chem.Eq			3		
14	6	6.1	3	Period/At				3	
15		6.2	1	Period/At			1		
16		6.3	2	Period/At			2		
17		6.4	2	Period/At			2		
18		6.5	4	Period/At			4		
19	7	7.1	3	Chem.bn	3				
20		7.2	2	Chem.bn		2			
21		7.3	2	Chem.bn			2		
22	8	8.1	1	Vol.an			1		
23		8.2	1	Vol.an			1		
24		8.3	1	Vol.an			1		
25		8.4	3	Vol.an			3		
26	9	9.1	4	Vol.an			4		
27	Section B	10	1	Period/At	1				
28		11	1	Chem.bn			1		
29		12	1	Chem.bn			1		

30	13	1	Chem.bn			1	
31	14	1	Chem.bn		1		
32	15	1	Chem.bn	1			
33	16	1	Vol.an			1	
34	17	1	Vol.an		1		
35	18	1	Period/At	1			
36	19	1	Chem.Eq				1
37	20	1	Chem.bn		1		
38	21	1	Chem.bn		1		
39	22	1	Chem.Eq			1	
40	23	1	Vol.an			1	
41	24	1	Vol.an			1	
Total marks	80	8		12	46	10	4
Total percentage	80	10%		15%	58%	13%	5%

England. AQA. 2016 chemistry examination Paper 2

England	Qnt.	Qt.pt	marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
Section A	1	1.1	2	Chem.Eq				2	
2		1.2	2	Chem.Eq			2		
3	2	2.2	4	Heat.of Rx			4		
4		2.2	1	Heat.of Rx		1			
5		2.3	1	Heat.of Rx			1		
6		2.4	1	Heat.of Rx		1			
7		2.5	3	Heat.of Rx			3		
8	3	3.1	1	Org. chem	1				
9		3.2	3	Org. chem	3				
10		3.3	1	Org. chem			1		
11		3.4	2	Org. chem		2			
12		3.5	1	Org. chem			1		
13		3.6	2	Org. chem		2			
14		3.7	2	Org. chem		2			
15	4	4.1	2	Chem.bd			2		

16		4.2	2	Chem.bd		2			
17		4.3	6	Chem.bd					6
18	5	5.1	2	Indust.chem			2		
19		5.2	1	Indust.chem	1				
20		5.3	1	Indust.chem		1			
21		5.4	2	Indust.chem			2		
22		5.5	2	Indust.chem			2		
23		5.6	1	Indust.chem		1			
24	6	6.1	1	Org.chem	1				
25		6.2	2	Org.chem			2		
26		6.3	2	Org.chem		2			
27		6.4	1	Org.chem	1				
28		6.5	1	Org.chem	1				
29	7	7.1	1	Org.chem	1				
30		7.2	7	Org.chem		7			
31	8	8.1	3	Vol.an			3		
32		8.2	2	Vol.an			2		
33	Sect.B	9	1	Org.chem	1				
34		10	1	Org.chem	1				
35		11	1	Org.chem			1		
36		12	1	Heat of Rx	1				
37		13	1	Org.chem		;		1	
38		14	1	Org.chem		1			
39		15	1	Org.chem	1				
40		16	1	Heat of Rx		1			
41		17	1	Org.chem		1			
42		18	1	Org.chem	1				
43		19	1	Chem.Eq			1		
44		20	1	Vol.an			1		
45		21	1	Chem.Eq			1		
46		22	1	Heat of Rx			1		
47		23	1	Chem.Eq				1	

Total marks	80	14	24	32	4	6
Percentage of total marks		18%	30%	40%	5%	8%

Final coding results AQA- 2016 chemistry merging results from paper 1 and paper 2.

	Marks	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
AQA- 1	80	8	12	46	10	4
	80	10%	15%	58%	13%	5%
AQA -2	80	14	24	32	4	6
	80	18%	30%	40%	5%	8%
Total Marks	160	22	36	78	14	10
Total Percentage	100	14%	23%	49%	9%	6%

Ireland 2016 chemistry examination

Ireland-	Qnts	Qt.pt	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
1	1	(a)	15	Vol. an.		15			
2		(b)	9	Vol. an.	9				
3		(c)	12	Vol. an.			12		
4		(d)	9	Vol. an.			9		
5		(e)	5	Vol. an.	5				
6	2	(a)	9	Org.chem.		9			
7		(b)i	12	Org.chem		9		3	
8		(b)ii	9	Org.chem	3	6			
9		(b)iii	6	Org.chem			6		
10		(c)i	9	Org.chem		9			
11		(c)ii	3	Org.chem	3				
12		(c)iii	2	Org.chem		2			
13	3	(a)	8	Heat of Rx	8				
14		(b)	18	Heat of Rx			18		
15		(c)	6	Heat of Rx			6		

16		(d)i	3	Heat of Rx		3		
17		(d)ii	3	Heat of Rx		3		
18		(d)_iii	3	Heat of Rx	3			
19		(d)_iv	3	Heat of Rx				3
20		(e)	6	Heat of Rx	6			
21	4	(a)	6	Period/At	6			
22		(b)	6	Period/At		6		
23		(c)	6	Period/At		6		
24		(d)	6	Chem.bd		6		
25		(e)	6	Vol.an	6			
26		(f)	6	Chem.Eq	6			
27		(g)	6	Org.chem			6	
28		(h)	6	Period/At	6			
29		(i)	6	Heat of Rx		6		
30		(j)	6	Period/At	6			
31		(k)_i	6	Indust.ch		6		
32		(k)_ii	6	Org.chem	6			
33	5	(a)i	6	Chem.bd		6		
34		(a)ii	3	Chem.bd	3			
35		(a)iii	12	Chem.bd	3	9		
36		(a)iv	3	Chem.bd		3		
37		(b)	9	Chem.bd		9		
38		(c)_i	6	Chem.bd	6			
39		(c)-ii	3	Chem.bd	3			
40		(c)-iii	4	Chem.bd	4			
41		(c)-iv	4	Chem.bd		4		
42	6	(a)-i	5	Indust. Ch	5			
43		(a)_ii	6	Indust. Ch		6		
44		(b)	6	Indust. Ch	6			
45		(c)-i	3	Indust. Ch	3			
46		(c)-ii	3	Indust. Ch	3			
47		(c)-iii	3	Indust. Ch	3			

48		(c)-iv	9	Indust. Ch			9	
49		(d)	6	Indust. Ch				6
50		(e)	9	Indust. Ch	9			
51	7	(a)-i	5	Chem. Eq.	5			
52		(a)-ii	12	Chem. Eq.			12	
53		(a)-iii	3	Chem. Eq.		3		
54		(b)	6	Chem. Eq.	6			
55		(c)-i	6	Chem. Eq.	6			
56		(c)-ii	18	Chem. Eq.			18	
57	8	(a)	6	Indust. Ch	6			
58		(b)-i	3	Indust. Ch		3		
59		(b)-ii	3	Indust. Ch	3			
60		(b)-iii	3	Indust. Ch		3		
61		(c)-i	3	Indust. Ch	3			
62		(c)-ii	15	Indust. Ch		15		
63		(c)-iii	3	Indust. Ch		3		
64		(d)_i	9	Indust. Ch	9			
65		(d)-ii	3	Indust. Ch	3			
66		(d)-iii	2	Indust. Ch	2			
67	9	(a)i	6	Org.chem	6			
68		(a)ii	3	Org.chem	3			
69		(a)iii	6	Org.chem	6			
70		(a)iv	3	Org.chem		3		
71		(b)i	3	Org.chem	3			
72		(b)ii	6	Org.chem	6			
73		(b)iii	3	Org.chem		3		
74		(c)-i	6	Org.chem	6			
75		(c)i	6	Org.chem		6		
76		(c)ii	8	Org.chem		8		
77	10	(a)i	6	Vol.an		6		
78		(a)ii-i	6	Vol.an			6	
79		(a)ii-ii	6	Vol.an			6	

80		(a)iii-i	3	Vol.an	3				
81		(a)-ii	4	Vol.an			4		
82		(b)-i	6	Period.At.	6				
83		(b)-ii	9	Period.At.		9			
84		(b)-iii	10	Period.At.			10		
85		(c)i	13	Period/At	13				
86		(c)ii	6	Period/At			6		
87		(c)iii	6	Period/At			6		
88	11a	(a)i	1	Chem. eq	1				
89		(a)-i	12	Chem. eq			12		
90		(a)ii	6	Chem. eq			6		
91		(a)iii	6	Chem. eq			6		
92	11b	(b)-i	4	Chem. bd					4
93		(b)-ii	6	Chem. bd			6		
94		(b)-iii	3	Chem. bd			3		
95		(b)-iv	3	Chem. bd		3			
96		(b)-v	3	Chem. bd		3			
97		(b)-vi	3	Chem. bd		3			
98		(b)-vii	3	Chem. bd		3			
99	11c	A-i	4	Indust. ch	4				
100		A-ii	9	Indust. ch	9				
101		A-iii	9	Indust. ch		9			
102		A-iv	3	Indust. ch		3			
103		B-i	6	Indust. ch	6				
104		B-ii	6	Indust. ch		6			
105		B-iii	3	Indust. ch	3				
106		B-iv	6	Indust. ch	6				
107		B-v	4	Indust. ch		4			
Total marks			647		245	219	167	12	4
Percentage of total marks					38%	34%	26%	2%	1%

The Netherlands 2016 chemistry examination

Netherland	Qnt.	Qt.pt	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
1	1	1	2	Org.chem		**2**			
2		2	2	Org.chem			**2**		
3		3	2	Org.chem			**2**		
4		4	3	Vol.an				**3**	
5	2	5	1	Period/At	1				
6		6	2	Chem.bd		2			
7		7	3	Heat of Rx.			3		
8		8	2	Org.chem	2				
9		9	2	Org.chem	2				
10		10	2	Org.chem		2			
11	3	11	2	Electrochem	2				
12		12	2	Electrochem		2			
13		13	4	Electrochem			4		
14		14	3	Electrochem		3			
15	4	15	2	Indust.ch		2			
16		16	3	Indust.ch			3		
17		17	2	Indust.ch	2				
18		18	2	Indust.ch			2		
19		19	2	Indust.ch	2				
20		20	4	Indust.ch				4	
21		21	2	Indust.ch	2				
22		22	2	Indust.ch		2			
23	5	23	3	Org.chem		3			
24		24	2	Org.chem	2				
25		25	2	Org.chem	2				
26		26	2	Vol.an		2			
27		27	2	Vol.an			2		
28		28	2	Vol.an				2	
29	6	29	2	Org.chem	2				
30		30	2	Org.chem					2
31		31	4	Org.chem		4			
32		32	3	Org.chem			3		

33	33		2	Org.chem				2	
Total marks			**77**		**19**	**24**	**21**	**11**	**2**
Percentage of total marks					**25%**	**31%**	**27%**	**14%**	**3%**

New South Wales (NSW) 2016 chemistry examination

NSW	Qnts.	Qt.pt	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
1	Section 1	1	1	Org.chem	1				
2		2	1	Indust.chem	1				
3		3	1	Org.chem	1				
4		4	1	Chem.bd.	1				
5		5	1	Vol.an.	1				
6		6	1	Vol.an.			1		
7		7	1	Vol.an.	1				
8		8	1	Vol.an.		1			
9		9	1	Period/At	1				
10		10	1	Vol.an.	1				
11		11	1	Org.chem	1				
12		12	1	Vol.an.			1		
13		13	1	Period/At				1	
14		14	1	Heat of Rx		1			
15		15	1	Org.chem			1		
16		16	1	Elect.chem		1			
17		17	1	Org.chem		1			
18		18	1	Vol.an.			1		
19		19	1	Vol.an.			1		
20		20	1	Indust.chem					1
	Section 2								
21	21	(a)	1	Electro.ch	1				
22		(b)	4	Electro.ch			4		
23	22	(a)	1	Indust. chem	1				
24		(b)	2	Indust.chem			2		
25		(c)	2	Indust.chem				2	
26	23	(a)	3	Heat.Rx			3		
27		(b)	3	Heat.Rx			3		

28	24	(a)	4	Indust.ch			4		
29		(b)	3	Indust.ch			3		
30	25	i	4	Heat.Rx					4
31	26	(a)	2	Org.chem		2			
32		(b)	4	Org.chem				4	
33	27	i	4	Vol.an			4		
34	28	(a)	2	Heat of Rx		2			
35		(b)	3	Heat of Rx			3		
36	29	(a)	2	Vol.an		2			
37		(b)	4	Vol.an			4		
38	30	i	7	Indust.chem			7		
39	31	(a)i	2	Indust.chem		2			
40		(a)ii	3	Indust.chem		3			
41		(b)i	3	Indust.chem	3				
42		(b)ii	4	Indust.chem		4			
43		(c)i	3	Indust.chem				3	
44		(c)ii	4	Indust.chem			4		
45		(d)	6	Indust.chem				6	
46	32	(a)i	2	Electrochem.	2				
47		(a)ii	3	Electrochem.		3			
48		(b)i	3	Electrochem.		3			
49		(b)ii	4	Electrochem.				4	
50		(c)i	3	Electrochem.		3			
51		(c)ii	4	Electrochem.			4		
52		(d)	6	Electrochem.			6		
53	33	(a)i	2	Org.chem	2				
54		(a)ii	3	Org.chem		3			
55		(b)i	3	Org.chem				3	
56		(b)ii	4	Org.chem		4			
57		(c)i	3	Org.chem			3		
58		(c)ii	4	Org.chem		4			
59		(d)	6	Org.chem			6		
60	34	(a)i	2	Period/Atom	2				
61		(a)ii	3	Period/Atom		3			
62		(b)i	3	Period/Atom		3			

63		(b)ii	4	Period/Atom			4		
64		(c)i	3	Period/Atom		3			
65		(c)ii	4	Period/Atom			4		
66		(d)	6	Period/Atom				6	
67	35	(a)i	2	Electro.ch		2			
68		(a)ii	3	Electro.ch		3			
69		(b)i	3	Electro.ch		3			
70		(b)ii	4	Electro.ch		4			
71		(c)i	3	Electro.ch		3			
72		(c)ii	4	Electro.ch		4			
73		(d)	6	Electro.ch			6		
Total marks			200		20	67	79	29	5
Percentage of total marks			200		10%	34%	40%	15%	3%

Scotland – 2016 chemistry examination

Scotland	Qnts.	Qt.pt	Marks	Topic/s	*Remember*	*Understand*	*Apply*	*Analyse*	*Evaluate*
	Section 1								
1	1	1	1	Period/At	1				
2		2	1	Chem.bd.	1				
3		3	1	Chem.bd.	1				
4		4	1	Heat of Rx			1		
5		5	1	Chem.bd.	1				
6		6	1	Chem.bd.				1	
7		7	1	Org.chem		1			
8		8	1	Heat of Rx			1		
9		9	1	Org.chem	1				
10		10	1	Org.chem	1				
11		11	1	Org.chem		1			
12		12	1	Org.chem		1			
13		13	1	Chem.Eq			1		
14		14	1	Heat of Rx			1		
15		15	1	Chem.Eq		1			
16		16	1	Heat of Rx		1			
17		17	1	Chem.bd.	1				

18		18	1	Chem.Eq			1	
19		19	1	Heat of Rx		1		
20		20	1	Vol.an	1			
	Section 2							
21	1	(a)	1	Heat.Rxt	1			
22		(b)i	1	Heat.Rxt			1	
23		(b)ii	1	Heat.Rxt		1		
24		(c)	1	Heat.Rxt			1	
25	2	(a)i	1	Period/Atom		1		
26		(a)ii	2	Period/Atom		2		
27		(b)i	1	Period/Atom		1		
28		(b)ii	2	Period/Atom		2		
29		(c)i	1	Period/Atom			1	
30		(c)ii	1	Period/Atom			1	
31	3	(a)	1	Chem.bd	1			
32		(b)	2	Indust.ch			2	
33		(c)	1	Indust.ch	1			
34	4		3	Org.chem				3
35	5	(a)	1	Org.chem	1			
36		(b)i	1	Org.chem	1			
37		(b)ii	1	Org.chem	1			
38		(c)i	2	Org.chem		2		
39		(c)ii	1	Org.chem		1		
40		(c)iii	2	Org.chem	2			
41	6	(a)	1	Org.chem			1	
42		(b)	1	Org.chem	1			
43		(c)	1	Org.chem	1			
44		(d)i	1	Org.chem		1		
45		(d)ii	1	Org.chem	1			
46		(e)i	1	Org.chem		1		
47		(e)ii	2	Org.chem			2	
48	7	(a)	1	Indust. ch		1		
49		(b)i	1	Indust.ch	1			

50		(b)ii	1	Org.chem	1				
51		(b)iii	1	Org.chem	1				
52		(b)iv	1	Org.chem	1				
53		(c)i	1	Org.chem	1				
54		(c)ii	1	Org.chem		1			
55		(c)iii	2	Org.chem			2		
56		(c)iv	1	Org.chem	1				
57	8	(a)	2	Heat.Rx			2		
58		(b)i	1	Org.chem		1			
59		(b)ii	1	Org.chem		1			
60		(c)	2	Org.chem			2		
61	9	(a)i	2	Heat.Rx			2		
62		(a)ii	1	Heat.Rx		1			
63		(a)iii	1	Heat.Rx			1		
64		(b)	2	Heat.Rx			2		
65	10		3	Indust.ch					3
66	11	(a)i	1	Vol. an	1				
67		(a)ii	2	Vol. an		2			
68		(a)iii	2	Vol. an			2		
69		(a)iv-A	1	Vol. an		1			
70		(a)iv-B	1	Vol. an			1		
71		(a)v	1	Vol. an			1		
72		(b)i	1	Vol. an	1				
73		(b)ii	1	Vol. an	1				
74		(b)iii	1	Vol. an	1				
75		(b)iv	3	Vol. an			3		
76	12	(a)i	1	Chem.bd	1				
77		(a)ii	2	Chem.bd			2		
78		(a)iii	1	Chem.bd		1			
79		(b)i	1	Indust.ch	1				
80		(b)ii	1	Indust.ch					1
Total marks			100		31	27	34	4	4
Percentage of total marks			100		31%	27%	34%	4%	4%

South Africa – 2016 chemistry examination

Sth.Africa	Qnts	Qt.pt	Mark	Topic/s	Remember	Understand	Apply	Analyse	Evaluate
1	1	1.1	2	Chem.bd	2				
2		1.2	2	Chem.Eq	2				
3		1.3	2	Org.chem	2				
4		1.4	2	Org.chem	2				
5		1.5	2	Org.chem		2			
6		1.6	2	Indust.chem		2			
7		1.7	2	Vol.an	2				
8		1.8	2	Chem.Eq		2			
9		1.9	2	Electrchem	2				
10		1.10	2	Vol.an				2	
11	2	2.1.1	1	Org.ch			1		
12		2.1.2	1	Org.ch			1		
13		2.1.3	1	Org.ch			1		
14		2.1.4	1	Org.ch			1		
15		2.2.1	3	Org.ch			3		
16		2.2.2	2	Org.ch			2		
17		2.2.3	2	Org.ch			2		
18		2.3.1	1	Org.ch			1		
19		2.3.2	1	Org.ch			1		
20	3	3.1	2	Org.ch	2				
21		3.2	1	Org.ch	1				
22		3.3	3	Org.ch		3			
23		3.4	2	Org.ch		2			
24		3.5	3	Org.ch			3		
25	4	4.1.1	1	Org.ch			1		
26		4.1.2	1	Org.ch			1		
27		4.1.3	1	Org.ch			1		

28		4.2	4	Org.ch		4	
29		4.3.1	2	Org.ch			2
30		4.3.2	1	Org.ch			1
31		4.3.3	2	Org.ch			2
32		4.3.4	1	Org.ch			1
33	5	5.1.1	2	Heat.Rx	2		
34		5.1.2	3	Heat.Rx			3
35		5.1.3	2	Heat.Rx			2
36		5.1.4	3	Heat.Rx			3
37		5.2.1	3	Heat.Rx			3
38		5.2.2	4	Heat.Rx			4
39		5.2.3	1	Heat.Rx		1	
40		5.3.1	1	Heat.Rx		1	
41		5.3.2	1	Heat.Rx		1	
42	6	6.1	2	Chem.eq	2		
43		6.2.1	1	Chem.eq		1	
44		6.2.2	4	Chem.eq			4
45		6.3	2	Chem.eq			2
46		6.4.	9	Chem.eq			9
47	7	7.1.1	2	Vol. an	2		
48		7.1.2	3	Vol. an		3	
49		7.2.1	2	Vol. an			2
50		7.2.2	9	Vol. an			9
51	8	8.1.1	1	Electrochem			1
52		8.1.2	2	Electrochem			2
53		8.1.3	3	Electrochem			3
54		8.2.1	2	Electrochem		2	
55		8.2.2	3	Electrochem			3
56		8.2.3	4	Electrochem			4

57		8.2.4	1	Electrochem		1			
58	9	9.1	1	Electrochem	1				
59		9.2	2	Electrochem		2			
60		9.3.1	1	Electrochem			1		
61		9.3.2	1	Electrochem			1		
62		9.3.3	2	Electrochem			2		
63		9.4	2	Electrochem		2			
64	10	10.1.1	1	Indust.ch			1		
65		10.1.2	1	Indust.ch			1		
66		10.1.3	1	Indust.ch			1		
67		10.1.4	3	Indust.ch			3		
68		10.1.5	4	Indust.ch			4		
69		10.2	4	Indust.ch			4		
Total marks			150		22	29	97	2	0
Percentage of total marks			150		15%	19%	65%	1%	0%

Appendix I: Data of percentage attaining honours in physics and chemistry 1966-2016

			Physics		**Chemistry**	
		Total sitting LC	Percentage sitting Higher-level	Percentage honours grade.	Percentage sitting Higher-level	Percentage honours grade.
Syllabus 1	1966	12573	10%	***42%***	8%	47%
	1967	13590	10%	***42%***	11%	43%
	1968	14757	10%	***41%***	9%	44%
	1969	16986	15%	***No data available***	16%	No data available
	1970	18975	9%		14%	
	1971	20780	7%		11%	
	1972	24163	6%		11%	
	1973	26892	6%	***48%***	11%	52%
	1974	29206	6%	***50%***	11%	58%
	1975	32559	7%	***50%***	11%	59%
	1976	35268	8%	***48%***	12%	51%
	1977	35804	8%	***46%***	12%	43%
	1978	35510	8%	***41%***	12%	54%
	1979	36539	8%	***58%***	12%	56%
	1980	38336	8%	***51%***	13%	52%
	1981	41428	No data available			
	1982	41428				
	1983	43858	11%	***59%***	13%	64%
	1984	45773	11%	62%	14%	59%
	1985	47736	No data available			
Syllabus 2	1986	47857				
	1987	50446	13%	63%	14%	60%
	1988	51159	13%	58%	13%	62%
	1989	54038	13%	64%	12%	66%
	1990	55146	13%	67%	12%	63%
	1991	55641	12%	63%	11%	64%
	1992	55179	13%	61%	10%	63%
	1993	55230	13%	67%	11%	68%
	1994	59148	13%	60%	11%	63%
	1995	61221	13%	65%	11%	63%
	1996	53804	12%	62%	11%	64%

	1997	59053	11%	63%	10%	67%
	1998	59297	11%	63%	11%	70%
	1999	58002	11%	70%	10%	69%
	2000	55907	10%	72%	10%	73%
	2001	51935	11%	66%	10%	75%
Syllabus 3	2002	46900	13%	60%	12%	75%
	2003	47900	13%	57%	12%	79%
	2004	47498	12%	51%	13%	76%
	2005	46958	12%	51%	13%	77%
	2006	46384	11%	71%	12%	76%
	2007	44523	12%	72%	13%	78%
	2008	45394	11%	71%	13%	79%
	2009	46728	10%	73%	13%	78%
	2010	46791	10%	74%	13%	75%
	2011	46699	10%	73%	13%	76%
	2012	46236	10%	75%	15%	73%
	2013	47040	10%	73%	14%	74%
	2014	48875	11%	72%	15%	73%
	2015	50044	12%	69%	15%	74%
	2016	50766	12%	70%	15%	71%

Source:https://wayback.archive-it.org/11501/20210722124551/https://www.education.ie/en/Publications/Statistics/Statistical-Reports/Annual-Statistical-Reports.html.

Appendix J: Data of percentage of Leaving Certificate students taking higher level papers selected subjects

	Physics	Chemistry	Biology	Accounting	Geography
1987	13%	14%	29%	15%	21%
1988	13%	13%	28%	16%	20%
1989	13%	12%			
1990	13%	12%	28%	17%	21%
1991	12%	11%	27%	16%	22%
1992	13%	10%	26%	16%	25%

1993	13%	11%	27%	15%	26%
1994	13%	11%	33%	15%	32%
1995	13%	11%	36%	14%	34%
1996	12%	11%	37%	13%	35%
1997	11%	10%	33%	11%	35%
1998	11%	11%	35%	12%	40%
1999	11%	10%	32%	11%	43%
2000	10%	10%	31%	11%	43%
2001	11%	10%	30%	10%	44%
2002	13%	12%	27%	9%	42%
2003	13%	12%	27%	9%	43%
2004	12%	13%	32%	10%	43%
2005	12%	13%	35%	10%	42%
2006	11%	12%	37%	11%	38%
2007	12%	13%	38%	11%	38%
2008	11%	13%	39%	10%	39%
2009	10%	13%	41%	10%	39%
2010	10%	13%	42%	9%	41%
2011	10%	13%	46%	8%	43%
2012	10%	15%	47%	8%	41%
2013	10%	14%	48%	8%	40%
2014	11%	15%	48%	8%	39%
2015	12%	15%	50%	9%	39%
2016	12%	15%	48%	9%	36%

Appendix K: Data of students who achieved higher-level grades (A-C) 1987-2016 in selected subjects.

	Physics	Chemistry	Biology	Accounting	Geography
1987	63%	60%	58%	57%	57%
1988	58%	62%	59%	61%	56%
1989	64%	66%			
1990	67%	63%	65%	64%	58%
1991	63%	64%	62%	66%	62%
1992	61%	63%	69%	62%	62%
1993	67%	68%	58%	63%	67%
1994	60%	63%	68%	65%	64%
1995	65%	63%	61%	66%	64%
1996	62%	64%	65%	72%	67%
1997	63%	67%	67%	67%	72%
1998	63%	70%	64%	66%	71%
1999	70%	69%	70%	73%	71%
2000	72%	73%	69%	74%	72%
2001	66%	75%	69%	76%	70%
2002	68%	75%	73%	75%	70%
2003	66%	79%	72%	78%	73%
2004	73%	76%	72%	79%	72%
2005	71%	77%	71%	82%	74%
2006	71%	76%	72%	75%	71%
2007	72%	78%	72%	76%	76%
2008	71%	79%	72%	73%	74%
2009	73%	78%	70%	79%	75%
2010	74%	75%	71%	77%	77%
2011	73%	76%	70%	78%	76%
2012	75%	73%	71%	67%	74%
2013	73%	74%	70%	74%	75%
2014	72%	73%	69%	80%	75%
2015	69%	74%	75%	76%	77%
2016	70%	71%	69%	77%	76%

Appendix L: Proficiency level- action verbs used in Netherlands' chemistry specifications

TIMSS competence level	Sub-level	Use of chemical knowledge	Action Verbs
TIMSS 1- Know	1	Naming and recognising chemical concepts in chemical phenomena and observations and explain them in this situation	Appoint Recognise explain
TIMSS 2 – To apply	2	Concepts and thereto related concepts can use and describe in one standard problem definition.	Calculate (simple) Describe, Indicate, Use Classify Handling
	3	Concepts and thereto related concepts related to each other and thus give a conclusive reasoning	To declare, relate, make connections between, calculate (more variables) reasoning about/with the help of closing reasoning to give
TIMSS 3- Reasoning	4	Analysing with the help of concepts and professional concepts in a product design and formulating proposals when making an adjustment or an improvement to a process or a product	Analyse, calculate(complex), draw conclusions, formulate proposals,
	5	Applying concepts and concepts when conducting research in complex, critically assess problems and results and assess the effects of improvement proposals.	Make predictions, judge, to argue.