NCCA
An Chomhairle Náisiúnta Curaclaim agus Measúnachta
National Council for Curriculum and Assessment

Draft Leaving Certificate Chemistry specification

Contents

Senior cycle

Senior cycle educates the whole person and students' experiences in senior cycle contribute to their intellectual, social and personal development and their overall wellbeing. During senior cycle students develop a stronger sense of their identity, learning with and from their peers, teachers, other adults, and various media. Senior cycle has 8 guiding principles.

Senior Cycle Guiding Principles	
Wellbeing and relationships	Choice and flexibility
Inclusive education and diversity	Continuity and transitions
Challenge, engagement and creativity	Participation and citizenship
Learning to learn, learning for life	Learning environments and partnerships

These principles are a touchstone for schools and other educational settings, as they plan and design their senior cycle with the aim of enhancing the educational experience for all.

Senior cycle consists of an optional Transition Year, followed by a two-year course consisting of subjects and modules, key competencies, learning outcomes and a range of approaches to assessing student learning. Building on their learning in junior cycle, learning happens in schools, communities, educational settings, and other sites where students' increasing independence is recognised. Relationships with teachers are established on a more mature footing and students take more responsibility for their learning. Senior cycle provides a curriculum which challenges students to aim for the highest level of educational achievement, commensurate with their individual aptitudes and abilities. Students are supported to make informed choices as they choose different pathways through senior cycle. Their experiences in senior cycle should establish firm foundations for transition to further, adult and higher education, apprenticeships, traineeships and employment, and for meaningful participation in society, the economy and adult life.

The educational experience in senior cycle should be inclusive of every student, respond to their learning strengths and needs, and celebrate, value, and respect diversity. Students vary in their family and cultural backgrounds, languages, age, ethnic status, beliefs, gender, and sexual identity as well as their strengths, needs, interests, aptitudes and prior knowledge, skills, values and dispositions. Every student's identity should be celebrated, respected, and responded to throughout their time in senior cycle.

During senior cycle, students have opportunities to grapple with social, environmental, economic, and technological challenges and to deepen their understanding of human rights, social justice, equity, diversity and sustainability. Senior cycle gives every student opportunities to experience the joy of reaching significant milestones in their personal educational journey. Every subject and module students experience should contribute to the realisation of this overall vision for senior cycle.

At a practical level, senior cycle is supported by enhanced professional development; the involvement of teachers, students, parents, school leaders and other stakeholders; resources; research; clear communication; policy coherence; and a shared vision of what senior cycle seeks to achieve for our young people as they prepare to embark on their adult lives. It is brought to life in schools and other educational settings through:

- effective curriculum planning, development, organisation and evaluation
- teaching and learning approaches that motivate and interest students, that enable them to progress and improve and to deepen, apply and reflect on their learning and
- a school culture that respects students and promotes a love of learning.

Rationale

Leaving Certificate science education provides a means by which students can investigate the natural world to foster an evidence-based understanding of how it works. Students learn that science as a discipline is a process that requires logic and creativity to construct scientific knowledge through the sharing of ideas and by developing, refining, and critically analysing these ideas. Students experience science as a personal and collaborative activity that is exciting, challenging and powerful in transforming the world in which we live.

Chemistry is everywhere in our natural world. Studying chemistry involves understanding how the invisible world of atoms and molecules makes up the visible world we see around us. As an area of scientific study, it explains how all matter in the universe behaves and interacts by developing an understanding of how atoms and molecules behave and interact. New chemical substances and processes are being constantly created by chemists. Chemistry has, for example, transformed medical practice, changed the way food is produced, led the way in forensic science and has created and solved environmental problems. Chemists have embraced developments in technology and integrated digital tools to support their work. In a world increasingly shaped by science and technology, greater numbers of citizens need to acquire knowledge and understanding of chemical concepts. The work of chemists endeavours to respond to and influence many of the challenges and opportunities in our world today.

The study of matter, its behaviour and its interactions has evolved over time. It continues to evolve as an exciting human pursuit, and especially today with the impact of digital technology on the nature of scientific inquiry. Chemists use their skills and their understanding of chemical structure and processes to investigate systems for purposes or needs, or simply for enlightenment. Chemistry attempts to describe systems with a set of assumptions, concepts and models that enable chemists to explain and predict the behaviour and interactions of matter.

Students pursue answers to questions raised through their research investigations and become aware of the need for the ethical and sustainable use of matter. To generate primary data, students need to learn practical and experimental design skills and the value of appropriate risk assessment, in order to engage with the safe handling of chemicals. The skills developed will be the foundation for life-long learning and prepare them for a wide variety of careers and pathways, including future careers in chemistry. The specification is intended for all students who wish to study chemistry.

Aims

The aim of Leaving Certificate Chemistry is to develop the student's curiosity, enthusiasm, and enjoyment for studying chemistry. It seeks to build the knowledge, skills, values and dispositions necessary to nurture scientifically literate citizens and life-long learners. It aims to equip students for the challenges and opportunities of their futures, encouraging sustainable living in a-technologically-developing society.

More specifically, Leaving Certificate Chemistry aims to empower students to:

- build knowledge and understanding of specified core concepts and fundamental principles of chemistry
- develop the skills, values and dispositions needed to apply this knowledge to explain, analyse, solve problems and predict events in a variety of chemical systems and interactions
- demonstrate inquiry and practical skills consistent with the principles and practices of chemistry
- understand how society and science are interwoven, the everyday relevance and the ethical implications of chemistry.

Continuity and progression

Leaving Certificate Chemistry builds on the knowledge, skills, values and dispositions that stem from learners' early childhood education through to the junior cycle curriculum.

Junior Cycle

The learning at the core of junior cycle is described in the Statements of Learning, a number of which apply to scientific concepts, processes and practices, including problem-solving, design and communication skills, and to understanding and valuing the role and contribution of science and technology to society. Student learning in science is unified through the Nature of Science strand, which emphasises the development of a scientific habit of mind.

There is an emphasis on inquiry through which learners develop an understanding and appreciation of structures, processes and fundamental concepts that are essential to all science, as well as the ability to apply scientific principles to their everyday lives. All of the key skills developed across the curriculum during junior cycle support student learning in senior cycle. Many junior cycle subjects and short courses have close links with and support the learning in junior cycle science, particularly mathematics, geography, CSPE, PE, SPHE, home economics and the technologies (T4) subjects.

Junior Cycle Science has close links with Leaving Certificate Chemistry in helping students to continue to develop their evidence-based understanding of the natural world; to develop their capacity to gather and evaluate evidence: to consolidate and deepen their skills of working scientifically; to make them more self-aware as learners and to become more competent and confident in their ability to use and apply science in their everyday lives. Students build on theses scientific concepts, processes and practices as they progress through the two years of Leaving Certificate Chemistry.

Beyond Senior Cycle

Chemistry builds a solid foundation for students to progress to diverse futures, including the worlds of work, further education and training, and higher education. The study of chemistry can lead to many exciting opportunities in specialised areas from biotechnology to environmental chemistry to forensic science and also in the wider areas of science, engineering, technology-related jobs, laboratory work, computer science, education, mathematics, medicine, agriculture, business and finance.

In addition, chemistry incorporates a broad range of transferable skills and techniques, such as testing and evaluation, synthesis, generalisation, visualisation and logical thinking. It teaches a range of generically useful skills in areas such as communication, time management, organisation, and teamwork. These skills are relevant to all further study, and indeed all learning beyond formal education.

Leaving Certificate Chemistry will contribute to the development of scientifically literate members of society. Students will develop an appreciation of the social and cultural perspectives of chemistry and of the impact of science and technology on people and on the environment. The local and global challenges facing our communities are immense - energy demands, providing sufficient food and water, climate change, disease control, and so on.

Society needs scientifically literate citizens who will pursue careers in chemistry and related areas. Equally, those who choose other pathways will need the habits of mind that doing science imbues, in a world where sources of knowledge can often be subject to disinformation. Studying chemistry assists students in making informed decisions about the positive and negative impacts of chemistry on society. Students have an opportunity to acquire an appreciation of the creative potential of chemistry across the three themes of Health, Technology and Sustainability. Students learn the importance of reliable sources, peer review, ethics and evidence in logical decision making and will be well poised to address old and new challenges.

Key competencies in senior cycle

Senior cycle helps students to become more engaged, enriched and competent, as they further develop their knowledge, skills, values and dispositions in an integrated way.

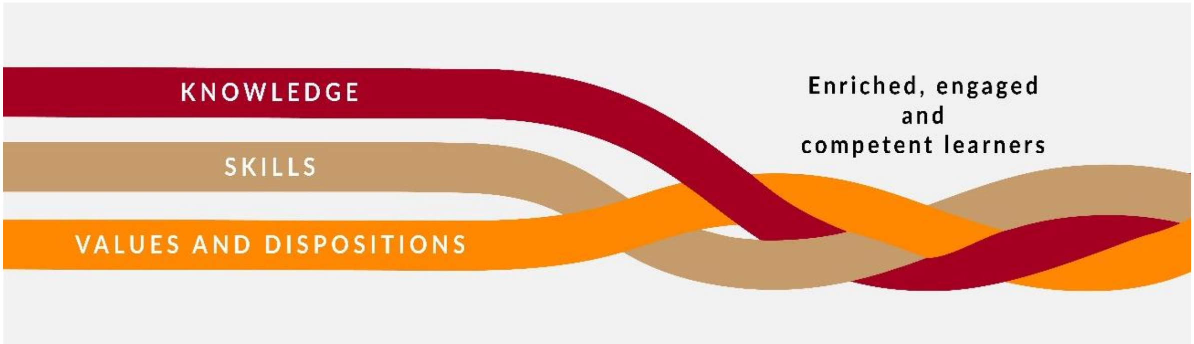

Figure 1 The components of key competencies and their desired impact

Key competencies[1] is an umbrella term which refers to the knowledge, skills, values and dispositions students develop during senior cycle.

[1] These are sometimes also referred to as capacities, or capabilities.

Students develop key competencies within and across the curriculum during senior cycle. Their learning is deeper when they can draw upon, integrate and apply their knowledge, skills, values and dispositions to various tasks, contexts, situations and events. The competencies:

- are linked and blend together
- are visible and important across the curriculum
- can help students and teachers to make meaningful connections between and across different areas of learning
- can improve students' overall learning.

The development of students' literacies and numeracy contributes to the development of competencies and vice-versa. Key competencies are supported when:

- students' literacies are well developed, i.e., when they can meaningfully and effectively read, watch, write, speak, listen, interpret and mediate meaning in a range of contexts
- students' numeracy is well developed, i.e., when they can understand numbers, data and symbols meaningfully and interpret and use them effectively.
- students make good use of various tools, including technologies, to support their learning.

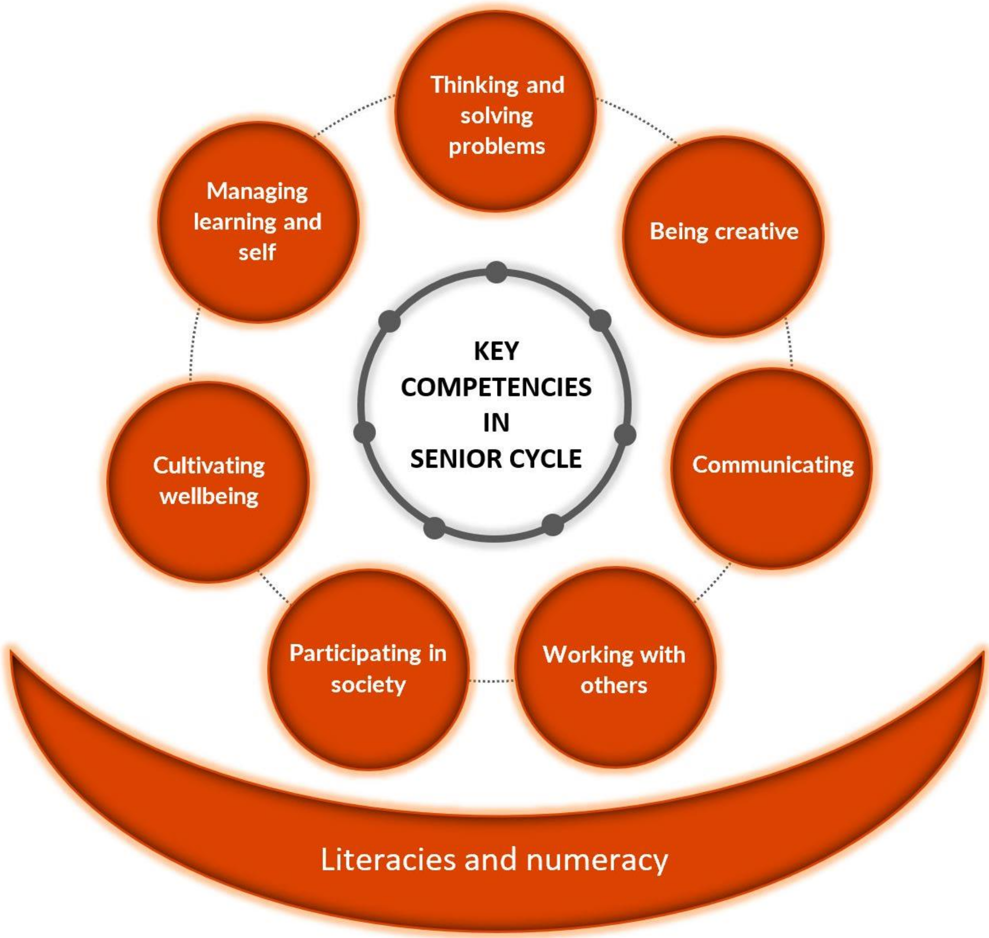

Figure 2 Key Competencies in Senior Cycle, supported by literacies and numeracy.

Key competencies can give young adults the power to meaningfully take part in their schools, families, communities, and society. As students mature, these key competencies can work together to help students handle and respond to more complex and varied tasks, as appropriate to their needs and abilities. They come to know what to do and how to do it, to know when to act and when not to act. Students whose key competencies are well-developed are better able to understand and learn; to deal with and respond to social opportunities and problems; to make the transition from school to further, adult and higher education, apprenticeships, traineeships and/or the world of work; and to embrace adult life.

The key competencies build on important learning from early childhood, primary and junior cycle. They come to life through the learning experiences and pedagogies teachers choose and through students' responses to them. Students can and should be helped to develop their key competencies no matter what path they follow through senior cycle or what subjects and modules they choose and irrespective of their past or present background, circumstances or experiences. As part of teaching, learning and assessing, they should have many opportunities to make their key competencies visible. The transformative potential of key competencies is most likely to be realised when teachers and students analyse and discuss the competencies they are developing and when teachers offer students opportunities to make meaningful connections across their different subjects and modules.

The key competencies can be developed in Leaving Certificate Chemistry in a range of ways.

Thinking and solving problems

As they work like scientists, students develop a scientific habit of mind. This involves drawing on a set of established practices, in which thinking and solving problems is of great significance. Students use critical thinking and competent problem-solving skills to demonstrate an understanding of scientific principles underlying the solutions to inquiry questions and problems posed in investigations. They evaluate models throughout the course and learn how to visualise and innovate their own internal models of chemical processes. To solve problems, students interpret scientific and media texts, evaluate processes, claims and conclusions and consider the quality of available evidence. They access, gather and process information from a variety of sources in both familiar and new situations. They do so with an open mind, underpinned by a natural curiosity about how the world works as they ask questions, gather and explore data, observe, and investigate the chemical world.

Being creative

As students engage in either practical or research investigations that are open in nature, they have the opportunity to explore areas of interest and create scientific questions, supported by primary and secondary data, and their own natural curiosity. Student creativity is developed initially, as they engage in the design and planning stages of investigations and is further developed as they engage in all aspects of investigation work. As students become more confident in taking risks and working with uncertainty, there will be more opportunities to be creative.

Communicating

Students communicate qualitative and quantitative information, gained from investigations, in a variety of forms from written to verbal and digital to visual. They use appropriate chemical terminology and scientific language that is suitable for specific audiences and contexts. Students will develop an understanding of how to frame scientific arguments by making claims and using logical reasoning based on evidence. Students also appreciate the importance of crediting others for their work. Through developing their scientific communication skills, students learn to listen actively, to question evidence and to seek clarity and understanding.

Working with others

Leaving Certificate Chemistry is underpinned by collaboration and working with others, through the lens of practical work, research and problem-solving. Through their classroom experiences, students learn to work co-operatively in pairs, groups and teams. They take on different roles, work together to achieve shared goals, give and respond to feedback from their teachers and peers, and interact safely and responsibly. This contributes to an appreciation that working collectively can energise a group, help motivation, and capitalise on all the talents in the group. Students learn to negotiate and resolve differences of opinion, as they discuss their different strategies and achieve compromise. These behaviours increase students' resilience, as they become flexible, adaptable and willing to learn from mistakes.

Participating in society

Studying Leaving Certificate Chemistry provides an opportunity for students to develop an awareness of science in society and some of the associated societal problems. Students' knowledge of sustainable futures develops as they critique and challenge systems that damage the natural world. Through the study of chemistry, students are supported in making informed choices as consumers, through their own personal behaviours and choices, contributing to a more sustainable world. Students also develop the ability to challenge assumptions as they engage with secondary data within these areas.

Cultivating wellbeing

Students develop their own wellbeing and the wellbeing of others in chemistry, as they become experienced in working safely in the laboratory. The development of positive working relationships supports the overall wellbeing of all those working in the chemistry class. As students navigate difficult tasks and make mistakes, they develop resilience and begin to appreciate the social concept of productive failure.

Managing learning and self

This competency contributes to the personal growth of students: they become more self-aware and use this awareness to develop personal goals. Leaving Certificate Chemistry is intended to be learner-centred and encourages student agency and decision-making, particularly in their investigative work and developing models. An important dimension of this competency is in building the know-how of students to recognise how to get things done, how to garner and use resources effectively, and how to act autonomously.

Literacies and numeracy

Literacies and numeracy support the development of key competencies in the Chemistry classroom. This is particularly relevant where students gather, organise and interpret primary data. Through their critical evaluation of secondary data from reliable sources, students' scientific literacy is further enhanced. They evaluate the relevance, accuracy, validity and reliability of the primary or secondary-sourced data in relation to investigations. They evaluate processes, claims and conclusions by considering the quality of available evidence, and use reasoning to construct scientific arguments.

Students have multiple opportunities throughout the specification to develop key competencies as they engage actively with the learning outcomes, particularly when they are supported by learning outcomes in the Unifying Strand.

Teaching and learning

Senior cycle students are encouraged to develop the knowledge, skills, values and dispositions that will enable them to become more independent in their learning and to develop a lifelong commitment to improving their learning. Leaving Certificate Chemistry supports the use of a wide range of teaching and learning approaches. The course is student-centred in its design and emphasises a practical experience of chemistry for each learner. As students progress, they will develop competencies that are transferable across different tasks and different disciplines, enabling them to make connections between chemistry, other subjects, and everyday experiences. By engaging in well-structured discussions, students will develop skills in reasoned argument, listening to each other and reflecting on their own work and that of others.

Scientific practices are best learned by doing, and in planning for teaching and learning, teachers should provide ample opportunity for students to engage with the scientific practices set out in the unifying strand. Whilst the contextual strands set out situations where students are required to gather primary data to verify observations and mathematical relationships, this is a minimum requirement and it is not expected that practical opportunities would be limited to these situations.

Through the cross-cutting themes, students will integrate their knowledge and understanding of chemistry with the ethical, social, economic and environmental implications and applications of chemistry. Increasingly, arguments between scientists extend into the public domain. By critically evaluating scientific texts and debating public statements about science, students will engage with contemporary issues in chemistry that affect their everyday lives.

They will learn to interrogate and interpret data—primary data that they collect themselves as well as secondary data collected by others—a skill which has a value far beyond chemistry wherever data are used as evidence to support argument. By providing an opportunity to examine and debate reports about contemporary issues in science, Leaving Certificate Chemistry will enable students to develop an appreciation of the social context of science. They will develop competencies in scientific communication by collaborating to generate perspectives and present them to their peers.

Teachers are best positioned to make professional judgements on how to develop knowledge, skills, values and dispositions with their students through an appropriate balance of explicit instruction and inquiry-based approaches, as well as assessment strategies that can then inform teaching and learning. Providing opportunities for students to develop a range of inquiry skills will be necessary to progress along the continuum of inquiry. The variety of activities that students engage in will enable them to take charge of their own learning by setting goals, developing action plans and receiving and responding to assessment feedback. Leaving Certificate Chemistry provides numerous opportunities for teachers to teach the subject and select materials that respond to the strengths, needs and interests of all students. A focus on an inquiry-based approach to teaching and learning, which is central to chemistry, means that students can be engaged in learning activities that complement their own needs and ways of learning. The content of the course is generally specified in broad terms to allow the selection and exploration of topics in ways that are of most interest and relevance to the students.

Students vary in the amount and type of support they need to be successful. Levels of demand in any learning activity will differ, as students bring different ideas and levels of understanding to it. The use of inclusive pedagogies, such as differentiated instruction and universal design for learning, with strategies such as adjusting the level of skills required, asking questions of varying cognitive demand, varying the amount and the nature of teacher intervention, and varying the pace and sequence of learning will allow students to interact at their own level.

Digital technology

Digital technology can play a role to further enhance learning, teaching and assessment. It can help to create opportunities for students to develop scientific knowledge, skills, values and dispositions in ways that are more engaging, and also in ways that could not have been achieved without the use of technology. For example, as students engage with Leaving Certificate Chemistry, they will have opportunities to use digital technology to:

- visualise, explain and model the behaviour and interactions of matter
- collect, record, analyse and display data and information
- develop and improve investigative research skills
- become more independent learners through, for example, appropriate digital/online supports
- enhance their experience in the chemistry laboratory.

Strands of study and learning outcomes

The Leaving Certificate Chemistry specification sets out the knowledge of most worth for senior cycle chemistry students.

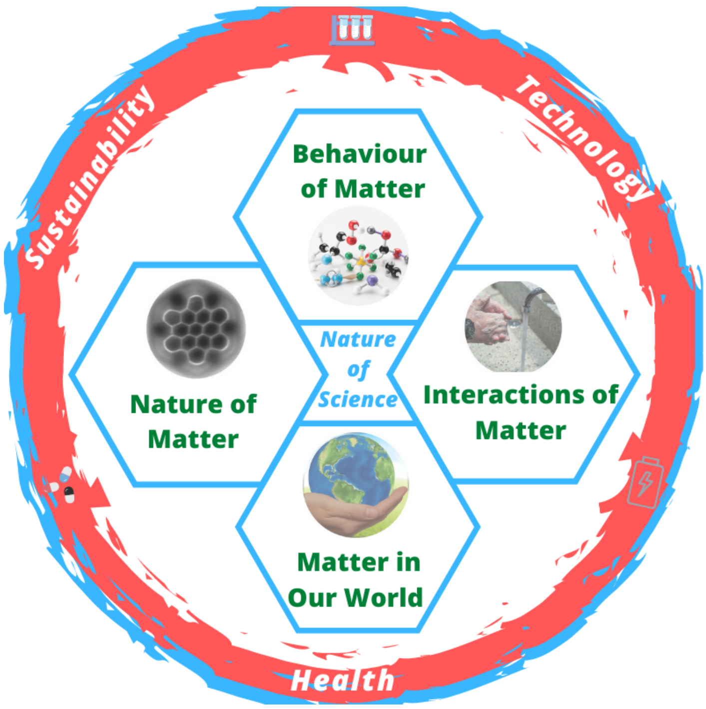

Figure 3 Overview of LC Chemistry

This is done through the strands and the identification of cross-cutting themes. There are five interrelated strands: The Nature of Science, which is the unifying strand, and four contextual strands—The Nature of Matter, Behaviour of Matter, Interactions of Matter, and Matter in Our World. The design of the strands reflects the aim of Leaving Certificate Chemistry.

The sequence in which the strands and learning outcomes are presented does not imply any particular order of teaching and/or learning. The presentation has a logical and coherent approach designed to facilitate both interpretation and implementation.

The learning outcomes of the unifying strand specify the knowledge, skills, values and dispositions that underpin the principles and practices of thinking and working like a scientist, and are essential to students' learning about science. These principles and practices permeate the learning outcomes of the contextual strands.

Three themes that cut across all strands are identified as Health, Sustainability, and Technology. They act as lenses through which students can explore the application of knowledge from chemistry.

The strands of Leaving Certificate Chemistry are set out to reflect the expectations for students, realised through the learning outcomes of the course. Each strand is introduced through outlining the core concepts and areas[2] students will engage with in the strand; connections with relevant learning in other strands are also highlighted. The 'students learn about' column, whilst not a definitive list or narrative, provides detail on the depth of knowledge, skills, values and dispositions students will acquire in realising the learning in the learning outcomes. The action verbs used in the learning outcomes are described in the glossary of action verbs and should be used to provide additional clarity to the strands of study.

While the learning outcomes associated with each strand are set out separately in this specification, this should not be taken to imply that the strands are to be studied in isolation or in the order in which they are presented. The content and activities of the contextual strands are intended to be experienced through the lens of the unifying strand. As students progress, they build on their knowledge, skills, values and dispositions incrementally, while constantly deepening their understanding of the nature of science. Learning outcomes can often be achieved explicitly through a spiral of contexts or implicitly through other learning outcomes. For example, skills such as separation techniques, conducting serial dilutions or investigating boiling points can be most effectively achieved through a variety of learning outcomes requiring these skills. The students' engagement and learning are optimised by a fully integrated experience of all strands, with students gaining increased independence over their learning.

[2] The following abbreviations are used to help navigate each strand –U (Unifying strand), NM (Nature of Matter), BM (Behaviour of Matter), IM (Interactions of Matter) and MW (Matter in our World).

The strands allow for frequent opportunities, expressed in the learning outcomes, for students to engage in investigative work as they use primary and/or secondary data. Where students are asked to use primary data to support conclusions, then it is expected that students will generate this data, individually or in small groups, through some practical/experimental work. Where students are asked to use secondary data, they have the opportunity to examine and evaluate information from data gathered through research activities, or, as relevant, use secondary data to support or verify the conclusions from their experimental work. In some investigations, groups of students may gather their own data (primary) and when the groups share this data with other class groups, it constitutes secondary data.

Some learning outcomes require students to carry out investigations that are primarily experimental or primarily research-based. For clarity, learning outcomes requiring primarily Experimental Investigations are denoted by the superscript ^{EI}. Students are expected to carry out these investigations mainly through the learning outcomes in the *Investigating in chemistry* section of the unifying strand. Learning outcomes requiring primarily Research-based Investigations are denoted by the superscript ^{RI}. Students are expected to carry out these investigations mainly through the learning outcomes in the *Chemistry in society* and *Communicating in chemistry* sections of the unifying strand.

Learning outcomes should be achievable relative to each student's individual aptitudes and abilities. Learning outcomes promote teaching and learning processes that develop students' knowledge, skills, values and dispositions incrementally, enabling them to apply their key competencies to different situations as they progress. Students studying at both Ordinary level and Higher level will critically engage with Chemistry, but the context, information and results arising from that engagement will be different.

Ordinary level	Higher level
Only the learning outcomes that are presented in normal type.	All learning outcomes including those in **bold type**.
Students engage with a broad range of knowledge, mainly concrete in nature, but with some elements of abstraction or theory.	Students engage with a broad range of knowledge, including theoretical concepts and abstract thinking with significant depth in some areas.
Students demonstrate and use a moderate range of cognitive skills and tools, select from a range of procedures and apply known solutions to a variety of problems in both familiar and unfamiliar contexts.	Students demonstrate and use a broad range of specialised skills to evaluate, and use information, to plan and develop investigative strategies, and to determine solutions to varied, unfamiliar problems. They identify and apply skills and knowledge in a wide variety of both familiar and unfamiliar contexts.
Students demonstrate and use scientific literacy skills when selecting evidence and data to communicate findings and draw conclusions to questions posed by themselves and others.	Students develop advanced scientific literacy skills and use appropriate evidence and data to effectively communicate findings and draw conclusions to questions posed by themselves and others.

Table 1: Design of learning outcomes for ordinary and higher level

The Leaving Certificate Chemistry specification is designed for a minimum of 180 hours of class contact time. An overview of each strand is provided below, followed by a table. The right-hand column contains learning outcomes which describe the knowledge, skills, values and dispositions students should be able to demonstrate after a period of learning. The left-hand column outlines specific areas that students learn about. Taken together, these provide clarity and coherence with the other sections of the specification.

Unifying Strand: The Nature of Science

This strand builds on the unifying strand from Junior Cycle Science and continues to bring to life the practices and norms underpinning the facts, concepts, laws and theories of science, and of chemistry. Building on existing knowledge, students develop an appreciation of science as a process and a way of knowing, thinking and doing. They also develop an understanding that the discipline of science includes understanding the nature of scientific knowledge as well as how this knowledge is generated, established, developed, applied and communicated.

As they learn to work like scientists, they develop a habit of mind that sees them rely on a set of established principles and practices associated with scientific inquiry to gather evidence, generate models and test their ideas on how the natural world works. It becomes apparent that the process of science, and of chemistry, is often complex and iterative, following many different paths, but always underpinned by these established principles and practices. Students learn to obtain and evaluate primary data and secondary data.

Students develop an understanding that whilst science is powerful, generating knowledge that forms the basis for many advances and innovations in society, it has limitations. They will also discover that the application of scientific and chemical knowledge to real world issues can be influenced by considerations such as economic, social, sustainability and ethical factors.

Unifying Strand Learning Outcomes

Students learn about	Students should be able to
U1 understanding about chemistry	
The power of models for developing understanding and meaning, and the limitations of models The nature and evolution of scientific knowledge; recognising bias Science as a global enterprise that relies on evidence, clear communication, international conventions, peer review, repeatability and reproducibility	a. appreciate how scientists work and how scientific ideas are modified over time b. conduct research relevant to a scientific issue and evaluate different sources of information including secondary data, understanding that a source may lack detail or show bias

U2 investigating in chemistry How to use trends in categories, tables, graphs and data in general, to make predictions and deepen understanding Using SI units for measurement and conversion to and from commonly used units, identifying potential sources of random and systematic error, and giving due consideration to the limits of the precision and accuracy of measurement Safe laboratory practice and appropriate risk assessment Using models to understand the investigation; manipulating mathematical representations of data and using scientific notation Unit analysis, order of magnitude Justifying opinions to evaluations of other arguments, citing reliable sources	a. recognise questions that are appropriate for scientific investigation in chemistry b. pose testable hypotheses developed using scientific theories and explanations, and evaluate and compare strategies for investigating hypotheses c. design, plan and conduct investigations; explain how reliability, validity, accuracy, precision, error, fairness, safety, integrity, and the selection of suitable equipment have been considered d. produce and select data (qualitatively / quantitatively), critically analyse data to identify patterns and relationships, identify anomalous observations, draw and justify conclusions e. review and reflect on the skills and thinking used in carrying out investigations, and apply their learning and skills to solving problems in unfamiliar contexts
U3 communicating in chemistry Recording and analysing findings using appropriate methods, including a portfolio/log of experimental and research data Communicating results and findings to a range of audiences	a. organise and communicate their research and investigative findings, using relevant scientific terminology and representations b. evaluate media-based arguments concerning science and technology

U4 chemistry in society Being more personally effective in addressing the impact of science and technology on society How to discuss scientific claims	a. research and present information on the contribution that scientists make to scientific discovery and invention, and its impact on society b. appreciate the role of chemistry in society; and its personal, social and global importance; and how society influences scientific research
U5 abstraction to representation Visualisation as a key aspect of understanding core concepts	a. relate observable phenomena to the chemical processes at the atomic or molecular level

Strand 1: Nature of Matter

In this strand, students develop an understanding of the particulate nature of matter. This is emphasised through the Kinetic Theory of Matter explaining the states of solids, liquids and gases. Matter can be quantified using the concept of a mole.

Students examine how atomic theory has evolved over time, and how models have been progressively developed. Students discover that previous models still have use in understanding atomic structure and that the current model of atomic theory is the best fit for the evidence available.

Students learn to use trends in the periodic table of elements to explain and predict the behaviour and interactions of matter, using key concepts such as electronic structure and electronegativity. Students study chemical formulae and how chemical reactions are represented. They develop the skills necessary to balance chemical equations, understanding that conservation laws govern the reactions. As students learn how to quantify matter, consistent with the practices and principles of science, they come to appreciate the power of precision, the importance of units of measurement, and how unit analysis and estimation play a key role in chemistry. In later strands students study models that expand their learning from the nature of matter to explain and predict the behaviour and interactions of matter.

Strand 1 Learning Outcomes

Students learn about	Students should be able to
NM1 Matter	
The Kinetic Theory of Matter The particulate nature of matter : pure substances (elements, compounds) or mixtures of substances. Changes of state : solid ↔ liquid; solid ↔ gas; liquid ↔ gas. (Analysis is qualitative **and should include assumptions and limitations of the model)** Brownian motion and diffusion of gases as evidence for the Kinetic Theory of Matter (calculations not required).	a. investigate experimental evidence for the Kinetic Theory of Matter [EI] b. analyse the Kinetic Theory of Matter to: • explain the nature and behaviour of matter at the particulate level • model how matter changes state
Pure Substances and Mixtures How separation techniques are based on the different physical properties of substances. Techniques including: precipitation, recrystallisation, liquid-liquid extraction, thin-layer chromatography of colourless and coloured mixtures (including Rf values), distillation (simple, fractional), filtration, decanting, evaporation.	c. justify the use of different separation techniques for isolating one or more components of a mixture and conduct experiments using appropriate techniques [EI]
Conservation of Mass Chemical and physical properties; chemical and physical change.	d. distinguish between physical change and chemical change of matter
The laws of conservation of mass and of energy that underpin all physical and chemical changes.	e. verify, using primary data, the law of conservation of mass and explain through the use of models [EI]

Students learn about	Students should be able to
NM2 Atomic Structure	
Atomic Theory Dalton's Theory and its significance. The development of the model of the atom, through the work of Thomson and Rutherford to the Bohr model. **The development of the current model through the work of DeBroglie, Heisenberg, Schrodinger, and Chadwick.** Properties of the proton, neutron and electron. Atomic number, mass number, relative atomic mass and isotopes (including definition of the term).	a. outline the development of current atomic theory, including main contributions and refinements by key scientists b. evaluate previous models of the atom against the current model, **stating the assumptions and limitations in each case** c. describe the atom using the current model of atomic theory, including subatomic particles
Identifying **Electron transition, photon energy and frequency, Ground state, excited states, $E_m - E_n = hf$** Identifying elements: • from flame tests (primary data) • **from their line emission spectra (primary or secondary)** (limited to salts of: Na, K, Cu, Li, Ba and Sr)	**d. describe and explain the origin of lines on the atomic emission spectrum of hydrogen** e. identify an element using appropriate primary and secondary data
Electronic Structure Arrangements of electrons (in main energy levels, **in sublevels and in orbitals**) for the first 20 (**36**) elements and their ions (excluding transition metal ions), **including s, p, d sublevels, and shapes of s, p orbitals**	f. describe the electronic structure of elements and associated ions, identifying stable electronic configurations
Radioactivity Alpha, Beta, Gamma Radiation - nature and penetrating ability, with examples. Half-life (calculations involving decay constants not required)	g. compare chemical and nuclear reactions h. distinguish different forms of radiation

Students learn about	Students should be able to
NM3 The Periodic Table	
Development The significance of the contribution of Mendeleev, with Moseley's key refinement, to the development of the modern periodic table	a. describe the development of the modern periodic table
Properties of Elements Specific groups of elements : Groups 1, 2, 17 and 18 The unreactivity of Group 18 elements	b. identify specific groups of elements and describe physical and chemical properties of elements within each of these groups
Using the Table How to use the periodic table, and trends in the periodic table, as a guide to thinking about useful and predictive relationships, related to the following: • atomic number, relative atomic mass **and atomic (covalent) radius** • electronic structure • electronegativity (using Pauling scale) • chemical reactivity (including the octet rule) • physical properties • **first ionisation energy and successive ionisation energies** • **tendency of metallic character to decrease from left to right across the table** (limited to the first 20 **(36)** elements)	c. examine and explain the arrangement of elements in groups, periods and blocks in the periodic table of elements **d. distinguish between d-block elements and transition elements** e. examine trends and relationships in the periodic table **f. explain trends in first ionisation energies, including exceptions, and in successive ionisation energies and atomic radii**
NM4 Quantifying Matter	
The Mole The significance and scale of the mole as a means of quantifying the amount of matter in chemistry.	a. define and explain the mole in terms of the Avogadro constant, and relate the mole to how the amount of a substance can be quantified

Students learn about	Students should be able to
How the mole concept allows the number of particles, mass, relative atomic/molecular mass, volume (for gases) and moles to be interrelated. Definitions of molar mass, relative molecular mass, density.	b. solve problems involving relative atomic mass and percentage abundance
<u>Molar Volume</u> Molar volume of a gas and Avogadro's Law The conditions for standard temperature and pressure (STP)	c. state Avogadro's law and deduce the molar volume of a gas **d. conduct an experiment to determine the relative molecular mass of a gas**
<u>Chemical Solutions</u> Chemical solutions that includes: solutions, solutes, solvents, dilution and serial dilutions, concentration, unsaturated / saturated solutions, supersaturated solutions, standard solutions, solutions made from primary standards, taking into account precision, accuracy, volumes and glassware required. Units for expressing concentration : g/L, mol/L, **%w/v, %v/v**, and ppm.	e. model a range of solution concentrations and use knowledge to prepare solutions, including primary standard solutions f. convert between units of concentration
<u>Stoichiometry</u> Applying the concept of a mole and balancing chemical equations is underpinned by the law of conservation of mass. The concept of a mole as applicable to stoichiometry and to the analysis of quantitative problems, including: gravimetric analysis, percentage composition, theoretical and actual yields, percentage yields, volume of gases, simple unit analysis, **exact stoichiometric amounts, limiting reagents and reagents in excess.**	g. use the concept of a mole to: • determine empirical and molecular formulae • balance equations for reactions where reactants and products are specified • analyse and solve quantitative problems based on balanced equations

Strand 2: Behaviour of Matter

With the particulate nature of matter as a model, students learn that many of the properties and behaviours of matter can be explained by the types of forces between particles and verified through experimental investigations. Behaviour of gases can be modelled through the Kinetic Theory of Matter and the Ideal Gas Equation.

Students use trends in the periodic table, coupled with the fundamentals of collision theory, to predict how electrons are transferred or shared to make bonds. They learn that the nature of bonds is on a continuum, from ionic through polar covalent to pure covalent bonds and that electronegativity can be used as a core concept to predict the type of bonding between atoms. Students learn how to explain physical properties through analysing forces between molecules and will use the Valence Shell Electron Pair Repulsion Theory to model and explain the shape of molecules.

Students expand their study of the behaviour of matter to carbon-based compounds – organic chemistry. They learn about hydrocarbons as the basis for understanding and forming other organic compounds. Students learn how to explain and predict the behaviour of hydrocarbons, analyse primary data on the properties of saturated and unsaturated hydrocarbons and learn about the importance of classifying hydrocarbons. In strand 4, students can broaden their learning from hydrocarbons to the wider family of organic compounds.

Strand 2 Learning Outcomes

Students learn about	Students should be able to
BM1 Chemical Bonding	
Electronegativity and Bonding The nature of chemical bonds that lies on a continuum from ionic through polar covalent to pure covalent bonds. How the concept of electronegativity, and explaining trends in electronegativity values, can be used to predict the nature of the chemical bond along the continuum.	a. describe and compare different types of chemical bonding b. predict the nature of chemical bonds between atoms, using trends in electronegativity values

Students learn about	Students should be able to
Modelling Using Lewis diagrams to represent bonds and how bonding can be described in terms of orbital overlap, **including the orbital overlap in sigma and pi bonds, and delocalised bonding**. Predicting how atoms bond involving the use of valence and the application of the octet rule (limited to the first 20 (**36)** elements). Properties of compounds to include: electrical conductivity, thermal conductivity, melting and boiling points, solubility in water and state of matter at room temperature.	c. model different types of bonding to predict chemical formulae **and outline the limitations in predicting bonding between atoms** d. relate the properties of simple compounds to the nature of bonding present
The nature of metallic bonding: explained in terms of delocalised valence electrons and the positively charged metal ions.	e. **compare the nature of metallic bonding with the nature of bonding along the continuum, accounting for differences and similarities in properties**
Identifying Using primary evidence to identify the presence and nature of ions in salts, and in solutions, above certain minimum concentrations, observed through: • Flame tests • Electrical conductivity • Reaction with reagents (equations required) Specific anions, linked to treatment, hardness and contamination of water, can be identified: chlorides, nitrates, phosphates, sulfates, sulfites, carbonates, hydrogencarbonates.	f. investigate, using primary data, the presence of ions in salts and in solutions, and identify an anion and cation in an unknown salt [EI]
Allotropy The definition of allotropy and that many elements have allotropes, including elemental carbon which can exist in a range of allotropes with different structures and physical properties – diamond, graphite, graphene and fullerenes.	g. compare the properties and structures of allotropes of carbon h. discuss the use of carbon allotropes in society

Students learn about	Students should be able to
BM2 Intermolecular forces and molecular shapes	
Intermolecular Forces A range of intermolecular forces that fall collectively under the umbrella of van der Waal's forces: • **London dispersion forces** • Permanent dipole-dipole, including Hydrogen bonding • **Ion-dipole forces** **(Dipole moments are not required)**	a. distinguish between intramolecular bonding and a range of intermolecular forces
Physical Properties How the nature of intermolecular forces can influence physical properties (changes of state) and evidence for the effects of intermolecular forces can be analysed using appropriate secondary data. (The range of compounds includes water and appropriate inorganic and organic compounds.) **How symmetry can give rise to non-polar compounds even in the case where individual polar bonds exist within the molecule.**	b. relate observed physical properties for a range of compounds to the type of intermolecular forces, **accounting for trends** **c. explain qualitatively the influence of polarity, and symmetry, on intermolecular forces**
Molecular Shapes How the shapes of molecules can determine overall polarity and also influence physical properties. **The shapes of molecules that can be explained by the VSEPR theory (of the form ABn for up to four pairs of electrons around a central atom, single bonds only) and visualised using diagrams, 3D models and digital models.**	d. use the shapes of molecules of simple compounds to predict physical properties **e. use VSEPR theory to predict and model the shapes of molecules**
Crystalline Solids Different crystal structures that can be compared under the following headings:	f. distinguish between the structures of amorphous and crystalline solids

Students learn about	Students should be able to
• species occupying lattice points • binding forces • physical properties Crystalline solids exemplified by: sodium chloride, ice, copper, and allotropes of carbon that have been studied.	g. model ionic, molecular, **metallic** and covalent crystalline structures and relate the structure to the physical properties
BM3 Behaviour of Gases	
Real Gases Relationships between pressure, volume, temperature of real gases	a. outline the development of the gas laws **and the ideal gas equation**
The Ideal Gas The model of an Ideal Gas which was developed to enable analysis and predictions of how gases behave and how previous laws developed by scientists including Boyle, Charles, **Gay-Lussac (law of combining volumes)** and Avogadro, are now synthesised into a single ideal gas equation ($PV = nRT$). (van der Waal's equation is not required)	b. explain what is meant by the ideal gas, **accounting for deviations of real gases from ideal gas behaviour**
Modelling How to verify and use the gas laws	c. solve and interpret quantitative problems using the gas laws
BM4 Hydrocarbons	
Sources and Impact How organic compounds are divided into many groups, with hydrocarbons being the simplest organic compounds, in terms of composition, consisting of C and H only. The continued, extensive use of hydrocarbons, the main sources being fossil fuels, living matter and synthesis.	a. outline the main sources of hydrocarbons and their uses in industry and society b. identify and research one major impact on society of the extensive use of hydrocarbons [RI]

Students learn about	Students should be able to
Properties and Structure How to prepare ethene, using ethanol; investigation includes combustion and tests for unsaturation, using bromine water and acidified potassium manganate(VII)	c. prepare ethene, observe its physical properties, and investigate some of its chemical properties [EI]
How based on the type of carbon-carbon bonds present, hydrocarbons can be sub-divided into aliphatic (alkanes, alkenes, alkynes) and aromatic hydrocarbons (exemplified by benzene). The naming of hydrocarbon compounds follows systematic IUPAC rules. (up to C10 only to be considered)	d. describe and compare different groups of hydrocarbons, including composition, bonding and structure, and relate these to their characteristic properties e. explain and predict differences in properties of: • straight chain alkanes of different carbon number • alkanes of the same carbon number • monounsaturated straight chain alkenes
The nature of the carbon-carbon bonds, the intermolecular forces and relative molecular mass that can also help to explain the properties of hydrocarbons. The characteristic properties include state of matter, boiling point, combustion, solubility in water and non-polar solvents, and reactivity. (aliphatics only) Prediction of the behaviour for alkanes and alkenes up to C6.	f. explain the relative chemical stability of alkanes
Reasons for alkane stability amongst hydrocarbons, including low polarity **and sigma bonding**	
Modelling How structure, and some characteristic properties of hydrocarbons, can be predicted through bonding and spatial arrangements of atoms. The way 3D models also relate to the condensed and expanded molecular formulae of the hydrocarbons.	g. construct and examine 3 dimensional models of hydrocarbon molecules and explain how bonding and isomers influence the spatial arrangement of atoms for these molecules h. explain and compare the shapes of ethane, ethene, ethyne **and benzene molecules in terms of sigma and pi bonds, including delocalised pi bonding**
Structural isomers exemplified by alkanes and alkenes up to C6 **and cis-trans geometric isomers exemplified by butene,** which can be visualised using diagrams, 3D models and digital models.	i. **distinguish between structural and-geometrical isomerism, including how isomerism gives rise to different properties**

Strand 3: Interactions of Matter

In this strand students learn about the models used to explain energy transfer in chemical reactions and how proton and electron transfer are central to understanding interactions. These models are an important component of how scientists understand the natural world and how chemists can control and predict reaction outcomes.

Students learn how collision theory provides a model for understanding the conditions necessary for particles to react. The particulate nature of matter underpins the model. As all chemical reactions involve the making and/or breaking of bonds, chemical reactions will generally involve energy transfer and physical change. Students learn about change in enthalpy as a measure of energy change in the form of heat. They learn how to determine experimentally, quantify and predict the enthalpy change of reactions. Students examine the factors affecting the rate of a reaction and gather primary data to confirm and quantify the influence of each of these factors.

Students examine reactions that are constantly driven in both directions, and learn about dynamic chemical equilibrium as a core concept of chemistry. They investigate Le Châtelier's principle and use the principle to make predictions about the effects of disturbances to the state of equilibrium. They discover that many of the factors that affect rates of reaction also impact on the state of chemical equilibrium, and the relationship between these core concepts will be investigated.

Students learn about the characteristic properties of acids and bases and how to analyse acid-base reactions through the transfer of protons. They will understand how the transfer of electrons is central to understanding redox reactions and learn about some of the applications of redox reactions in modern society.

Strand 3 Learning Outcomes

Students learn about	Students should be able to
IM1 Thermochemistry	
<u>Enthalpy Change</u> The principle of the Law of conservation of energy underpinning all thermochemical processes. Bond-making releases energy and bond-breaking requires energy. Examples of processes involving energy transfer as heat including, but not limited to: combustion, neutralisation, thermal decomposition, rusting of iron, photosynthesis, respiration. Physical change also involves enthalpy change.	a. define bond enthalpy and explain enthalpy changes in a reaction in terms of making and breaking bonds b. explain, and model diagrammatically, processes of energy transfer using exothermic and endothermic reactions
<u>Quantifying Enthalpy Change</u> A change in enthalpy (ΔH) as a measure of the heat change in a process, at a constant pressure. The change in enthalpy for particular processes can be determined: • directly, using a calorimeter • **using bond enthalpy data** • from standard heats of formations of reactants and products	c. investigate, using primary data, how to determine ΔH for a suitable neutralisation reaction [EI] d. calculate ΔH for a chemical reaction and describe the energy transfer through a simple energy profile diagram e. **analyse a given reaction, involving covalent molecules, to explain and predict the value of ΔH using average bond enthalpy values**
<u>Hess's Law</u> **How to model Hess's Law diagrammatically as a series of reactions and energy cycles**	f. **calculate and predict enthalpy changes using Hess's Law**

Students learn about	Students should be able to
Combustion The combustion of hydrocarbon compounds with no more than one double or triple bond and primary alcohols up to C6. The heat of combustion of food samples and a series of alcohols, which can be estimated experimentally using spirit burners.	g. construct balanced equations for the complete combustion of hydrocarbons and primary alcohols, **and explain trends in the associated standard ΔH values** h. investigate, using primary data, the energy change of combustion and compare experimental values to standard values, accounting for differences [EI]
IM2 Rates of Reaction *Investigating* Measuring initial, average **and instantaneous** rates of reaction Examples of reactions that can be used to collect primary data include, but are not limited to: • calcium carbonate and hydrochloric acid • sodium thiosulfate and hydrochloric acid • decomposition of hydrogen peroxide	a. investigate, using primary data, the factors that affect rates of a reaction and interpret rate of reaction graphs, using primary and secondary data [EI]
Modelling Factors that may affect the rate of chemical reactions that can be explained through the collision theory: concentration, surface area, temperature, the presence of a catalyst. (For gaseous reactions, pressure is also considered.) **(Limitations: concentration may not always affect the rate, catalysts can become saturated/poisoned and collisions need to be oriented correctly.)**	b. describe collision theory, and give examples of slow and fast reactions c. define rate of reaction

Students learn about	Students should be able to
Catalysis Catalysed and uncatalyzed reactions, including an enzyme as a biological catalyst, surface adsorption and formation of intermediates	d. compare the energy profile diagrams of catalysed and uncatalysed reactions, for both exothermic and endothermic reactions e. outline two general catalytic mechanisms
IM3 Chemical Equilibrium *State of Equilibrium* The concept of reaching a state of dynamic chemical equilibrium including: • concentrations of reactants and products being constant (closed system) • rate of forward and reverse reactions are equal • the state of equilibrium can be achieved from either direction of the reaction	a. appreciate that some reactions tend to be reversible and explain the concept of dynamic chemical equilibrium
Modelling The equilibrium constant (K_c) **and its mathematical representation.** **Given: aA + bB ⇌ cC + dD then:** $\boldsymbol{K_c = \frac{[C]^c.[D]^d}{[A]^a.[B]^b}}$	b. explain the factors that affect the value of the equilibrium constant K_c, **and use the mathematical model of K_c to describe and predict how given reactions would proceed** c. **solve problems involving the mathematical model for the equilibrium constant K_c**
Le Châtelier's principle Changes in temperature, concentration and pressure, but not the use of catalyst, which can cause a disturbance to the state of dynamic equilibrium.	d. apply Le Châtelier's principle to a variety of processes to predict responses to disturbances to the equilibrium and **to predict conditions for optimising yields of product**

Students learn about	Students should be able to
How data can be gathered and analysed, through experimentation (Iron chloride-Potassium thiocyanate) and digital simulations, as evidence to show factors affecting dynamic equilibrium.	e. investigate, using primary and secondary data, how changes in temperature and concentration can affect the state of equilibrium [EI]
The Haber Process An industrial application involving: • catalysts • chemical equilibrium • **optimising production** • **compromise**	f. explain the Haber process as an industrial application of chemical equilibrium, and how chemical equilibrium principles can be applied to the production of ammonia g. outline the impact of the Haber process on society and consider its ongoing role
The role of the Haber process in the context of cross-cutting themes.	h. **outline the importance of a compromise between yield and rate of reaction for the industrial use of the Haber process**
IM4 Acid-Base Systems	
Categorisation Commonly used substances including, but not limited to: vinegar, citric juices, aspirin, antacids, toothpaste. Litmus as an indicator. Everyday examples of neutralisation including, but not limited to: • use of lime in agriculture • remedies for acid indigestion	a. justify categorisation of commonly used substances as acid or base, based on the display of certain properties and discuss common everyday examples of neutralisation
Reactions Various types of reactions involving acids and bases: • acid-base neutralisation • acid-metal • acid-carbonate	b. predict the products of, and write balanced equations for, acid-base reactions

Students learn about	Students should be able to
Modelling Two theories of acid-base systems: • Brønsted-Lowry • Arrhenius	c. compare two theories of acid-base systems and justify why Brønsted-Lowry theory is a more extensive model for explaining behaviour
Applications of the Brønsted-Lowry theory	d. **apply Brønsted-Lowry theory to identify, in chemical equations:** • **conjugate acid-base pairs** • **species acting as acids and bases**
Self-ionisation of water **Ionic Product of Water:** **$K_w = [H_30^+][OH^-] = [H^+][OH^-]$ (simplified)**	e. explain the self-ionisation of water **and deduce a mathematical representation for the ionic product of water (Kw), accounting for its temperature dependence**
pH pH scale; pH measurement using indicators and/or meters/sensors pH defined as $-log_{10}[H^+]$. pH as a function of tendency to dissociate and of concentration and temperature.	f. measure pH, and explain the pH scale **and its limitations** g. **investigate, using primary data, factors that affect the pH of a solution** EI h. distinguish between: • weak and strong acids (and bases) • concentrated and dilute acids (and bases)
Problems involving pH to include: **(i) dilute aqueous solutions of strong acids and bases** **(ii) dilute aqueous solutions of weak acids and bases involving appropriate K_a and K_b values (mixtures not required)**	i. **solve mathematical problems involving pH for dilute aqueous solutions**
Dissociation Dissociation of acids (HA) and bases (BOH): $\boldsymbol{K_a = \frac{[H_3O^+][A^-]}{[HA]}}$ **and** $\boldsymbol{K_b = \frac{[B^+][OH^-]}{[B]}}$	j. **deduce mathematical representations for weak acid dissociation constant (K_a) and weak base dissociation constant (K_b)** k. compare degrees of dissociation of strong and weak acids, and strong and weak bases, **using K_a and K_b values**

Students learn about	Students should be able to
Titration Curves Acid-base indicators, including how Le Châtelier's Principle applies. The change in pH during acid-base reactions of: • strong acid - strong base • strong acid - weak base • weak acid - strong base Issues around generation of curves for weak acid-weak base systems. (Limited to monoprotic and single inflection point curves)	l. **explain how weak acid and weak base acid-base indicators function** m. investigate pH titration curves, using primary and secondary data from acid-base reactions, justifying appropriate indicators for each titration [EI]
IM5 Electrochemistry *Oxidation and Reduction* Suitable examples and applications including: corrosion and its prevention, combustion of fuels, respiration, analysis of iron in iron tablets and/or in some lawnfeed / mosskiller, analysis of dissolved oxygen in water. (Examples, emphasising electron transfer and **assigning oxidation numbers**, restricted to compounds of the first 36 elements.) **Investigations of redox reactions using displacement reactions.** **The use of the electrochemical series as a guide to the relative tendency of metals to be oxidised.** *Electrochemical Cells* Examples of primary and secondary cells Galvanic Cell : Redox reactions can produce a flow of electrons, exemplified by the copper-zinc system	a. describe oxidation and reduction, using suitable examples and applications, identifying oxidising and reducing agents in given chemical reactions b. **apply oxidation numbers to balance redox reaction equations** c. **investigate, using primary data [EI]:** • **redox reactions, using simple experiments involving halogens** • **displacement reactions of metals, relating them to the electrochemical series** d. compare a primary and secondary cell e. conduct an experiment to create a simple galvanic cell and explain its operation

Students learn about	Students should be able to
Electrolytic Cell: An external electrical source can be used to drive redox reactions in electrolytic cells exemplified by: • electrolysis of copper sulfate to metallic copper at copper electrodes • electrolysis of acidified water and neutral salt solution **(Reactions at electrodes required.)**	f. conduct experiments in electrolysis, and explain the operation of the electrolytic cells
Applications Sustainable uses of energy that are important in addressing some of the challenges facing society. Applications of electrochemistry that could play a significant role such as electrochemical cells and the use of rechargeable batteries. Electrolysis, and its potential use for hydrogen production as a fuel for example, through electricity generated from sustainable sources.	g. research the role of electrochemistry in an area related to sustainability and technology in everyday life [RI]

Strand 4: Matter in our World

In this strand students have opportunities to specifically deepen their analytical skills and improve their personal effectiveness through learning practical and inquiry skills. They apply stoichiometric principles and laboratory techniques to prepare standard solutions, determine unknown concentrations, and solve abstract, conceptual problems. As they investigate and analyse authentic contexts, students develop their understanding of the core concepts and fundamental principles of chemistry.

Core concepts such as:

- electronegativity (which can be used to predict bond polarisation)
- acid-base reactions and proton transfer
- redox reactions and electron transfer

- changing geometry around the carbon atoms,

underpin much of the analysis and predictions of reactivity of organic compounds and functional groups. Students learn how to synthesise and modify organic structures. They learn about many applications of organic chemistry from pharmaceuticals to polymers and develop further laboratory skills and techniques to analyse organic compounds.

Many of the core concepts and skills can be embedded within specific domains (earth, atmosphere, water) as students learn about, research and investigate our chemical environment. Students have the opportunities to pose research questions and investigate areas linked to the atmosphere, water and the earth's resources. In this way students can gain an appreciation, in a personal and chemical sense, of the nature of challenges facing our world and also a greater understanding of science-related solutions.

Strand 4 Learning Outcomes

Students learn about	Students should be able to
MW1 Volumetric Analysis	
Standardisation Primary standards, and standard solutions, for acid-base and redox volumetric analysis.	a. recognise the importance of primary standards and standard solutions
Titrations Investigations, using primary data, to include analysis of: *(i)* strong acid - strong base *(ii)* strong acid - weak base *(iii)* weak acid - strong base (all above to point of complete neutralisation) *(iv)* Fe^{2+} solution (e.g. iron tablets, lawn feed) *(v)* dissolved oxygen	b. determine the concentration of analytes by titration, using primary standard solutions and/or solutions standardised using primary standards [EI]

Students learn about	Students should be able to
Volumetric Problems **Problem solving using varied units (see Quantifying Matter section). Volumetric calculations in familiar and unfamiliar contexts.**	c. **solve and analyse volumetric problems**
MW2 Reactivity of Organic Compounds	
Sources and Impact Sourcing organic compounds; industrial products based on organic compounds, as the main constituents, such as fuels, pharmaceuticals, plastics, pesticides and synthetics.	a. outline sources of organic compounds and the use and impact of products based on organic compounds
Representation The reactivity and behaviour of organic compounds that can be characterised by the presence of other atoms or groups of atoms chemically bound to the hydrocarbon molecule. These functional groups (using systematic IUPAC rules, up to C10) include: alkanes (including cyclohexane), alkenes, alkynes, aromatics (limited to benzene), alcohols (primary, secondary, tertiary), haloalkanes, monocarboxylic acids, esters (from monocarboxylic acids and primary alcohols only), aldehydes and ketones. Representations of the above molecules: • molecular formula • condensed structural formula • expanded molecular structures • 3D physical models (tetrahedral and planar geometry around the carbon atoms) • Use of R to represent part of an organic molecule Comparison involving structural isomerism.	b. apply rules for nomenclature and classify each functional group in terms of general formula and structure c. construct and compare representations of organic molecules

Students learn about	Students should be able to
Identifying Tests for unsaturation, Tollens' and Fehling's test Reactions of carboxylic acids with suitable metals (e.g. magnesium), suitable bases (e.g. NaOH and sodium carbonate); reaction of alcohols with sodium.	d. conduct qualitative analysis tests: • to distinguish between aldehydes and ketones • for the presence of carboxylic acid and alcohol functional groups
Physical Properties **How solubility, melting point, boiling point are influenced by molecular structures and properties**	e. **relate the physical properties of organic molecules to molecular size, type of bonding present and intermolecular forces**
Reaction Types and Schemes Types of reactions studied in organic chemistry: Addition, Substitution, Redox, Acid-Base, Elimination. (Conditions of temperature, solvent, catalyst, pressure, etc are not required unless specified.) Reactions include, but not limited to, the examples specified in reaction mechanisms below. Reaction schemes that can be used to: • describe the relationships between compounds • **predict reactions** • **explain behaviour (changes in geometry, why some reactions are not possible)**	f. describe **and discuss** five types of reactions **and analyse a given reaction in terms of the type(s) of reaction taking place** g. analyse an organic reaction scheme and predict possible reactions and reaction products
Reaction Mechanisms **The preparation of an ester using a reflux method** **Synthesis of benzoic acid by oxidation of phenylmethanol using $KMnO_4$ under basic conditions** How to use curved arrows or fishhooks to show the movement of electrons in the following reactions:	h. **conduct experiments to:** • **prepare an ester** • **synthesise benzoic acid, determining purity, melting point and yield**

Students learn about	Students should be able to
• ionic addition to ethene of chlorine, bromine, hydrogen chloride, water and hydrogen • dehydration of primary alcohols • free radical addition polymerisation of ethene forming polyethene using organic peroxide catalyst • free radical substitution reactions of alkanes with halogens	i. describe reaction mechanisms involving movement of electrons, including supporting evidence
Redox reactions of alcohols, aldehydes, carboxylic acids and ketones; acid-base reactions involving base hydrolysis of esters, including tri-esters in fats and oils. **(Use of redox reagents to convert between selected functional groups: hydrogen in the presence of nickel as reducing agent, sodium dichromate, potassium permanganate in acidic and basic conditions.) Inductive effects in carboxylic acids, resonance of the carboxylate ion; polarity in the alcohol structure.**	j. **discuss redox reactions and acid-base reactions of organic compound** k. **explain the acidity of carboxylic acid and alcohol functional groups**
<u>*Applications*</u> *Surfactants and Soaps* How the use of surfactants has made significant contributions to the health and sanitisation of society. A simple activity, using household reactants, to manufacture soap on a small scale at home or in the laboratory and the consequences of having limiting or excess NaOH for the manufacture of soap. Commercial and non-commercial manufacture of soap.	l. outline how a soap works, as an example of a surfactant, and the applications of surfactants in everyday life m. conduct an activity to prepare soap, with NaOH either limiting or in excess
<u>*Pharmaceuticals*</u> The use of organic compounds in natural products for medicinal/narcotic use (examples include, but not limited to, willow bark, cinchona bark and opium poppy.) The foundation of	n. compare the manufacture and basicity of a simply-made soap product with a commercial product

Students learn about	Students should be able to
the modern pharmaceutical industry based on core chemical concepts, involving intentional extraction / manufacture of active ingredients in a natural product and synthesis of new drugs. How most products of the modern pharmaceutical industry are large complex organic molecules with multiple functional groups made from simpler organic precursors, including, but not limited to aspirin, quinine, penicillin, taxol and opiates.	o. illustrate the use of organic compounds in pharmaceutical products
How to extract pure aspirin from an aspirin tablet and recrystallise the extract.	p. **investigate, using primary data, how to find percentage aspirin in an aspirin tablet** [EI]
Polymers Defining the term polymer and examples that include, but are not limited to: poly(ethene), poly(chloroethene) and poly(phenylethene). Applications of synthetic polymers including: fuels, food production and household products.	q. describe the structure and applications of addition polymers r. **relate the physical properties of addition polymers to their structures, and how non-biodegradability is related to chemical stability**
MW3 Our Chemical Environment *Investigating* The human impact on our chemical environment, through three domains, all of which are interconnected: Earth, Water, Atmosphere. The practice of chemistry as a collaborative, human endeavour, and how the social and global importance of chemistry can be further appreciated through meaningful, personal investigations.	a. discuss our chemical environment for each of the three domains and consider the interconnections across domains b. research, individually or collaboratively, one area of each of the three domains regarding the impact of humans on our chemical environment [RI]

Students learn about	Students should be able to
Atmosphere The cycles of nature and their significance in relation to natural and human-influenced climate change and sustainability. Greenhouse gases including, but not limited to: methane, carbon dioxide, NOx, sulfur oxides, water vapour, with each having different sources, abundances and greenhouse factors (represented by global warming potentials) The evidence for human influenced climate change is overwhelming. Some of the effects of the enhanced greenhouse effect include, but are not limited to: global warming, precipitation, acid rain, and ocean acidification. Possible solutions including but are not limited to: carbon sequestration, replacing CFCs with HFCs, reducing use of fossil fuels as energy sources.	c. relate aspects of the Nitrogen, Oxygen and Carbon cycles to climate change and sustainability d. describe the natural greenhouse effect and explain its significance e. discuss the evidence for the enhanced greenhouse effect and possible solutions to anthropogenic influences on the atmosphere
Water Water as a finite resource and how its processing for use has an energy and environmental impact. Water treatment: sedimentation, flocculation, filtration (sand and micro), chlorination, fluoridation, pH adjustment, UV treatment. Qualitative testing for ions, determining pH levels, estimating free chlorine levels and dissolved oxygen. Contamination: sewage, industrial and agricultural effluent, including the role of the Haber process, microplastics, heavy metals, acidification. Consequences including, but not limited to, eutrophication and increased BOD. Possible solutions including but are not limited to: sewage treatment, heavy metal precipitation and changing agricultural practices.	f. outline the water cycle, including its significance g. describe the steps necessary in the treatment of drinking water and appreciate the impact of providing clean water for human use h. analyse water samples, both qualitatively and quantitatively [EI] i. discuss causes of water contamination, biochemical consequences and possible solutions to one of the causes

Students learn about	Students should be able to
Earth Metals as a finite resource and the energy and environmental impact of processing metals for human use. Extraction: Physical, heating, reduction by carbon (coke), electrochemical means of extraction. Recycling: from sorting to compounding; Alternative energy sources including, but not limited to: electrochemical cells, hydrogen, nuclear energy and synthetic organic fuels: fermented ethanol and biomass for biofuels.	j. outline methods for the extraction of metals from their natural states based on their positions in the electrochemical series k. discuss the recycling of aluminium and plastics l. discuss the impact on sustainability of reduced dependence on energy sourced from fossil fuels, and sustainable alternatives

Assessment

Assessment in senior cycle involves gathering, interpreting and using information about the processes and outcomes of learning. It takes different forms and is used for a variety of purposes. It is used to determine the appropriate route for students through a differentiated curriculum, to identify specific areas of strength or difficulty for a given student and to test and certify achievement. Assessment supports and improves learning by helping students and teachers to identify next steps in the teaching and learning process. As well as varied teaching strategies, varied assessment strategies will support learning and provide information that can be used as feedback so that teaching and learning activities can be modified in ways that best suit individual learners. By setting appropriate and engaging tasks, asking questions giving feedback that promotes learner autonomy, assessment will support learning as well as summarising achievement.

Assessment for certification

Assessment for certification is based on the rationale aims, and learning outcomes of this specification. There are two assessment components: a written examination and an additional assessment component comprising of a Chemistry in Practice Investigation. The written examination will be at higher and ordinary level. Chemistry in Practice Investigation will be based on a common brief. Each component will be set and examined by the State Examination Commission (SEC).

In the written examination, Leaving Certificate Chemistry will be assessed at two levels, Higher and Ordinary level (Table 1, Pg 15). Examination questions will require students to demonstrate learning appropriate to each level. Differentiation at the point of assessment will also be achieved through the stimulus material used, and the extent of the structured support provided for examination students at different levels.

Assessment Component	Weighting	Level
Chemistry in Practice Investigation	40%	Higher and Ordinary
Written examination	60%	Higher and Ordinary

Table 2: Overview of assessment for certification

Additional assessment component: Chemistry in Practice Investigation

The additional assessment component of Leaving Certificate Chemistry (CiPI) provides an opportunity for students to display evidence of their learning throughout the course, in particular, the learning set out in the unifying strand. The senior cycle key competencies of thinking and solving problems, communicating, being creative, participating in society and managing learning and self, developed through all the learning in this course, will be applied through the student's engagement in the investigation.

The Chemistry in Practice Investigation involves students completing a piece of work in a specified time period in sixth year of senior cycle as evidence of their ability to conduct scientific research on a particular issue and to use appropriate primary data to investigate aspects of that issue. The Chemistry in Practice Investigation has been designed to exploit the potential of the additional assessment component to be motivating and relevant for students. It is also designed to give students practical opportunities to apply their knowledge, skills, values and dispositions to some of the cross-cutting themes and to the three chemical domains of Earth, Atmosphere and Water. It can also spotlight potential career paths by highlighting the relevance of learning in Chemistry to their lives.

It is envisaged that the additional assessment component will take up to 20 hours of class time to complete during term two of sixth year. Schools will have a level of autonomy over how these hours are allocated within the second term of sixth year.

Part 1

A broad thematic overview is published early in fifth year to provide the broad context that will inform the more detailed brief given in sixth year of senior cycle. The purpose of this broad overview is to:

- support students in developing their thinking and ideas on areas they would like to investigate during the specified completion period
- facilitate teachers in their planning, with the context set out in the overview acting as a lens through which to explore the learning outcomes linked to the cross-cutting themes of the course
- signpost for teachers and students, issues related to specific real world applications of chemistry
- signpost relevant documents or real scientific texts and data that might be useful to support the learning throughout the course

- allow students to develop a research log that they can draw on during the specified completion time period.

Part 2

A thematic brief is issued in term two of sixth year, the purpose of which is to set out the requirements of the Chemistry in Practice Investigation (CiPI). Although the thematic brief narrows the focus from the thematic overview, students still have agency to choose a CiPI topic that will be relevant, motivating and engaging for them.

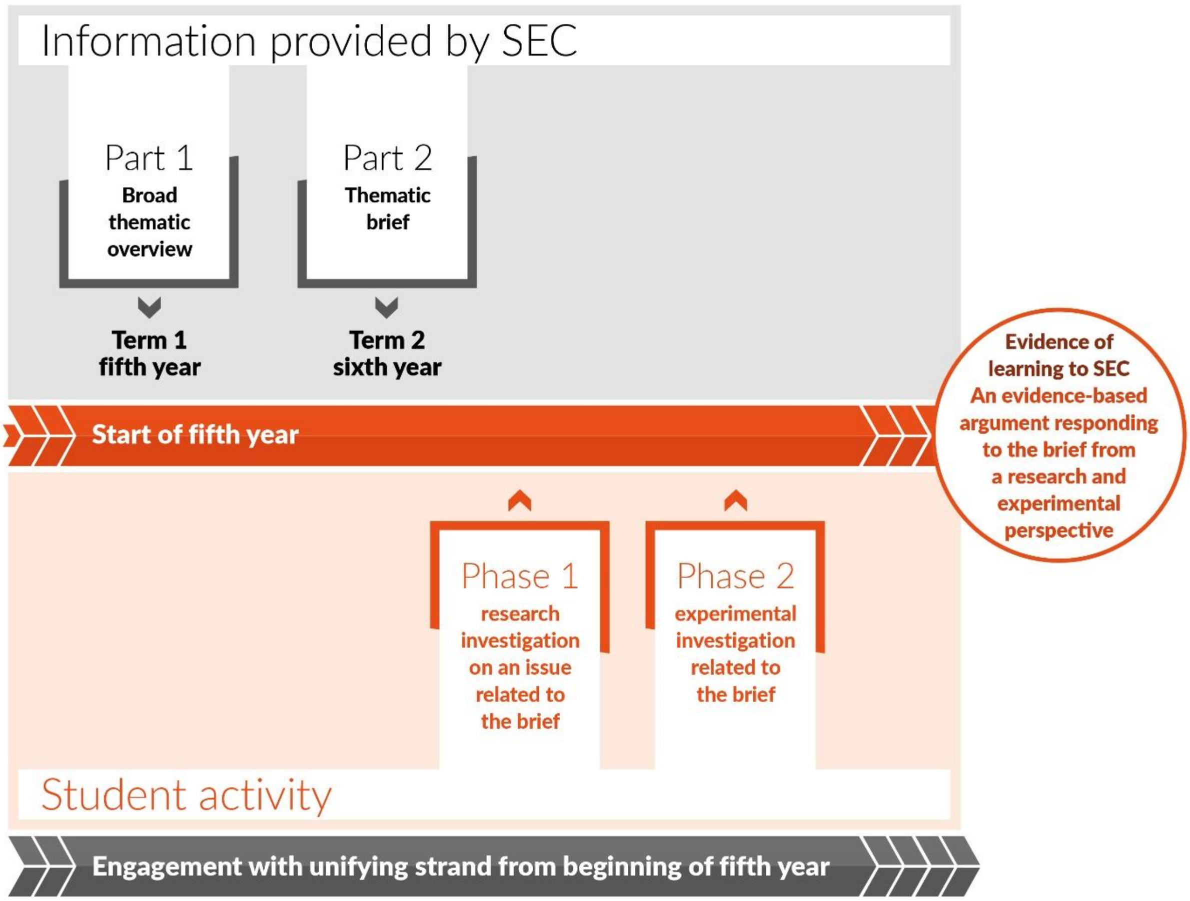

Figure 4: Visual overview of timeline for coursework component

Descriptors of Quality for the Chemistry in Practice Investigation

The descriptors below relate to the learning achieved by students in the Chemistry in Practice Investigation. In particular, the investigation requires students to:

- reason about chemical phenomena
- demonstrate research and experimental investigative skills
- relate their investigative work to the work of scientists in society.

	Students demonstrating a high level of achievement	Students demonstrating a moderate level of achievement	Students demonstrating a low level of achievement
Investigating	evaluate a wide range of appropriate sources related to the brief; identify key areas of investigation; where appropriate, pose a probing research question and a testable hypothesis that is underpinned by chemical concepts; use a thorough investigative design and appropriate methods to collect high quality primary data; draw valid conclusions justified by the data and related to any hypotheses made; evaluate the investigation; acknowledge and identify limitations in research, design and data gathering	evaluate a range of appropriate sources related to the brief; identify some areas of investigation; where appropriate, pose a research question and testable hypothesis that is underpinned by chemical concepts; use a somewhat structured investigative design and appropriate methods to collect good quality primary data; draw some conclusions that relate to any hypotheses made; evaluate the investigation to some extent and identify limitations.	source a limited range of material related to the brief; outline some areas of investigation; where appropriate, pose some form of research question or testable hypothesis; use an investigative design, with some experimental methods to collect primary data; limited consideration given to reliability of secondary sources used; draw some conclusion; does not identify limitations in the investigation.
Communicating	summarise key areas of the research investigation;	summarise some areas of the research investigation;	mention areas of the research investigation;

	Students demonstrating a high level of achievement	Students demonstrating a moderate level of achievement	Students demonstrating a low level of achievement
	clear and appropriate data presentation and analysis; describe their initiative and decision-making during their research and experimental investigation; present a coherent and consistent approach across the report with appropriate supporting references and reflections on the research and experimental investigation	adequate data presentation and analysis; describe limited initiative and decision-making during their research and experimental investigation; present a broadly coherent and consistent approach across the report with some supporting references and reflections on the research and experimental investigation	implement an investigation that leads to some form of data presentation and analysis; show limited initiative during their investigation; present an often incoherent and inconsistent approach across the report with few references or reflections
Relation to society	offer a considered reflection; locate the outcomes of the overall investigation within societal and scientific issues relating to the broad thematic overview and brief.	offer some reflections; relate the outcomes of the investigation to broader issues of society and science within the context of the thematic brief	offer few reflections; make limited links between the outcomes of the investigation and issues around society and science.
Knowledge and understanding	use relevant research into the thematic brief; engage accurately with chemical concepts being investigated throughout the investigation; show considerable understanding of the brief and describes clearly the purpose of the investigation; evaluate the reliability of any secondary sources used; describe thoroughly the chemical phenomena involved.	use some relevant research into the thematic brief; engage well with chemical concepts being investigated throughout the investigation; show some understanding of the brief and describes clearly the purpose of the investigation; consider the reliability of any secondary sources used; describes the chemical phenomena involved.	use some research into the thematic brief; have limited engagement with the concepts being investigated; show limited understanding of the brief and are unclear about the purpose of the investigation; outline few of the chemical phenomena involved.

Table 3: Descriptors of Quality: Chemistry in Practice Investigation

Written examination

The written examination will consist of a range of question types. The senior cycle key competencies (Figure 2) are embedded in the learning outcomes of this specification and will be assessed in the context of the learning outcomes. The written examination paper will include a selection of questions that will assess, appropriate to each level:

- the learning described in the four contextual strands of the specification and the unifying strand
- application of chemistry to issues relating to the cross-cutting theme—sustainability, health, and technology.

Reasonable accommodations

This Leaving Certificate Chemistry specification requires that students engage with the nature of the subject on an ongoing basis throughout the course. In addition, the assessment involves an additional component, the Chemistry in Practice Investigation, which accounts for 40% of the total marks awarded. In this context, the scheme of *Reasonable Accommodations*, operated by the State Examinations Commission (SEC), is designed to assist candidates in the Leaving Certificate who have physical/medical/sensory and/or specific learning difficulties.

Reasonable accommodations are designed to remove as far as possible the impact of a disability on a student's performance, so that he or she can demonstrate in an examination his or her level of achievement—they are not designed to compensate for a possible lack of achievement arising from a disability.

Leaving Certificate grading

Leaving Certificate Chemistry will be graded using an 8-point grading scale. The highest grade is a Grade 1; the lowest grade is a Grade 8. The highest seven grades (1-7) divide the marks range 100% to 30% into seven equal grade bands 10% wide, with a grade 8 being awarded for percentage marks of less than 30%. The grades at Higher level and Ordinary level are distinguished by prefixing the grade with H or O respectively, giving H1-H8 at Higher level, and O1-O8 at Ordinary level.

Grade	% marks
H1/O1	90-100
H2/O2	80<90
H3/O3	70<80
H4/O4	60<70
H5/O5	50<60
H6/O6	40<50
H7/O7	30<40
H8/O8	<30

Table 4: Leaving Certificate Grading

Appendix 1 Glossary of action verbs

This glossary is designed to clarify the learning outcomes. Each action verb is described in terms of what the learner should be able to do once they have achieved the learning outcome. This glossary will be aligned with the command words used in the assessment.

Action verb	Students should be able to
Analyse	study or examine something in detail, break down in order to bring out the essential elements or structure; identify parts and relationships, and to interpret information to reach conclusions
Apply	select and use information and/or knowledge and understanding to explain a given situation or real circumstances
Appraise	evaluate, judge or consider text or a piece of work
Appreciate	recognise the meaning of, have a practical understanding of
Calculate	obtain a numerical answer showing the relevant stages in the working
Classify	group things based on common characteristics
Compare	give an account of the similarities and (or) differences between two (or more) items or situations, referring to both (all) of them throughout
Consider	describe patterns in data; use knowledge and understanding to interpret patterns, make predictions and check reliability
Construct	develop information in a diagrammatic or logical form; not by factual recall but by analogy or by using and putting together information
Convert	change to another form
Criticise	state, giving reasons the faults/shortcomings of, for example, an experiment or a process
Deduce	reach a conclusion from the information given
Define	give the precise meaning of a word, phrase, concept or physical quantity
Demonstrate	prove or make clear by reasoning or evidence, illustrating with examples or practical application
Describe	develop a detailed picture or image of, for example a structure or a process, using words or diagrams where appropriate; produce a plan, simulation or model
Design	to conceive, create and execute according to a plan
Determine	obtain the only possible answer by calculation, substituting measured or known values of other quantities into a standard formula
Develop	to evolve; to make apparent or expand in detail
Discuss	offer a considered, balanced review that includes a range of arguments, factors or hypotheses; opinions or conclusions should be presented clearly and supported by appropriate evidence
Distinguish	make the differences between two or more concepts or items clear
Estimate	give a reasoned order of magnitude statement or calculation of a quantity
Evaluate (data)	collect and examine data to make judgments and appraisals; describe how evidence supports or does not support a conclusion in an inquiry or investigation; identify the limitations of data in conclusions; make judgments about the ideas, solutions or methods
Evaluate (ethical judgement)	collect and examine evidence to make judgments and appraisals; describe how evidence supports or does not support a judgement; identify the

Action verb	Students should be able to
	limitations of evidence in conclusions; make judgments about the ideas, solutions or methods
Examine	consider an argument or concept in a way that uncovers the assumptions and relationships of the issue
Explain	give a detailed account including reasons or causes
Explore	observe or study in order to establish facts
Find	general term that may variously be interpreted as calculate, measure, determine etc.
Formulate	express the relevant concept(s) or argument(s) precisely and systematically
Group	identify objects according to characteristics
Identify	recognise patterns, facts, or details; provide an answer from a number of possibilities; recognize and state briefly a distinguishing fact or feature
Illustrate	use examples to describe something
Infer	use the results of an investigation based on a premise; read beyond what has been literally expressed
Interpret	use knowledge and understanding to recognize trends and draw conclusions from given information
Investigate	observe, study, or make a detailed and systematic examination, in order to establish facts and reach new conclusions
Justify	give valid reasons or evidence to support an answer or conclusion
List	provide a number of points, with no elaboration
Measure	quantify changes in systems by reading a measuring tool
Model	generate a mathematical representation (e.g., number, graph, equation, geometric figure) or physical replica for real world or mathematical objects, properties, actions, or relationships [3]
Order	describe items/ systems based on complexity and/or order
Organise	to arrange; to systematise or methodise
Outline	give the main points; restrict to essentials
Plan	to devise or project a method or a course of action
Predict	give an expected result of an event; explain a new event based on observations or information using logical connections between pieces of information
Prove	use a sequence of logical steps to obtain the required result in a formal way
Provide evidence	provide data and documentation that support inferences or conclusions
Recall	remember or recognize from prior learning experiences
Recognise	identify facts, characteristics or concepts that are critical (relevant/appropriate) to the understanding of a situation, event, process or phenomenon
Reflect	to consider in order to correct or improve
Relate	associate, giving reasons
Research	to inquire specifically, using involved and critical investigation

[3] In science a model is a representation of an idea, an object, a process or a system that is used to describe and explain phenomena that cannot be experienced directly. Models are central to what scientists do, they guide research by being simplified representations of an imagined reality and as such, enable predictions to be developed and tested by experiment. It is through the process of validation or arguing the correctness of the model that the model evolves , demonstrating the tentative nature of scientific knowledge. The use of models involves the understanding that all models contain approximations and assumptions limiting their validity and predictive power.

Action verb	Students should be able to
Review	to re-examine deliberately or critically, usually with a view to approval or dissent; to analyse results for the purpose of giving an opinion
Sketch	represent by means of a diagram or graph (labelled as appropriate); the sketch should give a general idea of the required shape or relationship, and should include relevant features
Solve	find an answer through reasoning
State	provide a concise statement with little or no supporting argument
Suggest	propose a solution, hypothesis or other possible answer
Synthesise	combine different ideas in order to create new understanding
Understand	have and apply a well-organized body of knowledge
Use	apply knowledge or rules to put theory into practice
Verify	give evidence to support the truth of a statement