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An Chomhairle Náisiúnta Curaclaim agus Measúnachta
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Draft Leaving Certificate Physics specification

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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 eight 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.

Within the sciences, **Physics** attempts to develop a unified description of how matter and energy behave and interact with each other. The Universe is composed of a wide variety of simple and complex systems and physics attempts to describe these systems in terms of all-embracing fundamental concepts. In its search for basic laws and general principles, physics encompasses the study of the universe from the smallest subatomic particles to the largest galaxies. It involves asking fundamental questions and trying to answer them by observing, measuring, experimenting and developing models to explain the physical world. Physics is progressive, new data may answer some questions but raise others and this makes physics exciting and interesting.

Physicists are problem solvers, the analytical and practical skills developed by students of Leaving Certificate Physics will open a wide variety of opportunities in many fields.

Aims

The aim of Leaving Certificate Physics is to provide students with an experience that develops their interest in and enthusiasm for physics. In doing so, it aims to build the knowledge, skills, values and dispositions necessary for students to become scientifically literate citizens who are well-prepared for the challenges and opportunities of their future, embracing life-long learning and sustainable living, as citizens in a technologically developing society.

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

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

Continuity and progression

Leaving Certificate Physics 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 Physics 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 Physics.

Beyond Senior Cycle

Physics builds a solid foundation for students to progress to diverse futures, including participation in society and the world of work, further education and training, and higher education, in specialised areas such as science, engineering, technology-related jobs, computer science, education, mathematics, medicine, business and finance.
In addition, physics incorporates a broad range of skills, including, logical thinking, creative design, synthesis and evaluation. It teaches a range of generically useful skills in areas such as problem-solving, communication, time management, organisation, and teamwork. These skills are relevant to all further study, and indeed all learning beyond formal education.

Many important challenges facing society—energy demands, providing sufficient food and water, climate change and disease control—require major contributions from the scientific community. These challenges require not only innovative science solutions, but also social, political and economic ones that are informed by knowledge of the science that underpins the challenges.

The spread of disinformation is threatening democracies world-wide. Rationality and scepticism are important principles embedded in Leaving Certificate Physics. Students learn the importance of reliable sources, peer review, ethics and evidence in logical decision-making and are well poised to address these 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.

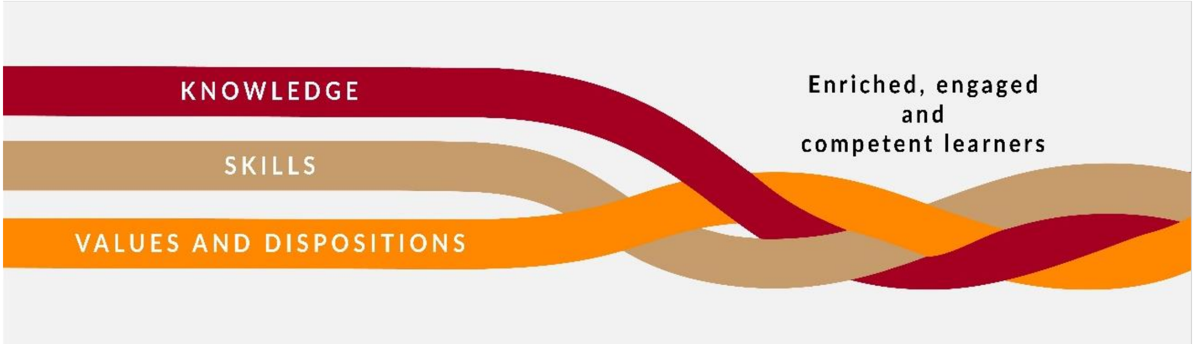

Figure 1 The components of key competencies and their desired impact

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

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.

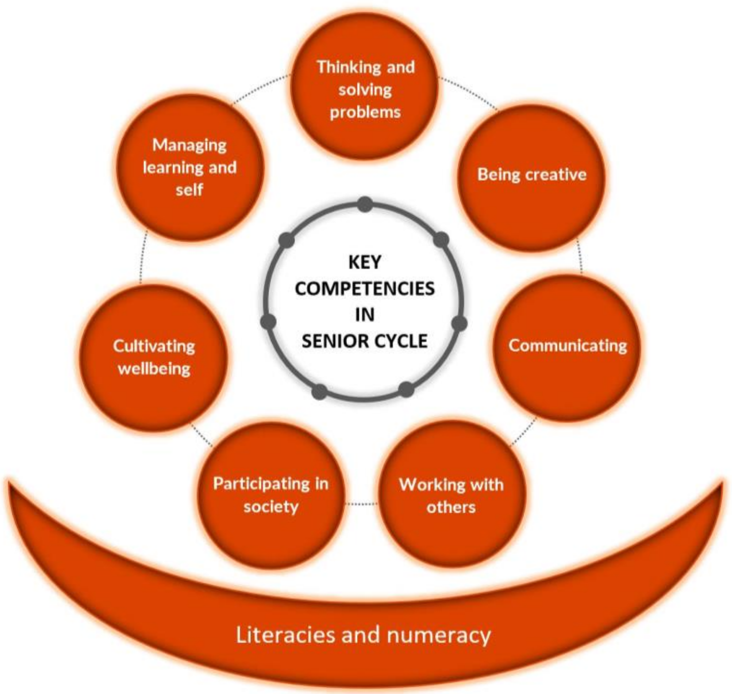

Figure 2 Overview of Key Competencies in Senior Cycle

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. These competencies can be developed in Leaving Certificate Physics in a range of ways.

Thinking and solving problems

Students use critical thinking and problem-solving skills to demonstrate an understanding of scientific principles underlying the solutions to inquiry questions and problems posed in investigations.

Appropriate and varied strategies are employed, including the use of models to qualitatively and quantitatively explain and predict cause-and-effect relationships. As they work like scientists, students synthesise and use evidence to construct and justify conclusions. To solve problems, students interpret scientific and media texts, evaluate processes, claims and conclusions and consider the quality of available evidence.

Communicating

Effective communication skills are developed through collaborative practical work. Students communicate qualitative and quantitative information gained from investigations using primary and secondary sources, digitally, visually, written and/or verbally as appropriate. They apply appropriate scientific notations and nomenclature and use scientific language appropriate for specific audiences and contexts.

Working with others

Leaving Certificate Physics is underpinned by collaboration and working with others. Students gain some appreciation of group dynamics and the social skills needed to engage in collaborative practical work. This contributes to an appreciation that working collectively can energise a group, help motivation, and capitalise on all the talents in the group. One of the most beneficial outcomes of working with others is in identifying, evaluating and achieving collective goals. Students learn to negotiate and resolve differences of opinion as they discuss their different strategies and achieve compromise.

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. 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. Students must develop confidence in their self-direction and exhibit tenacity and rigour. To manage learning and themselves, students must build on the metacognitive dimension of knowledge, whereby they develop strategies to learn and to build on previous knowledge.

Literacies and numeracy

Literacies and numeracy support the development of key competencies in the Leaving Certificate Physics classroom, and vice-versa. Students have opportunities to use the most appropriate and meaningful methods and media to organise and analyse data and information sources, including digital technologies and the use of a variety of visual representations as appropriate. They process both qualitative and quantitative data from primary[1] and secondary sources.

Students identify trends, patterns and relationships; recognise error, uncertainty and limitations in data; and interpret scientific and media texts. 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.

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 Physics 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 physics 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 physics, other subjects, and everyday experiences.

Modelling is at the heart of what physicists do and is front and centre of Leaving Certificate Physics meaning students will learn to use words, diagrams, numbers, graphs and equations, to explain phenomena, make justified predictions and to provide justified solutions to problems. 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 a unifying strand. Whilst 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.

[1]Primary data; data gathered first-hand through experimentation by the student

Through cross-cutting themes, students will integrate their knowledge and understanding of physics with the ethical, social, economic and environmental implications and applications of physics. 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 physics 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 physics 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 Physics will enable students to develop an appreciation of the social context of science. They will develop skills in scientific communication by collaborating to generate perspectives and present them to their peers.

Leaving Certificate Physics provides numerous opportunities for teachers to teach the subject and select materials that respond to the needs, strengths and interests of all students. The focus on an inquiry-based approach to teaching and learning, which is central to physics, means that Leaving Certificate Physics students can be engaged in learning activities that complement their strengths and needs. The course allows for the selection and exploration of topics in ways that are of most interest and relevance to students.

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. 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 strategies such as adjusting the level of skills required, varying the amount and the nature of teacher intervention, and varying the pace and sequence of learning promotes inclusivity. 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 students. By setting appropriate and engaging tasks, asking questions of varying cognitive demand and giving feedback that promotes learner autonomy, assessment will support learning as well as summarising achievement.

Digital technology

Digital technology can enhance learning, teaching and assessment, creating opportunities for students to develop scientific knowledge and skills and digital media literacy in ways that cannot be achieved without the use of technology. As students engage with Leaving Certificate Physics they have opportunities to use digital technology in a range of ways. For example, they may use digital technology to:

- collect, record, analyse and display data and information appropriately
- visualise the core concepts, models and theories that describe, explain and predict physical phenomena
- access and analyse large datasets (e.g. databases of speed, distance and time information) in ways that non-digital techniques of data collection/analysis cannot
- develop a deeper understanding of data through choosing the right tools for data collation, visualisation, analysis, and representation of results
- develop and improve investigative research, communication, and report writing skills
- become more independent learners through, for example, appropriate online supports
- enhance their experience in the physics laboratory
- develop their understanding of how physicists use digital technology in their work.

Strands of study and learning outcomes

The Leaving Certificate Physics specification sets out the knowledge that is of most worth for senior cycle physics students in strands and through the identification of cross-cutting themes. There are five strands; a unifying strand, The Nature of Science, and four contextual strands, Forces and Motion, Waves and Energy transfer, Electricity and Magnetism, and Modern Physics.

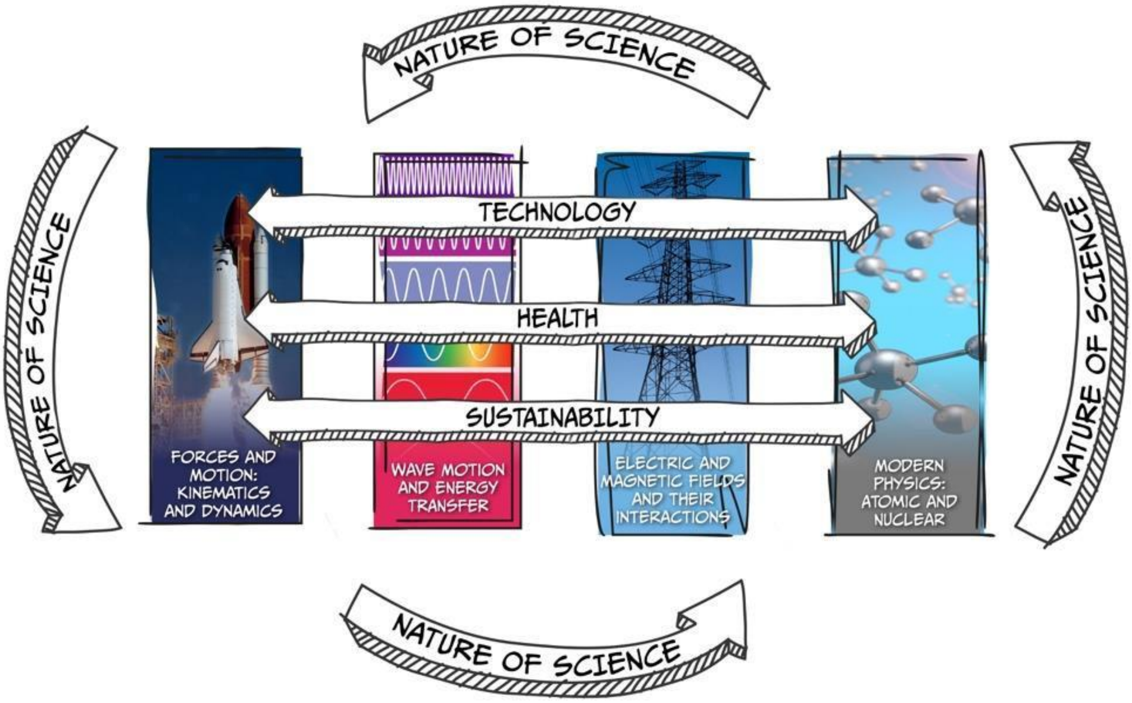

Figure 3 Overview of Leaving Certificate Physics

The Nature of Science underpins physics and so is considered a unifying strand (Figure 3); it permeates all the strands of the specification. The learning outcomes in this strand identify the knowledge, skills and values related to scientific practices which are essential to students' learning about science throughout the course, underpinning the activities and content in the other strands.

The learning outcomes in the other four contextual strands—Forces and Motion, Waves and Energy Transfer, Electricity and Magnetism, and Modern Physics—identify the knowledge of physics; i.e. the core concepts, models and theories that describe, explain and predict physical phenomena.

The specification identifies three cross-cutting themes—Technology, Health and Sustainability—to act as lenses through which students explore the application of the knowledge from physics. Through these lenses they pose questions, examine the benefits of applications of the core concepts, models and theories to individuals, the community and the environment, and evaluate associated risks and any unintended consequences.

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 Physics, but the context, information and results associated with that analysis are presented at different levels.

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 and 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 demonstrate and use scientific literacy skills when presenting appropriate evidence and data to effectively communicate findings and draw valid justified conclusions to questions posed by themselves and others.

Table 1 : Inclusivity in design of learning outcomes

The Leaving Certificate Physics specification is designed for a minimum of 180 hours of class contact time. Each strand contains an overview and a table. The left-hand column of the table builds on the overview and indicates what students will be learning. The right-hand column indicates the knowledge, skills, values and dispositions that students should be able to demonstrate at the end of the course. 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. Building on existing knowledge, students develop an appreciation of science as a process; a way of knowing and doing and an awareness that the discipline of science includes the nature of scientific knowledge as well as how this knowledge is generated, established and communicated. In senior cycle it is expected that students will be able to meet these learning outcomes with a greater degree of independence.

As they learn to work like scientists, they develop a habit of mind that sees them rely on a set of established procedures and practices associated with scientific inquiry to gather evidence, generate models[2] and test their ideas on how the physical world works. It becomes apparent that the process of science is often complex and iterative, following many different paths. Students will learn to obtain and evaluate primary data (i.e., collected by themselves) and secondary data (data collected by somebody else).

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 and that the application of scientific knowledge to problem solving 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
U2. Scientific knowledge • the nature of scientific knowledge • science as a global enterprise that relies on openness, clear communication, international conventions, peer review and reproducibility • recognising bias	a. appreciate how scientists work and how scientific ideas are modified over time b. conduct research relevant to a scientific issue, evaluate different sources of information including secondary data, understanding that a source may lack detail or show bias
U2. Investigating in science • questioning and predicting • objectivity	a. recognise and pose questions that are appropriate for scientific investigation b. pose testable hypotheses developed using scientific theories and explanations, and evaluate and compare strategies for investigating hypotheses

[2] Words, diagrams, numbers, graphs and equations

Students learn about	Students should be able to
• identifying potential sources of random and systemic error • evaluating data in terms of accuracy, precision, repeatability and reproducibility • distinguishing between fundamental and derived units, using SI units, prefixes and powers of ten for order of magnitude, converting units within SI and using an appropriate number of significant figures in calculations • communicating results to a range of audiences	c. design, plan and conduct investigations; explain how reliability, 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 f. organise and communicate their research and investigative findings in a variety of ways fit for purpose and audience, using relevant scientific terminology and representations
U3. Science in society • evaluating evidence for relevance, accuracy, bias • relating science to society by considering economic, social, sustainability and ethical factors	a. evaluate media-based arguments concerning science and technology b. research and present information on the contribution that scientists make to scientific discovery and invention, and evaluate its impact on society
U4. Dimensional analysis • unit analysis • making order of magnitude estimates	a. evaluate and articulate whether an answer is reasonable by analysing the dimensions / units and the order of magnitude

Strand 1: Forces and Motion: Kinematics and Dynamics

In this strand, students learn about Newtonian mechanics as a successful physical theory that explains the motion of objects. They explore how objects move (kinematics) and the reason why objects move in the way they do (dynamics). They use the verbal, mathematical and graphical language of kinematics to discuss and explain motion in one dimension as well as motion in a circle.

They are introduced to Newton's three laws of motion as valid mathematical models with underlying assumptions that accurately model systems as diverse as the planets of the solar system and helium atoms in a container. They learn how experiments and observations have confirmed the validity of Newtonian mechanics in many circumstances, but that the validity breaks down for objects moving close to the speed of light, or objects at the subatomic scale. In strand 4 they will learn how quantum mechanics is a more appropriate model when considering objects at the subatomic scale.

Given the central role that forces play in Newton's laws of motion, students explore forces common in everyday life such as weight, tension, friction, buoyancy and air resistance. They learn how to model a situation in which more than one force is acting on an object and how to find the resultant of those forces. In strands 2 and 3 they will see how many of these everyday forces can also be modelled as gravitational and electromagnetic interactions, two of the four fundamental forces in nature.

The concept of energy as one of the most fundamental concepts in science, is considered in the context of Newtonian mechanics. Students understand that conservation of energy is an essential principle in physics and explore how the concept of work, as a means of transferring energy through the application of a force, links energy and force. They learn how in certain situations, the concepts of work and energy can be applied to solve the dynamics of a mechanical system without directly resorting to Newton's laws. Students learn how this work-energy approach often provides a much simpler analysis than that obtained from the direct application of Newton's Laws since it deals with scalar rather than vector quantities. Beyond this strand, they learn how this problem-solving approach focusing on energy can be applied to a range of phenomena in electromagnetism, and thermal and nuclear physics.

Strand 1 Learning outcomes

Students learn about	Students should be able to
FM1. Particle motion in a straight line • Basic concepts for describing the motion of a particle; displacement, velocity, acceleration and time. • Relationships between the concepts; $v = \frac{\Delta s}{\Delta t}$, $a = \frac{\Delta v}{\Delta t}$ • Graphical Representation and interpretation: displacement -time graphs, velocity-time graphs	a. model motion of a particle in a straight line with justified assumptions b. measure constant and varying linear motion using primary data

• The kinematics equations under constant acceleration $v = u + at$; $s = ut + \frac{1}{2}at^2$; $v^2 = u^2 + 2as$	c. **derive the kinematic equations of motion**
• **Identifying and representing scalar and vector quantities** • **Resolving vectors into perpendicular components** • **Calculating the resultant of two vectors**	d. **verify the law of addition of vectors using primary and secondary data in one and two dimensions**
FM2. Forces acting on a particle • The concept of a force as a vector quantity • The concept of centre of mass • Types of forces: Normal, Frictional, Resistant, Tension, Buoyancy, Gravitational	a. model real-world situations using Newton's laws of motion b. verify Newton's 2nd law of motion by analysing primary and secondary data c. model problems involving the motion of a particle under a constant resultant force
• Resultant force as the sum of all forces • Newton's 2nd law of motion $F_{net} = ma$	
• Pressure as $\frac{Force}{Area}$; in fluids as $h\rho g$	d. model pressure
• The concepts of mass, density $\rho = \frac{m}{V}$ and momentum mv	e. relate pressure, force, and density of a fluid
• Conservation of momentum for a two-particle system in one **and two** dimensions	f. investigate the principle of conservation of momentum using primary and secondary data
• Collisions as governed by Newton's laws of motion and by conservation of momentum	g. verify using secondary data that collisions are governed by Newton's laws of motion h. model direct collisions in one **and two** dimensions
FM3. Stretching and compressing objects • Stretching and compressing objects ○ Hooke's Law; $F = -ks$	a. investigate the force needed to compress or stretch an object using primary and secondary data

○ Work done in stretching or compressing	b. verify Hooke's law for elastic objects using primary and secondary data c. model compressed and stretched objects
FM4. A work-energy model for analysing particle motion • $E_P = mgh$ • $E_k = \frac{1}{2}mv^2$ • $PE = \frac{1}{2}kx^2$ • $W = Fs$ • $P = \frac{W}{t}$ • The principle of conservation of energy	a. define work done by a constant force b. model authentic situations describing gravitational potential energy, elastic potential energy kinetic energy, work done and the rate of doing work c. investigate the principle of conservation of energy using primary and secondary data d. apply the principle of conservation of energy to authentic situations
FM5. Forces acting in a gravitational field • Mathematical models for g the acceleration due to gravity $g = 4l\frac{\pi^2}{T^2}$, $g = \frac{2s}{t^2}$ $g = \frac{GM}{r^2}$ • Newton's Law of Universal Gravitation as an inverse square law $F = \frac{Gm_1m_2}{d^2}$	a. verify models to determine g using primary and secondary data b. model the gravitational field strength at any point in a gravitational field, including at the surface of a planet
FM6. Uniform circular motion • The centripetal force required to maintain uniform motion in a circle $F = \frac{mv^2}{r}$ • Evidence that the force of gravity meets the centripetal force requirements for planetary motion $T^2 = \frac{4\pi^2R^3}{GM}$ • Relate the orbits of satellites to their uses	a. explain centripetal force b. model the dynamics of an object moving in a circle with constant angular velocity c. verify Kepler's 3rd Law using secondary data

	d. model situations involving the orbits of planets and satellites in near Earth and geostationary orbits

Strand 2: Wave Motion and Energy Transfer

In this strand, students are introduced to energy transfer in a number of ways. They categorise different types of waves and explore the distinguishing features of each. They are introduced to the anatomy of a wave and associated vocabulary and mathematical relationships.

They explore the electromagnetic spectrum; a special family of waves travelling at the speed of light and identify the members of this family by wavelength and frequency. The exploration of infra-red radiation provides an opportunity for students to look at the concept of heat transfer in more detail and offers a segue to the exploration of a particle model to make sense of the phenomenon of conduction and convection, describe observations from real life and make predictions about behaviour.

As they explore energy transfer through a variety of mediums, they explore boundary behaviour and are introduced to wave phenomena common to different categories of waves. Having used words, diagrams graphs and equations to describe the behaviour of waves, students apply this learning to real- life situations involving energy transfer. They apply their understanding of motion from strand 1 to make sense of the particle model of matter in relation to the transfer of heat energy between and within systems by conduction and convection.

They plan to fairly collect primary data and analyse secondary data, to verify observations and mathematical relationships and solve problems using these relationships.

Strand 2 Learning outcomes

Students learn about	Students should be able to
WMET1. The transfer of heat energy and temperature change • A definition of temperature • Thermometric properties of materials • Thermometer as a device	a. model thermometric properties b. analyse the suitability of materials for use as thermometers using primary and secondary data c. determine specific heat capacity and specific latent heat using primary data

Students learn about	Students should be able to
• The Kelvin and Celsius temperature scales • Relationships between heat energy and temperature change ○ Heat Capacity: $C = \frac{Q}{\Delta q}$ ○ Specific Heat Capacity: $c = \frac{Q}{m\Delta\theta}$ ○ Latent Heat: Q = ml ○ Specific latent Heat • The concept of a heat pump • Particle models of heating; conduction, convection changes of state • The concept of efficiency $\frac{Energy\ output}{Energy\ input} \times 100\ \%$ • U-value as the rate of transfer of heat through a material	d. verify models describing the relationships between heat energy, latent heat and temperature change using secondary data e. model authentic problems involving heat transfer, change of state and efficiency f. explore the impact of insulation on energy consumption and sustainability using secondary sources
WMET2. Travelling waves as models of disturbances transferring energy without transferring matter • Mechanical/ electromagnetic waves • Radiation • Longitudinal /transverse waves • Wave characteristics: Rest position, Displacement, Trough, Crest, Amplitude, Wavelength, Time period, Frequency • Mathematical models and relationships used to describe wave motion: ○ $T = \frac{1}{f}, v = f\lambda, c = f\lambda, E \propto A^2$	a. model the transfer of energy by waves
WMET3. Wave behaviour caused by the interaction of waves with their environment • Reflection (ray model) • Refraction (ray model) • Refractive index $n = \frac{\sin i}{\sin r}$	a. model wave behaviour in a variety of situations b. verify models for refraction using primary and secondary data c. verify models describing the relationship between image and object distances and the focal length of converging lenses using

Students learn about	Students should be able to
• Refractive index $n = \frac{c_1}{c_2}$ ○ Total Internal Reflection : $n = \frac{1}{\sin C}$ • Converging and diverging lenses ○ $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ • Diffraction • Interference • Polarisation	primary and secondary data and diverging lenses using secondary data d. explore the use of optics in a variety of applications using secondary sources
WMET4. Electromagnetic Energy • Electromagnetic spectrum and sources of electromagnetic energy; ionising radiation • Dispersion • Irradiance as the energy falling on a surface per unit time: $I = \frac{P}{A}$	a. categorise electromagnetic waves by their wavelength, frequency, ionising ability and everyday use b. examine primary and secondary evidence to support the wave nature of electromagnetic energy c. demonstrate dispersion and explain the phenomenon d. investigate solar irradiance and its impact on life on earth using secondary sources
WMET5. Sound Energy • sound energy needs a medium to travel through • ultrasound	a. examine primary and secondary evidence to support the mechanical wave nature of sound b. relate the pitch and loudness of sounds to their wave characteristics using primary and secondary data c. explore the use of ultrasound in technological and medical contexts using secondary sources
WMET6. Principle of superposition of waves • Stationary waves in strings as resulting from the interference of two waves along the same string moving in opposite directions • Common terms used to describe stationary waves: nodes, antinodes, harmonics and the fundamental mode of vibration	a. analyse standing wave patterns using primary and secondary data b. model the relationship between harmonics and the standing wave pattern c. verify the relationship between the length of a string and the frequency of a standing wave using primary and secondary data d. model standing waves on a stretched string

Students learn about	Students should be able to
$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$ • **Coherence** • **The diffraction grating** • **Young's Slits Experiment** ○ $\boldsymbol{n\lambda = d \sin\theta}$	**e. analyse diffraction using primary and secondary data** **f. model two source interference** **g. analyse two source interference using primary and secondary data** **h. determine the wavelength of light from primary data**
WMET7. Wave effects • The Doppler Effect $$f' = \frac{fc}{c \pm \mu}$$ • Resonance as the observed phenomenon when driving frequency = the natural frequency of vibration	a. investigate the Doppler effect using secondary data b. model authentic situations involving the relative motion between the source of a wave and the observer c. explore the Doppler effect in a variety of applications using secondary sources d. model real-life situations involving resonance e. relate a driving frequency to the natural frequency of an oscillating system, the amplitude of motion and the transfer of energy within the system

Strand 3: Electric and Magnetic Fields and their Interactions

In this strand, students are introduced to the concept of electric and magnetic fields as examples of vector fields of force and use field lines to represent the relative strength and direction of these fields. They explore evidence for electric charge as responsible for these electric and magnetic forces and fields and establish links with atomic structure, Newton's Laws of motion, and work and energy. They recognise the non-contact nature of the interaction between charged objects and explore similarities and differences with qualitative and quantitative aspects of gravitational forces. Applying a work/energy model allows them to explain electricity, from charged particles at the atomic level to the current that flows in homes and businesses.

As they examine evidence and interrogate models explaining the conductivity of materials they are introduced to semiconductors and learn to appreciate how their use has revolutionised our lives.

They learn that there are two kinds of electric currents: direct (DC) and alternating (AC). Knowing that electricity and magnetism are closely related they explore evidence that flowing electrons produce a magnetic field, and spinning magnets cause an electric current to flow. Electromagnetism is the interaction of these two important forces and electricity and magnetism are integral to the workings of nearly every gadget, appliance, vehicle, and machine they use.

As they progress through the strand students appreciate how discoveries about the interactions that take place between charged particles and electric and magnetic fields from Oersted to Faraday not only produced significant advances in physics, but also led to significant technological developments. These developments include the generation and distribution of electricity, and the invention of numerous devices that convert electrical energy into other forms of energy. Whilst the law of conservation of energy underpins all of these interactions, the conversion of energy into forms other than the intended form is a problem that constantly drives engineers to improve designs of electromagnetic devices to make them more efficient and sustainable.

Strand 3 Learning outcomes

Students learn about	Students should be able to

EMF1. Charge interactions
• Charge as a property of matter
• The atomic structure of matter
  ○ Free electrons and bound electrons
• Charging objects by friction / induction (Single sphere); grounding
• The conservation of charge in interactions
• The distribution of charge on conductors and insulators
	a. demonstrate forces
	  i. between charged objects
	  ii. between charged and neutral objects
	b. classify materials as conductors or insulators
	c. model the behaviour of insulators and conductors
	d. model static electrical phenomena

EMF2. Modelling electric fields • The electric force and Coulomb's Law as an example of an inverse square law $\frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{d^2}$ • Electric potential as $\frac{PE}{Q}$ • Electric field of a point charge $E = \frac{F}{q}$ • The vector nature of electric fields $\vec{F} = q\vec{E}$	a. model the electric force between point charges b. discuss the electric field as a model for the non- contact interaction between charged objects c. define electric field strength at a point d. use field lines to represent the relative strength and direction of electric fields around charged objects

EMF3. Electric circuits
• Electric potential and current
• Work, Power, Potential difference and emf
• $I = \frac{Q}{t}$
• $W = RI^2t$
• $V = \frac{W}{q}$
• $P = RI^2$
• $P = VI$
• Series and Parallel circuits
	a. model
	  ○ the relationship between work, charge and potential difference
	  ○ the relationship between current and charge
	  ○ the relationship between electric current, conventional current, power and resistance
	  ○ series and parallel circuits
	  ○ the rate of conversion of electrical energy in components of electric circuits
	  ○ fuses and circuit breakers

Students learn about	Students should be able to
• Heating effect of an electric current and its implications for electrical supply • Components: switch, light bulb, resistor, ammeter, voltmeter, diode, LDR, LED • Safety in mains electricity: Earthing, MCBs and RCDs	b. use primary and secondary data to verify the relationship between current flowing through and the voltage across an ohmic conductor

• Resistance and resistivity
  ○ Ohm's Law
    ▪ $R = \frac{V}{I}$
    ▪ $R = \rho\frac{l}{A}$
 	
• Non-ohmic conductors: Filament bulb, Diode, LDR Thermistor
 	
• Kirchhoff's Laws as a consequence of conservation of charge and energy
	c. determine the resistance of ohmic and non-ohmic conductors
	
	d. investigate the effect of temperature on the resistance of a conductor using primary and secondary data

• Derive expressions for combinations of resistors in series and parallel
  ○ $R = R_1 + R_2 + R_3$......
  ○ $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$......
	e. model resistances in electrical circuits

EMF4. Semi-conductors • Doping; n type, p type and p-n junction • The Depletion layer as a region with no charge carriers • Transistors as switches	a. explore the use of p-n junctions in real-world applications b. model an n-p-n transistor

EMF5. Magnetic fields around permanent and temporary magnets
 	
• The interaction of magnetic fields
 	
• Magnetic effect of an electric current
 	
• Force exerted by magnetic field generated by a moving charge
	a. model the relative strength and direction of magnetic fields around
	  ○ a single permanent magnet and permanent magnets in close proximity
	  ○ current carrying wire
	  ○ current carrying solenoid with and without ferrous core

Students learn about	Students should be able to
○ $F = BqV$ • Effect of a ferrous core on the magnetic field around a solenoid	b. explore the use of permanent and temporary magnets in authentic situations
EMF6. The force experienced by a current-carrying conductor in a magnetic field • Fleming's left-hand rule/ Right-hand rule to determine the direction of a motor effect force ○ $F = BIL$ • Simple DC motor and the role of the split ring commutator	a. investigate the relationship between the magnetic field and the electromagnetic force on a current- carrying wire b. model the motor effect c. model a DC motor
EMF7.Induced potential difference and the generator effect • **Magnetic Flux** $\boldsymbol{\Phi = BA}$ • **Faradays Law** • **Lenz's law** ○ $\boldsymbol{E = -\frac{d\Phi}{dt}}$ • Mutual Inductance in Transformers ○ $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ ○ $I_p V_p = I_s V_s$ • Electrical generation; A.C and D.C generators and their components ○ $v_{rms} = \frac{v_{max}}{\sqrt{2}}$ ○ $I_{rms} = \frac{I_{max}}{\sqrt{2}}$	a. investigate the relationship between a change in magnetic flux on any induced emf and subsequent current flow in a conducting coil b. model ○ the generator effect ○ ac and dc generators ○ transformers c. evaluate the use of induced potential difference in a variety of applications using secondary sources d. solve problems involving the efficiency of transformers e. evaluate transmission losses in the National grid using secondary sources f. evaluate evidence about local issues related to electrical generation and distribution using secondary sources

Strand 4: Modern Physics Atomic and Nuclear

In this strand, students gain a deep appreciation of the evolving nature of physics as they turn their attention to the late 19th and early 20th centuries when unexplainable observations were challenging accepted theories and models. They learn how this period saw major developments in physics as experimental discoveries motivated by the need for explanations revolutionised the accepted understanding of the nature of matter on an atomic scale and led to a new area of study; namely quantum mechanics.

By studying the development of atomic models through the work of Thomson and Rutherford, who established the nuclear model of the atom – a positive nucleus surrounded by electrons – students further their understanding of the limitations of theories and models. They explore the contribution of Bohr and his demonstration of the quantum mechanical nature of matter as a better way to understand the structure of the atom. A quantum explanation of observed properties of matter and light have inspired other great physicists such as de Broglie, Schrödinger and Heisenberg to develop more accurate models of matter, which in turn have been modified or abandoned in the light of further experimental investigations.

Students learn how experimental investigations of the nucleus have led to an understanding of the weak nuclear force responsible for the radioactive decay of certain nuclei, the ability to extract energy from nuclear fission and fusion, and a deeper understanding of the atomic model.

They explore how technologies arising from these theories have shaped the modern world. They look at modern instrumentation such as particle accelerators and how they have revealed that protons themselves are not fundamental and continue to provide evidence in support of the Standard Model of matter. In studying this strand, students can appreciate how the fundamental particle model is forever being updated and that our understanding of the nature of matter remains incomplete.

Strand 4 Learning outcomes

Students learn about	Students should be able to
MP1.Electron and X-Ray production • The electron as the indivisible quantity of charge e = 1.602×10^{-19} C • hot cathodes (which are negative) producing cathode rays which were identified as beams of electrons e.g CRO	a. analyse evidence supporting the existence and properties of the electron b. verify the basic principles of thermionic emission using secondary evidence

Students learn about	Students should be able to
• beams of electrons being deflected in uniform electric and magnetic fields. • electrons absorbed by metals. • beams of electrons incident on metal targets used to produce X-rays in X-ray tubes	c. model the production and deflection of a beam of electrons in a vacuum
MP2. Photoelectric emission • electrons being ejected or released from the surface of materials (generally a metal) when light of a suitable frequency falls on them • the wave theory of light and how it cannot account for the observed dependence of the photoelectric effect on frequency ○ E= hf ○ **Φ=hf_0** ○ **Threshold frequency f_0** ○ **Work function φ** • **the principle of conservation of energy underpins the effect** ○ **E= φ + ½mv^2** • the photoelectric effect and its applications in sensor technology	a. use secondary data to verify the photoelectric effect and the effect of varying ○ the intensity of incident radiation ○ the frequency of incident radiation b. appreciate how photoelectric emission supports the particle model of light c. model x-ray production and the photoelectric effect d. compare x-ray production and the photoelectric effect e. relate the photoelectric effect to the operation of a photocell f. evaluate the use of photocells using secondary sources
MP3. Early models of the atom • Thompson-Rutherford -Bohr • Energy levels and quantum leaps ○ $E_2 - E_1 = hf$	a. model the atom and emission spectra of atoms b. appreciate how the analysis of emission spectra data has contributed to our understanding of objects in the universe
MP4. Radioactivity • Detection of ionising radiation • Isotopes and nuclear stability, mass defect and binding energy • Ionising radiation: alpha particles, beta particles and gamma rays • The safety implications of radioactive emissions	a. analyse evidence to support the existence of natural background radiation b. classify radioactive emissions in terms of their ○ relative ionising effects ○ relative penetrating powers ○ charge and mass ○ deflection in Electric and Magnetic fields

Students learn about	Students should be able to
	c. model spontaneous radioactive decay
• **The strong and weak nuclear forces as a fundamental force of nature** ○ $A = -\frac{dN}{dt}$ ○ $A = \lambda N$ ○ $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$	**d. examine the model of half -life in radioactive decay and use it to solve problems involving the activity or the amount of a radioactive sample**
MP5. Mass energy equivalence • splitting the nucleus • $E = mc^2$ • accelerating particles	a. analyse Cockcroft and Walton's experiment and appreciate its significance as the first nuclear transformation by artificially accelerated particles
• **the evolving model of matter** ○ **quarks and leptons** ○ **pair production and pair annihilation**	**b. describe matter in terms of fundamental particles and their anti-particles**
MP6. Harnessing energy from nuclear processes • $E = mc^2$ • **controlled/uncontrolled chain reactions** • **positron–electron annihilation**	**a. model nuclear fission, nuclear fusion and particle– antiparticle interactions** **b. evaluate evidence about issues related to nuclear fission and fusion in electrical generation using secondary sources**

Assessment

Assessment in senior cycle involves gathering, interpreting, using and reporting 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 student learning and provide information to teachers and students 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 and giving feedback that promotes learner autonomy, assessment will support learning and promote progression, support the development of student key competencies and summarise achievement.

Assessment for Certification

Assessment for certification is based on the rationale, aim, and learning outcomes of this specification. There are two assessment components: a written examination and an additional assessment component comprising a Physics in Practice Investigation. The written examination will be at higher and ordinary level. The Physics 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 Physics will be assessed at two levels, Higher and Ordinary (Table 1 page 12). Examination questions will require students to demonstrate learning appropriate to each level. Differentiation at the point of assessment will also be achieved, the stimulus material used, and the extent of the structured support provided for students at different levels.

Assessment Component	Weighting	Level
Physics In Practice Investigation	40%	Higher and Ordinary
Written examination	60%	Higher and Ordinary

Table 2: Overview of assessment

Additional assessment component: Physics in Practice Investigation

The additional assessment component for LC Physics, a *Physics in Practice Investigation (PiPI*) provides an opportunity for students to display evidence of their learning throughout the course, in particular, the learning set out as outcomes in the unifying strand. The senior cycle key competencies of thinking and solving problems, being creative, communication, working with others, and managing learning and self, developed through all the learning in this course, will be applied through the student's engagement in the investigation. It 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. It has been designed to exploit its potential to be motivating and relevant for students, to draw together the learning outcomes and cross-cutting themes of the course and to spotlight potential career paths by highlighting the relevance of learning in Physics to their lives. It is envisaged that the additional assessment component will take up to 20 hours of class time to complete and schools will have a level of autonomy over how these hours are allocated.

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 physics
- 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 early in sixth year, the purpose of which is to set out the requirements of the Physics in Practice Investigation (PhysiPI). Although the thematic brief narrows the focus from the thematic overview, students still have agency to choose a PhysiPI topic that will be relevant, motivating and engaging for them.

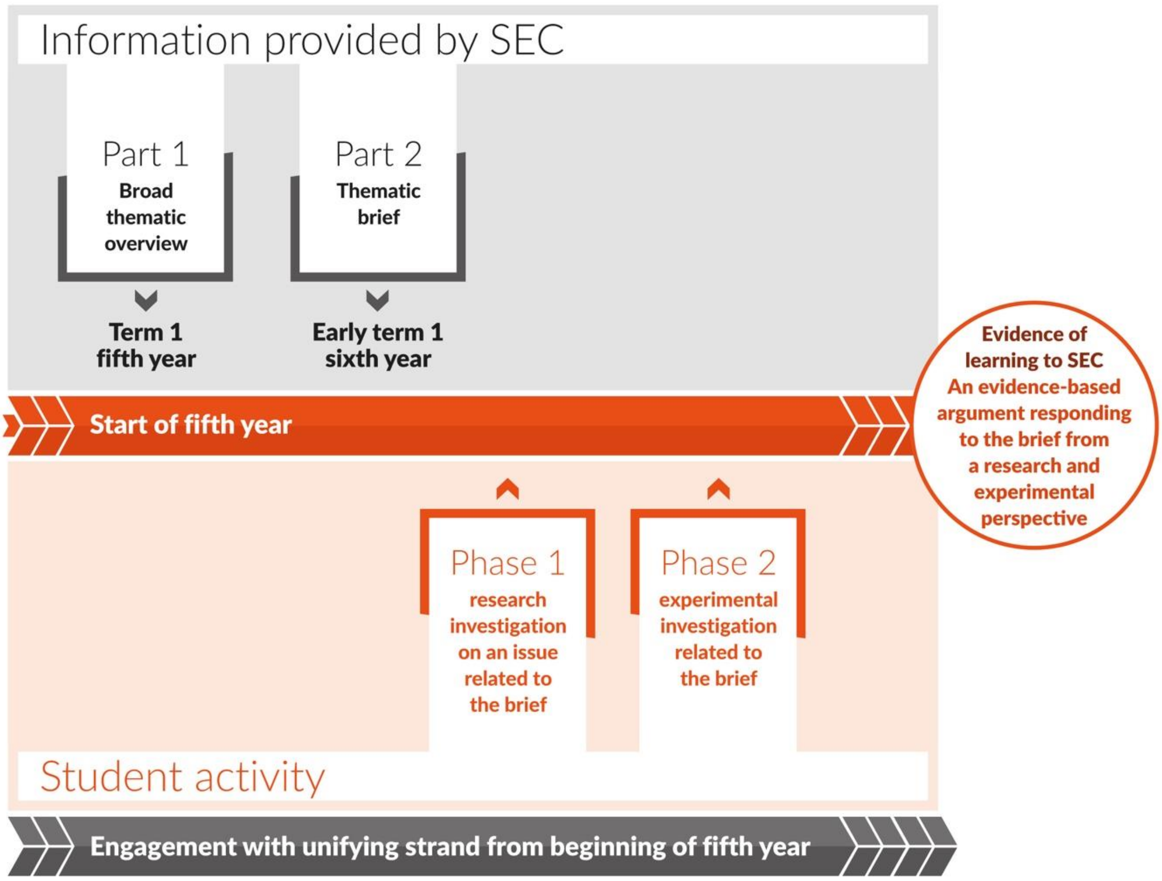

Figure 4: Timeline of activity for Physics in Practice Investigation

Descriptors of quality for the Physics in Practice Investigation

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

- consider issues related to real-world applications of physics
- demonstrate investigative skills
- relate their investigative work to the work of scientists in society
- communicate their findings appropriately and effectively.

	Students demonstrating a high level of achievement	Students demonstrating a moderate level of achievement	Students demonstrating a low level of achievement
Knowledge understanding	engage thoroughly with the concepts being investigated; describe clearly the purpose of the investigation; describes accurately, using appropriate means, the physical phenomena involved.	engage-with the concepts being investigated; describe the purpose of the investigation and the physical phenomena involved.	have limited engagement with the concepts being investigated and make little attempt to outline the physical phenomena involved.
Investigating	use a large number of varied, balanced and referenced sources; where appropriate pose a testable hypothesis that is underpinned by physics theory; use a clear investigative design and thorough appropriate methods to collect high quality primary data and evaluate the reliability of any secondary sources used; draw valid conclusions justified by	use a number of balanced mostly referenced sources; where appropriate pose a testable hypothesis that is underpinned by physics theory; use an investigative design and appropriate methods to collect good quality primary data and considers the reliability of any secondary sources used; draw conclusions that relate to any hypotheses made and identify potential sources of error in the investigative design; reflect on what worked and did not work.	use some referenced sources; where applicable pose a testable hypothesis supported by the teacher; use investigate design and methods to collect primary data that are unclear and make little effort to consider the reliability of any secondary sources used; draw limited conclusions and fail to identify potential sources of error in the investigative design; give an incoherent, illogical, or idealised reflection.
Communicating	design an investigation that leads to high quality data presentation and analysis; include, at their own initiative, new directions or approaches to experimentation and research as the work progresses.	design an investigation that leads to good quality data presentation and analysis; consider minor extensions or alterations to the plan.	design an investigation that leads to limited data presentation and analysis; show no evidence of on- going reflection.
Relating to society	offer a considered reflection locating the outcomes of the investigation within	reflect on how the outcomes of the investigation relate to real world issues.	makes limited links between the outcomes of the investigation and real-world issues.

	broader issues relating to the real world.		

Table 3: Descriptors of Quality: Physics 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 physics to issues relating to the cross-cutting themes—sustainability, health, and technology.

Reasonable accommodations

This Leaving Certificate Physics 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, 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 Physics 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

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
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
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
Derive	arrive at a statement or formula through a process of logical deduction; manipulate a mathematical relationship to give a new equation or relationship
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
Determine	obtain the only possible answer by calculation, substituting measured or known values of other quantities into a standard formula

Action verb	Students should be able to
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
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 limitations of evidence in conclusions; make judgments about the ideas, solutions or methods
Explain	give a detailed account including reasons or causes
Examine	consider an argument or concept in a way that uncovers the assumptions and relationships of the issue
Explore	Observe or study in order to establish facts
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
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

Action verb	Students should be able to
Measure	quantify changes in systems by reading a measuring tool
Model	Use words, diagrams, numbers, graphs and equations to describe phenomena make justified predictions and solve problems
Outline	give the main points; restrict to essentials
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
Recognise	identify facts, characteristics or concepts that are critical (relevant/appropriate) to the understanding of a situation, event, process or phenomenon
Recall	remember or recognize from prior learning experiences
Relate	associate, giving reasons
Use	apply knowledge or rules to put theory into practice
Verify	give evidence to support the truth of a statement