Diploma Programme

Physics teacher support material

First assessment 2025

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The International Baccalaureate aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end the organization works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.

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The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

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We nurture our curiosity, developing skills for inquiry and research. We know how to learn independently and with others. We learn with enthusiasm and sustain our love of learning throughout life.

KNOWLEDGEABLE
We develop and use conceptual understanding, exploring knowledge across a range of disciplines. We engage with issues and ideas that have local and global significance.

THINKERS
We use critical and creative thinking skills to analyse and take responsible action on complex problems. We exercise initiative in making reasoned, ethical decisions.

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We express ourselves confidently and creatively in more than one language and in many ways. We collaborate effectively, listening carefully to the perspectives of other individuals and groups.

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We act with integrity and honesty, with a strong sense of fairness and justice, and with respect for the dignity and rights of people everywhere. We take responsibility for our actions and their consequences.

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We critically appreciate our own cultures and personal histories, as well as the values and traditions of others. We seek and evaluate a range of points of view, and we are willing to grow from the experience.

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We show empathy, compassion and respect. We have a commitment to service, and we act to make a positive difference in the lives of others and in the world around us.

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We approach uncertainty with forethought and determination; we work independently and cooperatively to explore new ideas and innovative strategies. We are resourceful and resilient in the face of challenges and change.

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We understand the importance of balancing different aspects of our lives—intellectual, physical, and emotional—to achieve well-being for ourselves and others. We recognize our interdependence with other people and with the world in which we live.

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We thoughtfully consider the world and our own ideas and experience. We work to understand our strengths and weaknesses in order to support our learning and personal development.

The IB learner profile represents 10 attributes valued by IB World Schools. We believe these attributes, and others like them, can help individuals and groups become responsible members of local, national and global communities.

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The purpose of this teacher support material

Welcome to the Diploma Programme (DP) physics teacher support material (TSM). This material is designed to assist both new and experienced teachers to build or revise their course design. It is intended to add insight, inspiration and guidance to the teacher and student journey by:

- supporting experienced and inexperienced teachers alike in structuring and delivering a course
- supporting teachers with the organization of experimental work
- complementing IB professional development.

The TSM is structured to cover generic issues such as the approaches to learning and approaches to teaching and how these relate to physics, as well as subject-specific considerations such as nature of science (NOS) and skills in the study of physics.

A downloadable change document, *DP physics syllabus changes* (PDF), comparing the 2016 syllabus to this new version at the subtopic level is also available.

Acknowledgements

The International Baccalaureate (IB) would like to thank the educators who contributed time and resources to the development of the DP *Physics guide* and TSM.

Course overview

The DP physics course has been designed to be flexible and can be adapted to suit many contexts and learning environments. This section will help teachers become familiar with the structure of the course and the concepts that are at the heart of the syllabus. There are also examples of how guiding questions and linking questions, which are fundamental to the syllabus, may be used to support learning and teaching.

The structure of the physics syllabus is intended to promote concept-based learning and teaching that can be connected through three broad discipline-specific concepts: **energy**, **particles** and **forces**.

These three, broad, physics-based concepts appear throughout the programme and are organized into five themes: **space, time and motion**; **the particulate nature of matter**; **wave behaviour**; **fields**; and **nuclear and quantum physics**. The students' skill development should be integrated into the teaching of the content. The course structure reflects the fact that skills are best developed through a conceptual approach to teaching and learning.

Physics syllabus content overview

A. Space, time and motion	B. The particulate nature of matter	C. Wave behaviour	D. Fields	E. Nuclear and quantum physics
A.1 Kinematics • A.2 Forces and momentum • A.3 Work, energy and power • A.4 Rigid body mechanics ••• A.5 Galilean and special relativity •••	B.1 Thermal energy transfers • B.2 Greenhouse effect • B.3 Gas laws • B.4 Thermodynamics ••• B.5 Current and circuits •	C.1 Simple harmonic motion •• C.2 Wave model • C.3 Wave phenomena •• C.4 Standing waves and resonance • C.5 Doppler effect ••	D.1 Gravitational fields •• D.2 Electric and magnetic fields •• D.3 Motion in electromagnetic fields • D.4 Induction •••	E.1 Structure of the atom •• E.2 Quantum physics ••• E.3 Radioactive decay •• E.4 Fission • E.5 Fusion and stars •

• Topics with content that should be taught to all students

•• Topics with content that should be taught to all students plus additional higher level (HL) content

••• Topics with content that should only be taught to HL students

Conceptual approach

This table illustrates how the concepts are developed through each of the five themes.

How concepts are developed through themes in DP physics

Theme	Concept of energy	Concept of particles	Concept of force
A. Space, time and motion	A.2 Forces and momentum A.3 Work, energy and power A.4 Rigid body mechanics	A.1 Kinematics A.5 Galilean and special relativity	A.2 Forces and momentum A.3 Work, energy and power A.4 Rigid body mechanics
B. The particulate nature of matter	B.1 Thermal energy transfers	B.1 Thermal energy transfers	B.1 Thermal energy transfers

Theme	Concept of energy	Concept of particles	Concept of force
	B.2 Greenhouse effect B.3 Gas laws B.4 Thermodynamics B.5 Current and circuits	B.2 Greenhouse effect B.3 Gas laws B.5 Current and circuits	B.3 Gas laws B.4 Thermodynamics B.5 Current and circuits
C. Wave behaviour	C.1 Simple harmonic motion C.2 Wave model C.4 Standing waves and resonance	C.1 Simple harmonic motion C.2 Wave model C.4 Standing waves and resonance	C.1 Simple harmonic motion C.4 Standing waves and resonance
D. Fields	D.1 Gravitational fields D.2 Electric and magnetic fields D.4 Induction	D.3 Motion in electromagnetic fields	D.1 Gravitational fields D.2 Electric and magnetic fields D.3 Motion in electromagnetic fields
E. Nuclear and quantum physics	E.1 Structure of the atom E.2 Quantum physics E.3 Radioactive decay E.4 Fission E.5 Fusion and stars	E.1 Structure of the atom E.2 Quantum physics	E.3 Radioactive decay

The concept of energy

This concept appears in all five themes and the universality of the conservation of energy features throughout the course.

A. Space, time and motion

This theme introduces the idea of doing work as a means of transferring energy.

Topic A.2 defines whether or not kinetic energy is conserved through elastic and inelastic collisions. Conversion of energy naturally follows as the kinetic energy lost in inelastic collisions is converted into other forms including sound and thermal energy. This can lead to interesting discussions around the idea that energy exists in many forms but is completely different in appearance.

Topic A.3 defines "work" and then uses the work–energy principle to develop the concepts of how energy may be increased or decreased by doing positive or negative work. With these tools and definitions of potential and kinetic energy, it is possible to solve some kinematic problems, where energy is converted but conserved.

Topic A.4 develops the formula for rotational kinetic energy of extended objects, building on prior learning of uniform accelerated motion.

B. The particulate nature of matter

This theme develops models of particle behaviour on a microscopic level using velocity, mass, kinetic and potential energy and shows how these models explain macroscopic behaviours such as changes in pressure and temperature. The first law of thermodynamics is introduced as a formal statement of the conservation of energy.

Topic B.1 introduces internal energy at the outset with temperature defined as a measure of the mean particle kinetic energy. Specific heat capacity and specific latent heat are defined in terms of thermal energy transfers. The three key mechanisms of thermal energy flow—conduction, convection and radiation—are described.

Topic B.2 focuses on the greenhouse effect and is all about energy transfers.

Topic B.3 is about the ideal gas laws and develops the model that particles in an ideal gas experience no intermolecular forces and hence have no potential energy. This allows a good discussion on the use and development of models to evolve, including their utility. The topic also introduces the idea that internal energy of an ideal gas can be quantified according to the absolute temperature of the gas.

Topic B.4 introduces the conservation of energy formally in the form of the first law of thermodynamics and includes the second law as a caveat that determines the direction of energy flow. It also limits the conversion of thermal energy to kinetic energy and the efficiency of a heat engine is discussed along with the Carnot cycle as the most efficient cycle possible.

Topic B.5 defines potential difference as work done per unit charge, linking electrical energy to the theme studied.

C. Wave behaviour

This theme explores how progressive waves propagate energy from the source, and standing waves are closely associated with energy.

Topic C.1 discusses the energy changes within an oscillation, providing another context for the conservation of energy. The formulae for both the potential and kinetic energy of an oscillating mass are developed.

Topic C.2 outlines the concept of a progressive wave as a mechanism for transferring energy. Mechanical, sound and electromagnetic waves and their associated energy are compared.

Topic C.4 develops the concept of standing waves that are associated with energy. Although the energy is not propagated outwards per se, the standing waves do lead to progressive sound waves from string, woodwind and brass musical instruments etc. The resonance of vibrating objects under certain conditions maximizes the energy of the system.

D. Fields

This theme focuses on how stationary objects in a field have potential energy due to their position in the field. Moving objects have potential and kinetic energy, and the concept of conservation of energy is further explored. The concept of negative energy is also utilized to explain the potential energy between two (or more) objects bound together.

Topic D.1 defines gravitational potential energy and the work done in moving a mass through a potential gradient is determined. Orbital speeds and escape speeds allow kinetic energy to be calculated.

Topic D.2 defines electrical potential energy and the work done in moving a charge through a potential gradient is determined.

Topic D.4 develops the ideas that allow electricity generation to be understood and specifically that Lenz's law is a consequence of the conservation of energy.

E. Nuclear and quantum physics

This theme introduces the quantization of energy in both electron and nucleon energy levels. Conservation of energy continues as a key idea and the equivalence of mass and energy is introduced.

Topic E.1 introduces atomic structure and the idea that the energy of atomic electrons is quantized. If incoming photons have exactly the right frequency, and hence energy, electrons may move to higher levels. These are then unstable and fall back down, emitting a photon of the same frequency.

Topic E.2 introduces the photoelectric effect utilizing Einstein's equation, which is a statement of the conservation of energy.

Topic E.3 introduces nuclear binding energy, along with the concept of negative energy. The equivalence of a change in binding energy is linked to a change in mass. The nuclear binding energy per nucleon curve is a tool to help determine the likelihood of a particular nuclear reaction taking place.

Topic E.4 and **Topic E.5** develop the concepts of nuclear fission and fusion through the contexts of nuclear power generation and the energy sources of stars.

The concept of particles

This concept appears in all five themes and many theories and empirical discoveries in physics may be explained with models involving particles.

A. Space, time and motion

This theme explores how the behaviour of extended objects can be applied to the behaviour of particles. Observations of elementary particles have supported developments in the understanding of relativity.

Topic A.1 examines the motion of massless points, which are effectively particles.

Topic A.5 introduces the ideas of time dilation and length contraction and how they were confirmed through the observation of particles.

B. The particulate nature of matter

This theme focuses on the behaviour of particles in real-world applications such as thermal energy transfers, the greenhouse effect and the construction of electric circuits.

Topic B.1 develops models of the states of matter using particles and extends this to changes of state. The kinetic energy of particles is linked to absolute temperature, and models of conduction and convection are developed, which involve particle behaviour.

Topic B.2 introduces the greenhouse effect and a model is developed involving atmospheric gas molecules resonating as they absorb long wave infrared radiation from the Earth, some of which is then radiated back, causing additional heating.

Topic B.3 introduces the gas laws and builds on the concept of ideal gases, which are constructed from spherical particles that experience no interparticle forces.

Topic B.5 introduces electric current as a flow of charged particles, and resistance in metals as a physical opposition due partly to vibrations of much larger atomic particles in a lattice structure.

C. Wave behaviour

This theme considers the movement of particles undergoing simple harmonic motion and further develops the idea of the wave model for mechanical and sound waves.

Topic C.1 looks at the motion of particles (and extended objects) when subjected to a force that causes the particle to oscillate with simple harmonic motion.

Topic C.2 explores the wave model by building on the oscillation of particles introduced in topic C.1 as a model to explain the propagation of mechanical and sound waves through a medium.

Topic C.4 further explores the idea of the wave model by considering conditions required for the formation of standing waves in a system.

D. Fields

This theme focuses on how extended masses and charges are modelled to behave as point masses or charges when applying Newton's or Coulomb's laws. The effect of magnetic fields on point charges is also considered.

Topic D.3 builds on the idea of the effect of forces by considering how electric and magnetic fields may result in changes in the motion of particles.

E. Nuclear and quantum physics

This theme considers the existence of particles, starting with atoms and then, through scientific evidence, the existence of electrons, protons and neutrons.

Topic E.1 starts with the Geiger–Marsden–Rutherford experiment, which determines the structure of the nuclear atom and the arrangement of electrons well beyond the nucleus. The atom is largely empty space. The Bohr model places the electrons in quantized energy levels as evidenced by atomic spectra.

Topic E.2 develops wave–particle duality through the photoelectric effect. The de Broglie formula links wave-like and particle-like properties and Compton scattering is considered as additional evidence of the particle behaviour of light.

The concept of force

This concept appears in all five themes. Forces are key to understanding and explaining how particles and extended objects, that is, real observable things, affect each other, accelerate and gain or lose energy.

A. Space, time and motion

This theme introduces the various types and effects of forces on objects.

Topic A.2 develops the understanding of contact and non-contact forces through the application of Newton's laws of motion. Translational equilibrium is introduced, and free-body diagrams are developed as a way of visually representing forces both on a point and on an extended object. A resultant force causes a change of momentum of an object, and centripetal forces are introduced to explain circular motion.

Topic A.3 defines the concept of work as a force translating an object through a given displacement, thus enabling energy to be converted from one form to another or transferred from one object to another.

Topic A.4 develops an understanding of rotational dynamics by building on Newton's laws of motion of linear motion.

B. The particulate nature of matter

This theme explores the effect of forces between objects and on objects, and further develops this to provide an understanding of electric circuits.

Topic B.1 describes how particles that experience intermolecular forces are said to have potential energy as well as any kinetic energy they may have.

Topic B.3 defines an ideal gas as being composed of particles that experience no intermolecular forces, which is a good approximation to real gases at low pressure or high temperatures.

Topic B.4 describes how gases apply forces on the external environment and hence do positive work on a system. Negative work or external forces are required to return the system to its initial state so the cycle can repeat.

Topic B.5 defines potential difference as the work done per unit charge, and hence charges experience accelerating forces that give rise to an electric current.

C. Wave behaviour

This theme explores how waves are generated by an oscillating source and studies how the wave model can be explained in terms of restoring forces.

Topic C.1 introduces simple harmonic motion using the idea that the motion is defined by the restoring force being proportional to the displacement from and directed towards a fixed point.

Topic C.4 considers the effects of driving forces on resonant systems and those systems affected by damping.

D. Fields

This theme explores how mathematical models of different kinds of fields are developed. Models of forces between particles involve action at a distance and the concept of a field is developed to explain such interactions.

Topic D.1 uses Newton's law of universal gravitation to determine the size of the gravitational force between two masses.

Topic D.2 uses Coulomb's law to determine the size of the electrostatic force between two charges. The idea of field lines is further explored in terms of electrical fields.

Topic D.3 compares the parabolic motion of a charge in a uniform electric field with the circular motion of the same charge placed in a uniform electric field.

E. Nuclear and quantum physics

This theme explores the stability (or instability) of the nucleus in terms of the forces between nucleons.

Topic E.3 introduces nuclear force as a very short-range attractive force between particles within the nucleus of an atom.

The teaching sequence

The topics can be taught in many different sequences. It is common for teachers to start with an introduction to experimental inquiry, developing a range of skill-based techniques and strategies. A consideration of uncertainties is developed throughout the course and is essential for students to be able to write sensible conclusions. Theme A with kinematics, then dynamics is a common starting point as once forces and energy are known and understood they can be applied across all the other themes. Particles are then introduced in theme B. Examples of different possible routes through the syllabus are given in the section "Planning the teaching of the course" in this TSM. Teachers are encouraged to plan their own route according to their circumstances and interests. Wherever possible, teachers are encouraged to use local and global examples to extend students' appreciation and application of the course concepts.

The document "Routes through the course" (PDF) gives a sample route through DP physics.

Skills in the study of physics

The syllabus aims to encourage a hands-on inquiry approach wherever possible. Guided discovery and learning through seeing and doing is essential. The "Skills in the study of physics" section in the DP *Physics guide* summarizes the tools and inquiry process students are expected to experience during the course. This includes important laboratory techniques, mathematical and digital skills. Teachers are free to include these skills wherever they choose during the teaching of the course. Some linking questions in the understandings are connected to the skills section, and these may prompt application of experimental work that is appropriate to the content. For example, in topic A.1 the linking question "How does graphical analysis allow for the determination of other physical quantities? (NOS)" could be answered by determining the acceleration due to gravity in a freefall experiment, or a pendulum lab. In topic C.1 the linking question "How does damping affect periodic motion?" could lead to an idea for the internal assessment.

The document "Physics skills: Alignment with previous syllabus content" (PDF) lists a comparison of skills between DP physics (first assessment 2016) and DP physics (first assessment 2025).

Nature of science (NOS)

It is expected that an awareness of the process of science percolates throughout the course. An introduction to NOS is given in the guide and is covered in more detail in the "Nature of science" section of this TSM. Teachers are encouraged to include relevant examples and anecdotes from past and current scientific developments. Some linking questions in the understandings address NOS, to help prompt thinking about the scientific method, for example in C.2 "Can the wave model inform the understanding of quantum mechanics? (NOS)".

Data booklet

The IB publishes a *Physics data booklet* that contains electrical symbols, mathematical equations, constants, and physics equations relevant to the course. Students must have access to a copy for the duration of the course so that they can become familiar with its contents. Direct reference is made to relevant equations in the understandings sections of the guide. This helps to maintain the emphasis on interpretation and application rather than memorization of symbols, constants and equations. A clean copy of the *Physics data booklet* must also be made available to students for all examination papers at both standard level (SL) and HL.

Syllabus structure and features

This section contains examples of guiding questions and linking questions from the *Physics guide* and suggests ways in which they can be incorporated into classroom discussion.

The structure and features of the syllabus are shown here. This diagram illustrates the format of the syllabus and explains the recurring headings from the *Physics guide*.

This is the overarching theme.

This is the name of the topic.

Guiding questions frame the topic—by studying the topic students will be able to answer the question(s) with increasing depth.

Understandings list specific areas to be taught.

Standard level and higher level: 3 hours

3 hours total teaching is recommended, whether for standard level (SL) or higher level (HL).

Additional higher level is content for that level only.

Guidance provides clarifications and limitations to the topic.

Linking questions link one topic to another in physics or, when indicated by "(NOS)", the nature of science. They signpost related content and problem-solving beyond immediate content. Teachers and students are encouraged to create their own linking questions.

C. Wave behaviour

C.1 Simple harmonic motion

Guiding questions

What makes the harmonic oscillator model applicable to a wide range of physical phenomena?

Understandings

Standard level and higher level: 3 hours

Students should understand:

- conditions that lead to simple harmonic motion

Additional higher level: 4 hours

Students should understand:

- that a particle undergoing simple harmonic motion can be described using phase angle

Guidance

The significance of the minus sign in the defining equation for simple harmonic motion should be understood.

Linking questions

How can greenhouse gases be modelled as simple harmonic oscillators?

What physical explanation leads to the enhanced greenhouse effect? (NOS)

Guiding questions

Each topic starts with guiding questions. Students may be able to answer the questions in different ways at different stages of their learning, with increasing depth and breadth as their understanding of the topic develops.

The guiding questions can be used to support learning and teaching as:

- **openers** for a topic
- suggestions for an **overview** of the content
- **tools** for the assessment of learning
- **stimuli** to generate further guiding questions.

Each of these approaches is explored below using different examples of guiding questions from the guide.

Guiding questions as openers for a topic

The guiding question may provide a prompt for discussions based on students' prior knowledge, either from earlier courses or from topics previously studied within the course. Probing this knowledge may help suggest ways to introduce the content.

Example: B.1 Thermal energy transfers

Guiding question: How do macroscopic observations provide a model of the microscopic properties of a substance?		
Prior knowledge	**Questions for opening discussions**	**Developing understandings**
Students should be aware of: • the difference between macroscopic and microscopic properties of a substance • macroscopic properties, e.g. pressure, temperature, amount of a substance • microscopic properties, e.g. random particle kinetic energy, particle velocity, particle mass • how the structure of the different states of matter can be explained with a particle model • the link between pressure and particle collisions with the container walls • the link between temperature and random particle speeds.	• How are macroscopic and microscopic properties of a substance defined? • How are melting, evaporating, boiling, condensing and freezing explained using a particle model? • Is there a quantitative relationship between pressure and microscopic properties? • Is there a quantitative relationship between temperature and microscopic properties? • How are models linking macroscopic and microscopic properties developed? • Can alternative models, not involving particles, be developed to explain macroscopic observations? • How did our current understanding of	• Explaining how the kinetic theory explains macroscopic understandings such as the states of matter and changes of state • Developing the kinetic theory, from first principles of kinematics and Newton's Laws of motion, to obtain the key equation that links macroscopic observations to particle properties: $PV = \frac{1}{3}Nm < c^2 >$ • Solving problems involving pressure and temperature linked to particle properties such as velocity and mass

Guiding question: How do macroscopic observations provide a model of the microscopic properties of a substance?		
	macroscopic observations develop historically?	
NOS • How can observations of one physical quantity allow for the determination of another? • What role does the molecular model play in understanding other areas of physics?		
Extending learning • Discovering modern applications of the gas laws • Research into how our current understanding of the behaviour of gases relies on statistical mechanics and investigating the basic principles • What techniques are used to reduce temperatures to very near absolute zero, e.g. to test modern-day space telescopes such as the James Webb telescope		

Example: E.5 Fusion and stars

Guiding question: Can observations of the present state of the universe predict the future outcome of the universe?		
Prior knowledge Students should be aware of: • the Big Bang and the subsequent expansion of the universe • how stars are formed from collapsing clouds • the fact that stars form in galaxies and that there are billions of galaxies in the visible universe • improved observation techniques using space telescopes such as Hubble and James Webb.	**Questions for opening discussions** • What properties of stars and galaxies can we observe and measure? • What are the challenges faced using Earth-based observational devices such as radio telescopes and optical telescopes and how are these overcome? • What can be deduced from observations of distant stars and galaxies? This could include spectra leading to composition and surface temperature, redshift leading to recessional velocity and hence distance.	**Developing understandings** • Interpreting the stellar spectrum and brightness to determine temperature, composition, stellar radius and distance, along with the Hertzsprung–Russell (HR) diagram • Understanding how the Big Bang led to the expansion of space in the universe and the four possible outcomes: closed, flat, expanding and accelerating
NOS • In which ways has technology helped to collect data from observations of distant stars?		
Extending learning • The meaning of critical density and the existence of dark matter and energy with supporting evidence • How observations of type Ia supernovae led to the deduction that the universe's expansion is accelerating • What we will learn from observations made by the James Webb space telescope		

Guiding questions as suggestions for an overview of the content

The guiding question is a consolidation of what has been learned. This may help teachers to outline the expectations and timelines for the understandings within the topic.

Example: D.1 Gravitational fields

Guiding question: How are the properties of a gravitational field quantified?
Progression of learning • Forces are predicted using Newton's universal law of gravitation. • The gravitational field is defined as the force per unit test mass. • Field lines are used to map a field. • Kepler's third law is used as an example of how observable data such as orbital period and orbital radius can lead to predictions of planetary or stellar mass. • Potential energy may be determined from the amount of work needed to set up a particular configuration of masses leading to the definition of potential as the potential energy per unit mass. • Students realize that gravitational field strength is proportional to the rate of change of potential with displacement.
Higher level only • In many topics, the higher level (HL) course involves additional higher level content that leads to more in-depth study. HL students should therefore be able to give a more extensive response to the guiding question by the end of the unit.
NOS • A field is a mathematical model, used to explain interactions between objects.

Guiding questions as tools for the assessment of learning

The question could be asked at various times within the study of the topic, looking for increasing breadth and depth of answer as the understandings are covered and developed.

Example: D.3 Motion in electromagnetic fields

Guiding question: What can be deduced about the nature of a charged particle from observations of it moving in electric and magnetic fields?
Possible coverage early in the unit • Explaining the motion of charged particles in uniform electric fields • Explaining the motion of charged particles in uniform magnetic fields • Calculations based on definition of fields, force, velocity, etc. utilizing physics from "A. Space, time and motion" and "D. Fields" to solve problems • Use of thermionic diodes to demonstrate the motion of electrons in both electric and magnetic fields
Possible coverage later in the unit • Explaining the motion of charges in non-uniform electric and magnetic fields • Considering the effect of a magnetic field on a moving charge when the field and velocity are not perpendicular • Determining from previous learning how a charged particle will move in a combined electric and magnetic field
Possible further coverage on completing the unit

Guiding question: What can be deduced about the nature of a charged particle from observations of it moving in electric and magnetic fields?
• Collecting suitable data from a thermionic diode or similar to determine the specific charge of an electron, $\frac{e}{m_e}$ • Mass spectrometer and the part played by the electric field as a velocity selector and the magnetic field as the mass selector
NOS • Field models are used to determine the subsequent motion of a charged particle within a field. Limitations of the model can be discussed.

Guiding questions as stimuli to generate further guiding questions

Additional guiding questions may emerge while a topic is being covered. These fresh guiding questions may be used to help learning and teaching in any of the ways described in this section.

Example: C.3 Wave phenomena

Guiding question: What happens when two waves meet at a point in space?
Possible further guiding questions • How can a wave be broken down into its constituent component waves? • Is a point in the vacuum of empty space actually empty or could it be the sum of two waves in antiphase? These could be considered in reverse so that the possible components of a resultant wave could be deduced.

Example: E.1 Structure of the atom

Guiding question: What is the current understanding of the nature of an atom?
Possible further guiding questions • What does the wave model contribute to the nature of an atom? This guiding question is generally considered via the particulate model of matter but could be considered through a wave perspective. A different guiding question could reinforce the wave model of matter.

Linking questions

Linking questions are found at the end of each topic. They are designed to promote networking across the syllabus and may suggest:

- links between different topics
- references to skills in the study of physics
- references to the overarching nature of science (NOS) theme.

In seeking to answer these questions, students are encouraged to make connections across the syllabus to illustrate the interconnectedness of concepts and the holistic nature of the subject.

Teachers are encouraged to pose their own linking questions.

Students are expected to demonstrate networked knowledge as modelled through linking questions within the external assessment.

The linking questions can be used to support learning and teaching:

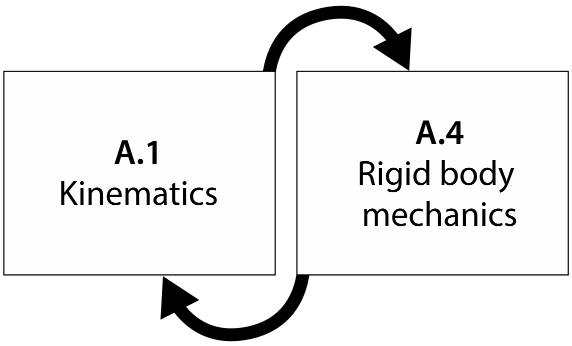
- as direct links between different topics
- to integrate learning with skills in the study of physics
- to integrate understanding of the NOS
- to apply physics in a real-world context.

Each of these approaches is explored in this section using different examples of linking questions from the *Physics guide*. Note that the "Possible answer" given to each question is not a model answer. It is just one example of how the linking question might be answered.

Linking questions as direct links between different topics

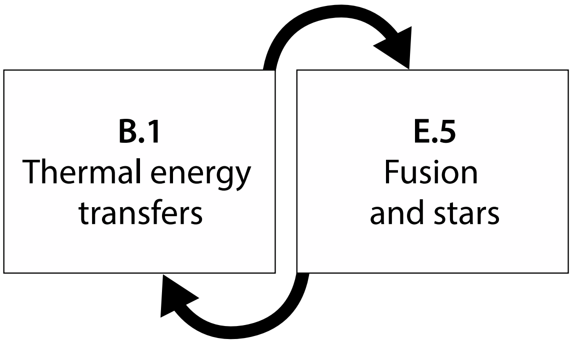
The linking questions can help to connect different areas of study where content overlaps. These questions can be asked in either direction, showing that the related content can be covered in either topic.

Example 1



Linking question: How are the equations for rotational motion related to those for linear motion?
Guidance on the link The equations of linear motion are often studied at the start of any physics course and are developed using graphs and definitions of key physical terms such as displacement, velocity and acceleration. When studying rotational motion in A.4 Rigid body mechanics, analogous equations can be constructed by translating terms from linear motion, such as displacement to the equivalent rotational term, angular displacement, etc.
Possible answer The equations for rotational motion are analogous to those for linear motion and may be formed by translating the linear term to the rotational term, e.g. velocity to angular velocity.
Real-world situations • Linear motion of cars on a straight line in a Formula 1™ Grand Prix™ • Circular motion of the same car as it rounds a bend of known radius • Using the equations of rotational motion to determine the velocity and acceleration after the car leaves the bend given the initial conditions

Example 2



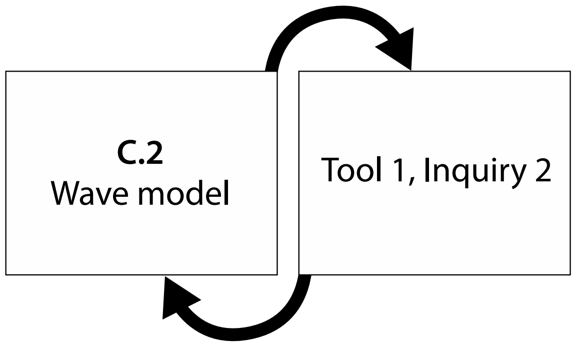
Linking question: What applications does the Stefan-Boltzmann law have in astrophysics and in the use of solar energy?
Guidance on the link The Stefan-Boltzmann law is used to determine the power output from a source of black-body radiation, i.e. the amount of radiation from a hot body. The same law is used in astrophysics to determine the power of a star, called the luminosity. Only the brightness or intensity of a star can be measured from Earth and how far away the star is must be known before the luminosity can be determined. This can lead on to techniques used to determine the distances to stars such as stellar parallax, spectroscopic parallax, i.e. using the HR diagram.
Possible answer The same law, the Stefan-Boltzmann law, is used to determine the power output of a hot object emitting black-body radiation and the luminosity or power output of a star undergoing nuclear fusion.
Real-world situations • This can be introduced through thermal energy transfer, conduction, convection and radiation, in a range of contexts and then compared with calculations for the luminosity of stars

Linking questions to integrate learning with skills in the study of physics

Some linking questions refer to the “Skills in the study of physics” section. These link to the tools or the inquiry process. This section is in the DP *Physics guide* and summarizes the laboratory and practical experiences students must gain during the course.

While teachers are free to include the skills within any topic, these linking questions aim to be a prompt or a suggestion for appropriate experimental work that can enhance learning in the topic.

Example 1



Linking question: What happens when waves overlap or coincide?

Guidance on the link

Tool 1 (Experimental techniques) includes measuring length to an appropriate level of precision as a specified applied technique. Inquiry 2 (Collecting and processing data) can be applied to interference experiments used to determine the wavelength of light.

This question could be solved by a range of interference investigations. A standard approach could be to investigate how fringe separation s depends on the distance of a double slit, slit separation d, to the screen D. The students collect a range of fringe separation values for different values of slit-screen distance.

Experimental techniques for fringe width are practised where the student should measure the distance across a number of fringes, say at least 11, then divide by the number of fringes, 10 in this case, to determine the fringe width with an uncertainty of at least ± 1 mm or less using a standard clear plastic 30 cm rule. The slit separation is usually recorded on the slits, but this could be measured with a travelling microscope to at least ± 0.01 mm. The distance to the screen could be measured with a tape measure to ± 1 cm, depending on the precision of the tape. This experiment introduces the student to techniques to accurately measure different lengths with different tools.

The gradient of the graph of s against D is wavelength $\frac{\lambda}{d}$.

Possible answer

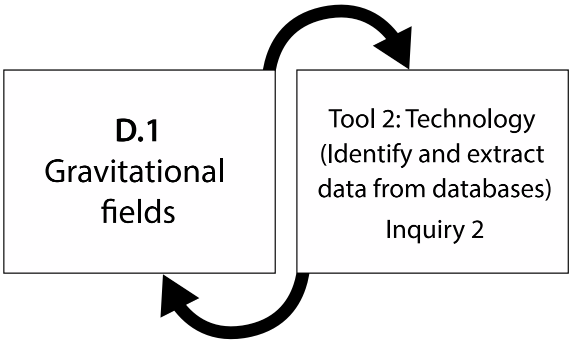
A series of bright and dark fringes are observed indicating constructive and destructive interference.

Real-world situations

The interference of light by reflection or transmission may be taught in many contexts.

- Anti-reflection films on glasses, cameras, etc.
- Holography
- CDs
- Noise cancelling headphones
- X-ray crystallography
- Geophysical surveys on land or sea

Example 2

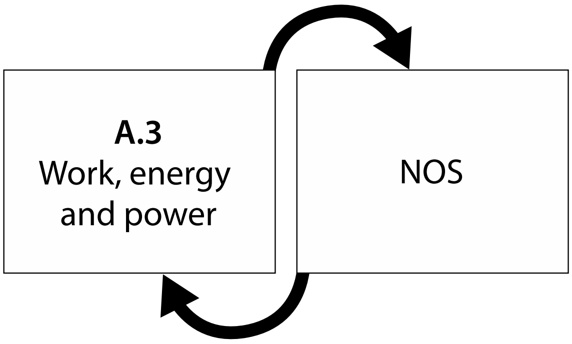


Linking question: What measurements of a binary star system need to be made in order to determine the nature of the two stars?
Guidance on the link Once Kepler's third law has been covered, it can also be applied to binary star systems in the form $(M_1 + M_2)P^2 = a^3$ where M_1 and M_2 are the masses of the two stars in solar masses, P is the period of the system in Earth years and a is the distance between the stars in AU. Other equations such as $M_1r_1 = M_2r_2$ where r_1 and r_2 are the distance of each star from the centre of mass of the system can be explored. As $a = r_1 + r_2$ then students can derive equations such as $r_1 = \frac{r_2M_2}{(M_1 + M_2)}$, etc. Students can then use data that astrophysicists can measure such as period and distance apart to determine the star masses. Students can find such data online if they look carefully.
Possible answer Period of orbit and distance between the two stars gives the masses. Measurements of black-body radiation, distance from Earth to the binary system and brightness will give information on chemical composition, surface temperature and stellar radius.
Real-world situations • Students could imagine they are astrophysicists who can only have access to data that they can directly measure. This data is available online and using this they can determine a range of properties such as those mentioned above

Linking questions to integrate the NOS

Some linking questions make reference to the overarching NOS theme, which is described in more detail in the DP *Physics guide*. These are designed to stimulate links to aspects of NOS in other parts of the course.

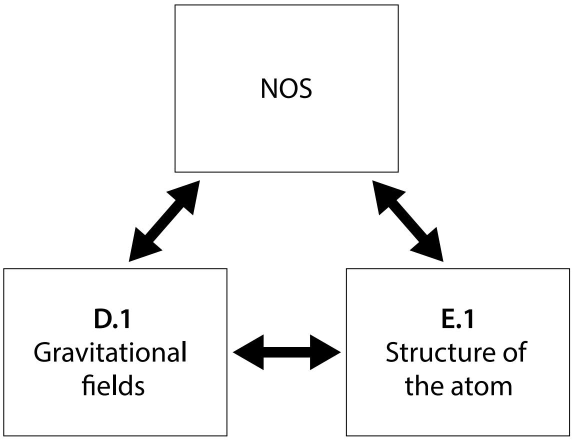
Example 1



Linking question: Where do the laws of conservation apply in other areas of physics?
Guidance on the link Conservation laws are applied in many areas of physics and the concept of conservation in a physics context is key to the understanding of the way matter behaves. These rules are fundamental to the understanding of the universe and are used to solve a variety of different problems. The conservation of energy is introduced in A.3 but the principle of conservation appears in many different areas of the course. A.2: conservation of linear momentum and kinetic energy in elastic collisions. A.4: conservation of angular momentum. B.1: in the context of thermal energy transfers, internal energy of a substance remains constant unless thermal energy is added or removed from the substance. This includes temperature rises/falls and changes of state. B.2: the energy budget of the Earth, power absorbed by the Earth equals the power emitted by the Earth, but anthropogenic greenhouse gases disturb this equilibrium. B.4: the first law of thermodynamics is a formal statement of the principle of the conservation of energy. C.1: simple harmonic motion is viewed as an example of conservation of energy between stored potential energy and kinetic energy in constant repeated cycles. D.1: the sum of potential and kinetic energy is conserved in orbits. D.2: total charge is conserved in any isolated system. If negative charges (e.g. electrons) are removed from a system, that system gains an equal amount of positive charge. D.3: the kinetic energy of a charge is constant in a magnetic field. D.4: Lenz's law is a consequence of the conservation of energy. The magnetic field induced must oppose the change in the field causing it so that positive work is done, which is converted into induced electrical energy. E.1: energy is conserved in electronic transitions (e.g. the photon energy is converted into raised electronic energy). E.1: one estimate of nuclear size is by considering the conversion of energy of an alpha particle from kinetic into potential energy. Total energy of the alpha particle is conserved. E.2: Einstein's photoelectric equation is an example of the conservation of energy. E.3, E.4 and E.5: in all nuclear reactions, energy is conserved. A change in energy may be seen as a change in mass through $\Delta E = c^2 \Delta m$ introducing the new concept that mass is a form of energy. Through fission and fusion, this energy may be harnessed as thermal energy from the kinetic energy of nuclear particles.
Possible answer

Linking question: Where do the laws of conservation apply in other areas of physics?
There are many areas of physics where conservation laws apply including mass, charge, energy and momentum. Energy appears in many forms including potential and kinetic on a microscopic scale and thermal, sound, light, electrical and nuclear in the macroscopic world.
Real-world situations • Thermal power stations • Nuclear power stations and nuclear fission • Nuclear fusion in stars and research at Joint European Torus (JET) and ITER • Alternative energy and creative energy sources such as pumped storage at a hydroelectric power plant, which use techniques of raising huge weights at times of low demand then dropping them to generate electricity at high demand

Example 2



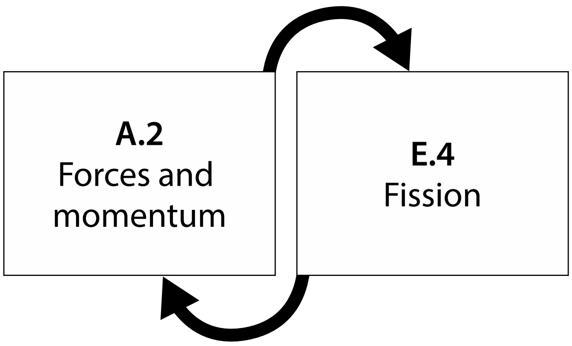
Linking question: How can the motion of electrons in the atom be modelled on planetary motion and in what ways does this model fail?
Guidance on the link This link to NOS considers possible analogous models between planetary motion, which is well understood being observable and hence relatively straightforward to visualize, and the motion of electrons round a nucleus in an atom. It is logical to compare Coulomb's law with Newton's law and assume that the atomic electrons form a planetary type system, and this works quite well for the hydrogen atom with just one electron orbiting a solitary proton. However, the model fails quite drastically when spectral and other evidence is considered, which suggests that energy levels are quantized, as developed by the Bohr model, which has no analogy in gravitational systems. The model fails further, if that is possible, when electrons are considered to be waves, the amplitude of the wave function representing the probability of finding an electron at a particular position. This NOS link to D.1 Gravitational fields and E.1 Structure of the atom is an excellent example of the caution needed when trying to use a model developed in one area of physics and applying it to another.
Possible answer The motion of electrons in the atom can be modelled on a planetary system to a very limited extent using Coulomb's law and works reasonably well for hydrogen. The Bohr model requires quantized electron energy levels, for which there is no gravitational analogy and the Schrödinger model is based on wave mechanics and hence completely different.

Linking question: How can the motion of electrons in the atom be modelled on planetary motion and in what ways does this model fail?
Real-world situations • Comparison of the solar system and the hydrogen atom • Evidence for the Bohr model and its successes • Successes of the Schrödinger model • Many linking questions, while focusing on linking different topics, also provide opportunities to consider aspects of NOS. The scenario above demonstrates this by probing the assumptions and limitations of models

Linking questions to apply physics to a real-world context

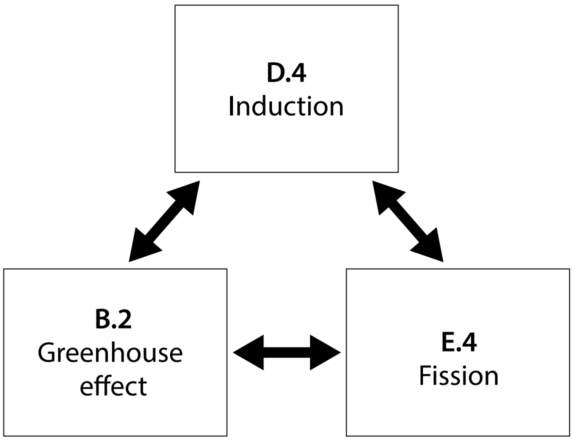
Some linking questions make an explicit connection to applications of physics in our world, and include an environmental, ethical, social or economic focus. These questions are designed to prompt similar questions promoting links to relevant topical issues throughout the course.

Example 1



Linking question: In which way is conservation of momentum relevant to the workings of a nuclear power station?
Guidance on the link Nuclear fuel rods used to generate electricity contain about 95% uranium-238 and 5% uranium-235. It is the uranium-235, however, that undergoes fission, generating huge amounts of thermal energy. The neutrons released in a uranium-235 are known as fast neutrons and they have very large amounts of kinetic energy, up to 1 MeV and this is more likely to be captured by a uranium-238 nucleus than by a uranium-235 nucleus. To increase the likelihood of a future fission, the neutrons are slowed down to thermal energies typically between 1 to 1,000 eV. The neutrons are slowed down by inelastic collisions with atomic particles in the moderator, which is often composed of water or graphite.
Possible answer Momentum is conserved in all atomic level collisions. In a moderator, neutrons collide inelastically with the moderator atoms, therefore losing kinetic energy to the surroundings, momentum being conserved in the process.
Real-world situations • Studying the generation of electricity by a nuclear power station

Example 2



Linking question: How do different methods of electricity production affect the energy balance of the atmosphere?

Guidance on the link

Environmental considerations have moved up the agenda in recent years. The COP26 climate conference held in 2021 highlighted the potential environmental catastrophe, due to climate change, if the Earth's average temperature exceeds 1.5 K above pre-industrial times. The consensus was to cut drastically electricity generation using coal, which has been the mainstay of the developed world for over a century, as burning coal leads to the largest production of carbon dioxide compared to all other fossil fuels. There was a broad agreement to achieve carbon neutrality (i.e. adding no net carbon dioxide to the atmosphere) by 2050 although some developing countries may take longer.

Burning fossil fuels to produce electricity adds carbon dioxide to the atmosphere. Being a greenhouse gas, carbon dioxide molecules absorb long wave infrared, emitted by the Earth behaving as a black body, then re-emit the thermal radiation in all directions, i.e. 50% is radiated back to the Earth and is effectively trapped, thus heating the Earth up beyond its previous equilibrium temperature. The balance between incident power from the sun and emitted power from the Earth is therefore disturbed.

Several renewable sources of energy are now in mainstream use such as onshore and offshore wind, wave power, hydroelectric, solar and tidal energy. These are clean sources and do not affect the energy balance of the atmosphere at all. As technology and hence efficiencies improve, fossil fuel generation is likely to be phased out in favour of renewable sources. Nuclear power also has no impact on the atmosphere and can provide a reliable source of electricity when other renewable sources, which are weather dependent, are not so reliable. Energy storage in batteries, pumped storage and using gravity to generate electricity or using falling weights are all being developed to provide reliable energy security.

Possible answer

Burning fossil fuels to produce electricity produces carbon dioxide, a greenhouse gas, which leads to additional global warming by disrupting the energy balance in the atmosphere. Renewable and nuclear sources do not affect the atmosphere in this way.

Real-world situations

- Electricity generation
- Phasing out coal, but relying on gas in the medium term
- Increase in onshore and offshore wind as well as tidal schemes
- Building new nuclear reactors with a focus on "micro" generators

Linking question: How do different methods of electricity production affect the energy balance of the atmosphere?
• Development of nuclear fusion

Nature of science (NOS)

The rationale for NOS

Students develop a thorough and lasting understanding of the natural sciences, which has value on several levels.

1. It develops scientific literacy—being able to engage with local and global scientific issues is central to many of the qualities in the IB learner profile.
2. It provides a framework in which students can more easily access science subjects, as in the following examples.
    - Knowing that established laws often have limitations may allow for more flexible thinking, e.g. applying Newton's second law where velocity approaches the speed of light.
    - Appreciating that technological developments can open up new possibilities for computational modelling allows for the understanding of complex systems.
3. It supports student learning in theory of knowledge (TOK)—NOS understandings are the starting point for being able to think critically about the natural sciences and knowledge more broadly.

Engaging with NOS

Teachers are not expected to address NOS as a stand-alone topic, but instead to integrate it within the teaching of the subject. As always, it is best to vary the style of teaching rather than resort to a formulaic strategy for NOS. Several approaches are outlined here.

- It is often helpful when introducing new scientific concepts to frame them in terms of the progression of science and the use of scientific methodologies. This might mean briefly revisiting a preceding model or theory, or reviewing the evidence or technology that led to new understandings.
    - The Bohr model of the atom was formed due to new evidence (from atomic emission spectra) that could not be explained by Rutherford's model.
- The experimental programme allows for the exploration of many aspects of NOS. Additional activities can help to strengthen students' understandings.
    - Students could be presented with an experimental procedure that has clear methodological problems (e.g. it does not indicate when to stop a stopwatch during a rates-of-reaction experiment). They are asked to critique it to ensure valid data is produced. The critique can be done before, during or after the practical work.
    - Students could be provided with a data set that may or may not be as expected. Students carry out the experiment and share data to compare with the teacher's data set. This can highlight the importance of reproducibility and reliability.
    - Students could be asked to find data in the literature for further comparison.
    - The activities above could be connected so that features of the peer-review process are discussed.
- NOS might be used to set the scene and form the introduction to a topic. A teacher may choose to begin a lesson by presenting a current news article, past event or topic of debate. Alternatively, a retrospective approach could be taken, with the final minutes of a lesson or a homework task being used to look at the NOS aspects exemplified by the topic.
- A short "circus activity" (e.g. after reviewing a topic or subtopic) can be used to discuss the impact of science on society. Students rotate around five stations and are given two minutes to brainstorm

possible impacts on the environmental, political, social, cultural and economic domains. A short discussion could follow to identify which area of society might be most impacted.

Real-life example	What issue is highlighted in the example?	Which aspect of NOS does the example demonstrate?
An article comparing predictions of the spread of COVID-19 based on mathematical modelling to data on virus transmission	Differences between predicted and actual transmission data suggest there are limitations to mathematical modelling in science.	Scientific models always have strengths and limitations.
Retraction by Professor Frances Arnold, a Nobel laureate in Chemistry, of a research paper she and co-researchers wrote in 2019	She explained that the results in the paper were not found to be reproducible in other studies.	Data must be reproducible before it can be considered scientifically reliable.
Nuclear power as a carbon-neutral but controversial energy source	Environmental and economic advantages to using nuclear energy must be weighed against ethical issues and environmental problems.	Ethical, environmental, political, social, cultural and economic consequences must be considered during (governmental) decision-making.

Examples of integrating NOS

The format that follows might be used to integrate relevant NOS aspects and other concepts that are related to experimental work, for example **hypothesis**, **reproducibility**, **reliability**, **validity**, **prediction** and **uncertainty**.

Outline	Example content (focusing on reproducibility and reliability)
Introducing NOS aspects —10 minutes	Show students an article about or tweet from Professor Frances Arnold, a Nobel laureate in Chemistry, relating to her announcement in early 2020. She retracted her 2019 paper on enzymatic synthesis of beta-lactams because the results were not reproducible. Now discuss the following questions. • What is meant by “reproducible”? • Why is reproducibility important? • How might reproducibility affect reliability? • How might the scientific community have responded?
Group experimental work —40 minutes	Any data collection can be used here to fit a topic. Ideally, small groups each collect one set of data for a range of independent variable values. For example: • number of layers of insulation vs rate of cooling of a test tube filled with hot water.
Review of NOS concepts —10 minutes	A class discussion around NOS concepts could include the following questions. • How do individual data points from different groups compare? They would be expected to be similar but not necessarily identical. Standard deviation could be used to quantify this. • How are anomalies identified? Some educated judgement would be required to find them. If anomalies are not obvious, further repeats or checks of other secondary data may be used. • How do different groups’ trendlines compare? If data are reproducible, general trends will be the same.

Outline	Example content (focusing on reproducibility and reliability)
	• Would students consider the collected data to be reproducible? • How might the above points link to the reliability of the data?

NOS and the external assessment

There will be some assessment of NOS, reflecting its role as an overarching theme of the DP sciences course. The assessment questions will test general understanding of NOS, not memorization of detailed facts relating to individual NOS statements. For this reason, there is merit in teachers using contexts other than those specified in the syllabus to help to develop students' NOS understanding.

Thorough understanding of NOS will help students to perform well in data analysis questions. Skills in understanding, interpreting and analysing data presented in a variety of forms is another transferable outcome from an effectively taught course.

Students could be given a copy of the NOS table in the subject guide, either at the start of the two-year course or at the start of the revision period as the end of the course approaches. The table includes all NOS aspects and their descriptions. If a copy is provided, teachers should emphasize that this is not something to be memorized, but instead should be used for reference and for helping to develop understanding.

NOS and TOK

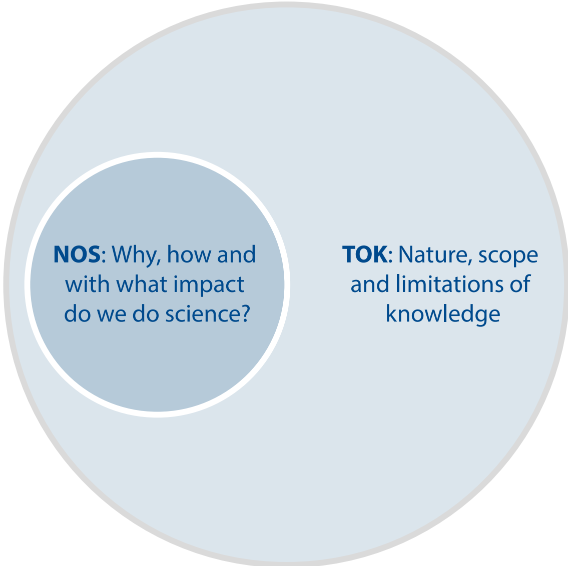
In TOK, students are encouraged to consider how knowledge claims are generated, evaluated, used and justified. This should promote an understanding of the differences between the natural sciences and disciplines such as mathematics, economics and languages.

The NOS component of the course has been designed to give students an excellent understanding of a natural science as an academic discipline. It should be a source of pride to teachers that their students can speak confidently and reflectively about natural sciences in TOK lessons. This will happen if the NOS component is integrated effectively into the teaching of the course.

Ideas relating to TOK can be addressed throughout the course. When and how frequently this is done is left up to teachers, and no specific TOK items have been included in the syllabus. There is no specific assessment of TOK in DP science examinations, although understanding of the aspects of NOS is assessed.

A Venn diagram can be used to illustrate the relationship between NOS and TOK.

The relationship between NOS and TOK



NOS focuses on understanding science through concepts such as **evidence**, **patterns and trends**, **falsification**, **theories** and **global impact of science**. These are central to scientific literacy and are considered only in the context of science.

In TOK, students are expected to think critically about their NOS understandings by exploring broad, underlying and often overlapping concepts such as **evidence**, **certainty**, **justification**, **objectivity** and **responsibility**. Considering the tensions, limitations and challenges related to these concepts in contrast with other areas of knowledge production should lead to student understandings that are nuanced and contestable. Some examples of the types of questions teachers might ask in TOK—"knowledge questions"—and possible responses to these, are provided in the following table.

Knowledge question*	Possible ideas to explore
What kinds of explanations do natural scientists offer?	• The role of scientific theories • The need for and limitations of using imagination in explanations • The extent to which we can claim certainty in a theory
How do we ensure the validity of evidence in the natural sciences?	• Problems with using inductive reasoning • The role of reproducibility • The limitations of peer review
How should we decide on appropriate ethical constraints on scientific research?	• The role of the scientific community in society • Possible tensions, e.g. for-profit companies funding healthcare research • Difficulties defining moral values

* Although these questions are focused on the natural sciences, they could equally be applied to and explored in other disciplines, such as history or the arts.

Building from NOS to TOK

NOS aspects can be extended to ask broad TOK questions (knowledge questions) that might lead to a range of possible perspectives and arguments. The *Theory of knowledge guide* highlights concepts that could be used in this exploration: **evidence**, **certainty**, **truth**, **interpretation**, **power**, **justification**, **explanation**, **objectivity**, **perspective**, **culture**, **values** and **responsibility**.

Asking a broad question containing a TOK concept*	Example perspectives in response to the knowledge question	How might we consider the question in other areas of knowledge beyond the subject?
How accurate must predictions be to justify a claim?	Perspective 1—A scientific law such as the conservation of mass must be 100% accurate within its parameters. Perspective 2—Laws in physics sometimes have limitations so cannot always be used to make accurate predictions.	Human sciences—the complexity of analysing human behaviour makes predictions inherently less accurate. Psychology—psychologists try to predict human behaviour through experience (past behaviour), experimentation and observations. Some approaches to understanding behaviour are reductionist while others take a holistic approach and take into account several factors (biological, cognitive and sociocultural). The arts—predictions are constantly tested and repurposed in the creative process. Artworks' claims are never limited to what was predicted. History—although facts, interpretations and conjectures in history may be useful to inform and have a better understanding of present and future events, they are not meant to serve as predictions. Additionally, "hindsight bias" may lead to an apparent prediction after events occur.
Does replicable data imply we are certain of our knowledge?	Perspective 1—The ability to replicate data reliably improves our confidence in the data. Perspective 2—Methodological errors may impact the validity of replicated data.	The arts—how do we consider replicas? Psychology—the field of psychology is currently experiencing a "replication crisis", resulting in concerns over the credibility of research findings. This crisis has led to the questioning of psychological research practices and findings. History—biased/partial or incorrect information in a source may be replicated in many secondary sources, which does not make the knowledge they provide more certain. A piece of information repeated in thousands of sources by mistake may lead to flawed/incomplete knowledge of historical events. In the same manner, the existence of similar accounts of a historical event (which could be considered "replicable/ confirming data") does not mean we can be absolutely certain of them.
What counts as enough evidence to corroborate a theory?	Perspective 1—The more evidence the better. Perspective 2—The type of evidence (i.e. quantitative vs anecdotal) is more important than the amount.	Mathematics—a theorem in mathematics depends on logical certainty (rigorous proof) and not "weight of evidence" (amount). Psychology—psychological theories assist in explaining and predicting human behaviour. Through research, evidence is obtained to either support or refute a theory; however, nothing is ever "proven" in psychology. Human sciences—confirmation bias (the focus or framing of a theory/hypothesis) might determine what evidence is considered and collected. Researchers may disregard evidence that contradicts a theory because they may not be looking for it.

Asking a broad question containing a TOK concept*	Example perspectives in response to the knowledge question	How might we consider the question in other areas of knowledge beyond the subject?
		Many studies in human sciences have been criticized recently because they have been conducted in relatively homogenous settings (e.g. capitalist economies, Western societies and educated populations), making the generalizations drawn from them applicable only to certain populations. This is the WEIRD ("Western, educated, industrialized, rich and democratic") critique. History—looking for sources that originated in diverse contexts (rather than just more evidence from similar sources) is necessary for getting a more complete picture. Historical arguments and narratives are constructed through available evidence, so considering the origin (and purpose) of sources, as well as their limitations, is important. Even after gathering a considerable amount of evidence, historians can make conclusions that may be valid but ultimately untrue (or only partially true). Arts (literature)—in order to present a particular interpretation (theory) of a work of art, sufficient coherent evidence needs to be presented to support it. The more evidence available to support an interpretation (in this work alone or in others by the same artist, period/ movement, etc.), the more valid it can be considered.

* This is a simple way to form a TOK question, but it is by no means the only way.

Introduction

This section aims to explore and illustrate approaches to learning and approaches to teaching in the context of Diploma Programme (DP) physics. This course is distinct in that it is part of the IB Diploma, where concurrency of learning in different areas of study is emphasized. Connections are therefore encouraged with your students' other IB courses, and with both your local and the global context.

The IB approaches to learning and approaches to teaching offer a framework of deliberate skills and attitudes underpinning learning and teaching. These approaches aim to support the IB mission and develop skills that enhance students' learning, both during and beyond their DP experience. Connections are therefore made to the learner profile attributes and international-mindedness, and other features at the heart of an IB education, not least a broadly constructivist and student-centred approach, where contextual relevance, concurrency of learning and a connected curriculum are paramount.

The **approaches to learning** framework comprises five skills groups.

1. Thinking skills
2. Communication skills
3. Social skills
4. Self-management skills
    - Organizational skills
    - Affective skills
5. Research skills

The **approaches to teaching** refer to the six pedagogical principles that underpin IB programmes.

1. Teaching based on inquiry
2. Teaching focused on conceptual understanding
3. Teaching developed in local and global contexts
4. Teaching focused on effective teamwork and collaboration
5. Teaching designed to remove barriers to learning
6. Teaching informed by assessment

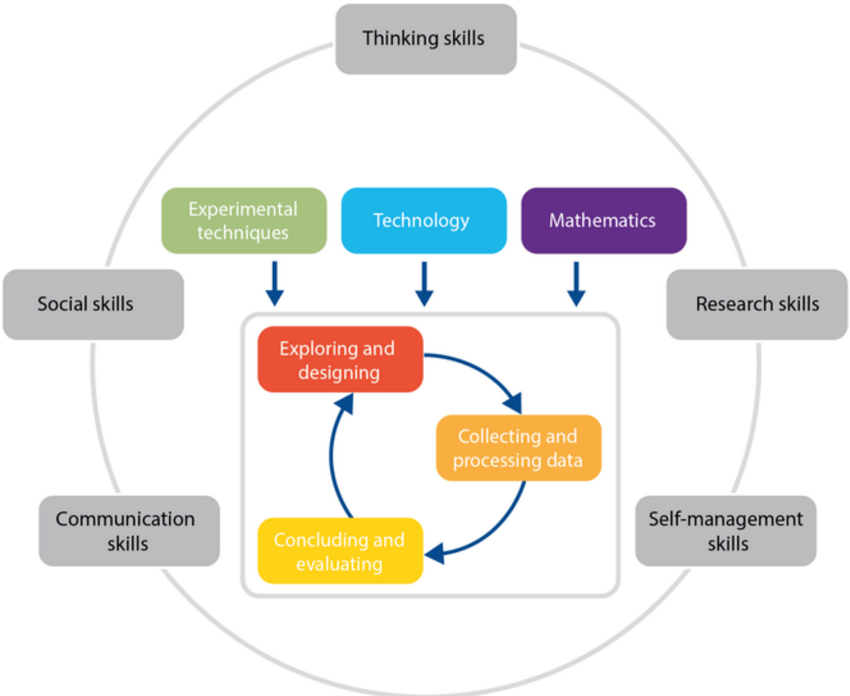
IB authorization and evaluation processes require schools to demonstrate implementation, development and review of the approaches to learning and approaches to teaching, as they relate to the *Programme standards and practices*.

This section therefore suggests how to develop different approaches to learning and approaches to teaching, for example sharing ways to help foster conceptual understanding. There are also ideas for including international-mindedness in the course, and suggestions linking topics to real-world contexts. These aim to enhance students' interest and help them see the relevance of their learning to current global challenges.

Approaches to learning

The approaches to learning framework aims to develop skills in students that support their learning throughout the DP/Careers-related Programme (CP) and beyond. They are interconnected and together support the development of the skills in the study of physics.

Tools and inquiry process for developing skills in physics



Thinking skills

Thinking skills are a broad category of approaches to learning, focusing on critical thinking, metacognition and reflection. The purpose is to develop not only discipline-specific tools in students but also curiosity, open-mindedness and creativity (International Baccalaureate, 2015). This approaches to learning skill category is connected to learner profile attributes, most significantly **thinkers**, which involves analysing and tackling problems as well as reaching reasoned, ethical decisions (International Baccalaureate, 2020a).

Nature of science (NOS) and the skills in the study of physics are two overarching frameworks in the physics curriculum. The relationship between these frameworks and approaches to learning is bidirectional: thinking skills are cultivated by and help to integrate NOS and experimental skills and techniques into the course. For example, patterns and trends are a central feature of scientific knowledge production identified as an aspect of NOS. The metacognitive awareness developed through thinking skills helps students identify and explore trends in their study of physics and at various stages of the inquiry process. Conversely, tools such as technology and mathematical skills can support the exploration of patterns and trends, which in turn helps to build thinking skills.

Examples

- Metacognition—students sharing their thought processes as they work through an explanation, test question or numerical exercise. Topics that are strongly interconnected, such as energy and kinematics, are good opportunities to support this.
- Metacognition and reflection—exploring then reflecting on different ways to remember parts of the syllabus content.
- Reflection—using visible thinking routines such as "Connect, Extend, Challenge" to reflect on learning, or "I Used to Think … Now I Think …" to explore changes in thinking (Project Zero, 2015).
- Critical thinking—discussing patterns with peers across the entire programme, and doing this collaboratively and frequently.
- Critical thinking—discussing ethical implications of advances in and applications of physics. Examples include the peer-review process and the development of technologies to generate electricity from different sources such as wind, tides and waves.
- Critical thinking—testing generalizations, assumptions, hypotheses and conclusions. Examples include exploring assumptions about heat loss or specific heat capacity in calorimetry experiments and considering cases where the ideal gas model needs to be applied.
- Critical thinking—applying knowledge in familiar and unfamiliar situations.
- Visible thinking—engaging in practices that help make thought processes visible, such as "I Used to Think … Now I Think …" (Project Zero, 2015).

Communication skills

Communication covers a range of applications, media and skills. Good communication allows students to convey their understanding in assessments, and facilitates learning, formative assessment, interpersonal relationships and collaboration (International Baccalaureate, 2015).

Communication skills include spoken and written communication, as well as listening and body language.

In physics, written language has a special role in communication. Mathematical and physical symbols are very often used. The importance of a shared code for communication can be studied by considering the International System of Units (SI), or discussing how cultures that do not use the Latin alphabet nevertheless have to become acquainted with it in the study of physics.

Successful communication also includes constructing arguments and clear lines of reasoning. These can be used in articulating and organizing written and verbal answers, in scientific investigation and in mathematical calculations.

Communication skills clearly underpin the **communicator** learner profile attribute. Effective communication is bidirectional: not only conveying personal views and understanding, but also listening to the views of others (International Baccalaureate, 2019). Actively seeking and reflecting on other perspectives is also a feature of being **open-minded**, and therefore ties in with the IB principle of international-mindedness.

Examples

- Verbal—using visible thinking routines such as "Think, Pair, Share" (Project Zero, 2015) encourages students to engage in dialogue about the syllabus content. This gives them opportunities to practise using scientific vocabulary to articulate their understanding.
- Written—explicitly teaching methods for drafting and redrafting pieces of extended writing that are particularly suited to a scientific investigation. For example, students could practise reviewing writing at different levels.

  Students use a piece of written work, e.g. an extract from an example scientific investigation.

  - They assess its focus and its organization of ideas by extracting the main themes in each paragraph.
  - They review how clearly each paragraph conveys its main ideas.

    - They read the extract again, focusing on spelling and grammar errors.
- Written and visual—creating a scientific poster to summarize the outcome of an inquiry, instead of writing an extensive laboratory report.
- Diagrammatic—comparing and contrasting different diagrams showing a particular phenomenon.
- Symbolic—using physics texts written in a different language so that students can discuss how much they are able to infer from it, based on the symbols and equations present in the text. Wikipedia articles about a different language (using a different alphabet) are a good source of this. For example, try searching for "Kirchhoff's circuit laws", in English, on the Chinese edition of Wikipedia (https://zh.wikipedia.org/).

Social skills

Students' social skills operate at various levels: among students, between students and other members of the school community, between students and the local community, and between students and the much wider global community. Effective social skills not only support learning, but also broaden the mind and encourage responsible global citizenship. The broad relevance of social skills can be observed across several learner profile attributes (International Baccalaureate, 2020a).

- **Inquirers**: learning with others
- **Risk-takers** and **communicators**: collaboration
- **Principled**: respect for the rights of others
- **Open-minded**: seeking other points of view
- **Caring**: empathy, compassion and respect

In physics, social skills can be incorporated into learning processes by explicitly teaching communication and collaboration strategies, as well as locating the course content in local and global contexts. The collaborative sciences project is an excellent opportunity to focus on certain social skills, given its primary focus on collaboration. In addition, the project's emphasis on the United Nations Sustainable Development Goals fosters awareness of global issues and thus an awareness of the situations of others.

Examples

- Students completing the collaborative sciences project.
- Students completing a risk assessment for student-designed experiments that considers risks to self, to others and to the environment, and ways to minimize the risk.
- Providing a model of constructive and balanced feedback, and giving students explicit guidelines on giving each other feedback.
- Students and teachers working together to establish expectations through which learner profile attributes are applied, to:
    - support an empathetic, compassionate and respectful learning environment
    - encourage discussion and exploration in an atmosphere of attentive listening and critical thinking (e.g. Socratic seminars).
- Problem-solving in small groups. For example, groups could work together reproducing the reasoning behind the quantization of energy for an electron in an atom, starting from the idea of having a standing wave formed in the orbit.
- Problem-solving in small groups. For example, groups could work together calculating the orbital speed and radius of a geostationary satellite.

Self-management skills

Self-management skills are classified into two categories.

- Organizational skills

- Affective skills

Organizational skills cover the management and organization of time, tasks and resources. Effective organization can encourage balance and help to develop independence in students. These skills are therefore connected to the **balanced** and **inquirer** learner profile attributes, respectively.

Affective skills are related to traits such as state of mind, self-motivation and resilience. This set of skills is linked to the learner profile attribute of being **risk-takers**, which seeks to equip learners with the determination and forethought needed to face uncertainty, challenges and change (International Baccalaureate, 2020a).

Examples

- Organizational skills
  - Setting interim deadlines for long tasks and projects such as the scientific investigation or extended essay.
  - Exploring revision techniques such as concept mapping, note-taking and use of flash cards.
  - Explicitly teaching effective use of practice questions and markschemes.
  - Discussing strategies for organizing files, both digital and paper-based.
- Affective skills
  - Providing opportunities for low-stakes retrieval practice to build fluency, understanding and motivation.
  - Using strategies to identify and fill knowledge gaps, such as thorough test corrections or Q&A sessions.
  - Encouraging self-reflection to acknowledge progress and identify areas of opportunity.

Research skills

Research skills encompass competence with a range of skills that need to be deliberately taught and practised. These include finding out background information, conducting preliminary experiments, composing research questions, and collecting and analysing data. Implicit in much of this is evaluation, for example of data, hypotheses, sources, arguments, methodologies, uncertainties. This set of skills is deeply connected to the inquiry process and thus the inquirer learner profile attribute (International Baccalaureate, 2020a).

Research skills figure heavily in the skills in the study of physics, the collaborative sciences project, the scientific investigation and the extended essay.

Examples

- Developing strategies to organize references.
- Providing opportunities for presenting results of extended research projects in condensed formats, e.g. scientific posters.
- Discussing the common features of good research questions, using examples of both good and poor quality.
- Organizing class activities involving collecting data from databases.
- Comparing the reliability of different information sources, e.g. the portrayal of a scientific news item in various media sources.
- Designing and using activities involving processing, analysing and evaluating experimental results. These could be heavily scaffolded in the beginning, then gradually less so as students build up the required skills.
- Practising past paper and examination-style questions related to research questions, investigation design, data collection, analysis and evaluation.

Approaches to teaching

The approaches to teaching refer to six pedagogical principles that underpin IB programmes. They aim to empower teachers to create meaningful learning experiences.

Inquiry

Inquiry-based approaches to learning and approaches to teaching involve a high degree of student engagement and interaction to develop natural curiosity in students. The approaches can take a variety of forms that differ in their degree of teacher guidance. Banchi and Bell (2008) propose four levels of inquiry.

1. As part of **confirmation inquiry**, the question, process and outcome of the inquiry are provided by the teacher.
2. During **structured inquiry**, teacher guidance begins to be withdrawn.
3. During **guided inquiry**, teacher guidance continues to be withdrawn.
4. In **open inquiry**, students determine the question, procedure and outcome.

Other forms of inquiry-based learning and teaching include experiential learning (Kolb, 1984) and problem-based learning (Boud, Feletti, 1997).

Scientific inquiry can be experienced by everyone. Subjects such as physics offer students opportunities not only to conceptualize scientific inquiry—a central feature of NOS—but also understand it is a process that they too can undertake.

The inquiry process comprises three stages: inquiry, action and reflection. In physics, this process is evident in the skills in the study of physics, the scientific investigation and the collaborative sciences project. The inquiry process lies at the heart of the skills in the study of physics. The *Physics guide* identifies the specific inquiry skills that students must experience in their study of the course. These inquiry skills must be integrated into the course, providing students with several opportunities to master them. The collaborative sciences project also provides an opportunity to develop these inquiry skills within an interdisciplinary context and in collaboration with peers.

Effective teaching of the inquiry skills will equip students to demonstrate them in external and internal assessment. One example is when they undertake the scientific investigation, where they plan, carry out, analyse and evaluate an investigation to address a research question of their own.

Examples

Confirmation inquiry

Students perform a teacher-directed inquiry to confirm an outcome.

- Learning to use video analysis software and using it to confirm the value of the acceleration of free fall
- Carrying out an experiment to show that increasing the length of a conducting wire in a circuit increases the resistance of the circuit

Structured inquiry

Students determine the outcome themselves; the aim and procedure are provided by the teacher.

- Determining Kepler's third law using graphical analysis of planetary orbit data extracted from databases
- Determining the refractive index of Perspex using pins

Guided inquiry

Students conduct an inquiry that addresses a question provided by the teacher, using a procedure of their choice.

- Investigating the factors affecting the bounce height of a ball
- Determining the speed of sound in air

Open inquiry

Students determine the question, process and analysis.

- Writing their own factual, conceptual and debatable questions in relation to a topic
- Undertaking the collaborative sciences project
- Undertaking the scientific investigation

Experiential learning

Students engage in inquiry opportunities outside the classroom.

- Taking a field trip to a local theme park
- Interviewing members of the school community who work in physics- or engineering-related fields

Problem-based learning

Students are presented with a question or problem to solve.

- Determining the material of an object through calorimetry. Students are given an unknown material and asked to determine what it is using a calorimeter, thermometer and other laboratory equipment
- Creating a circuit with fixed specifications using a limited set of materials, e.g. using a fixed voltage power source, a set of resistors and connectors to connect an LED light to a 3 V battery
- Considering relativistic effects. Determining when to send (and what to say) in a happy birthday message to an astronaut aboard a spaceship moving away from Earth

Conceptual understanding

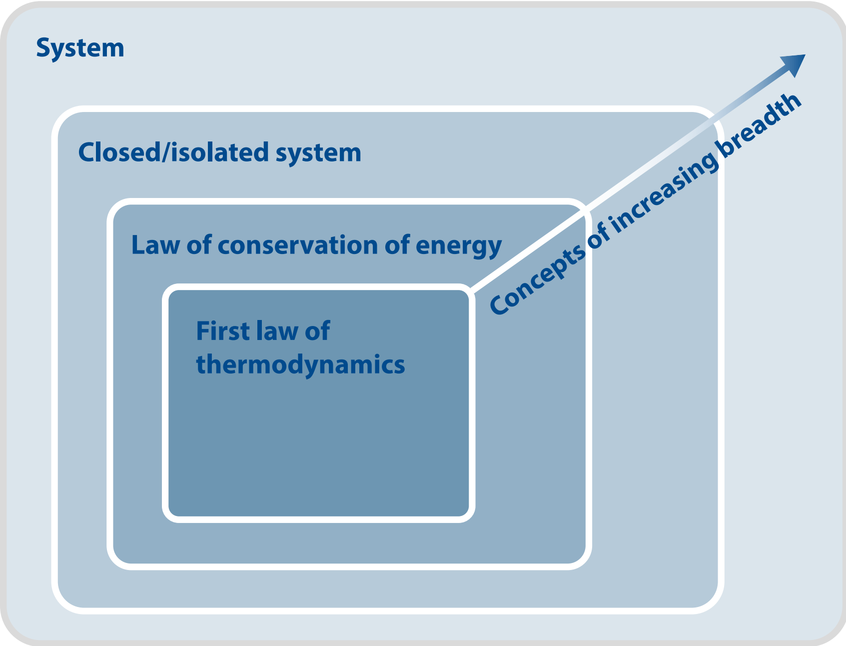
In IB programmes, conceptual understanding is defined as understanding that connects factual, procedural and metacognitive knowledge. It results from a process in which students consciously organize connections between prior and new knowledge into networks, then further develop or reconfigure those networks. This is a non-linear, ongoing process throughout which understandings evolve and misconceptions are identified and dispelled. In DP physics, these interconnections are explored through the linking questions. The linking questions in the *Physics guide* are not exhaustive, and students and teachers are invited to write their own.

Teaching for conceptual understanding is important because conceptual understanding enables students to be aware and critical of their own knowledge and understandings. They can then transfer and apply skills, knowledge and understandings to new or different contexts in creative, generative, autonomous, dynamic ways. Conceptual understanding supports the IB mission because it enables students to conceive multiple solutions to a problem, imagine different perspectives on issues, and understand more deeply how ideas change in different contexts.

Teaching approaches that promote conceptual understanding include classification, generalization, representation, internalization, concepts-in-use and near and far transfer.

A conceptual approach fosters the organization of knowledge into networks, which can evolve as students acquire new understandings. Thus, a conceptual understanding is supported by mental categories of varying breadth. These concepts or mental categories can be broad concepts that help to integrate knowledge across disciplines, or narrower, subject-specific concepts that help to organize and link disciplinary understandings. An example of a sequence of concepts of increasing breadth is shown in the figure.

Example sequence of increasing conceptual breadth



Concept-based teaching and learning does not preclude the teaching of content. In fact, a sound knowledge base is the foundation for conceptual understanding (Mills, Gay, 2018). By engaging with a conceptual approach, however, it should be remembered that ideas and knowledge—both declarative and procedural—do not exist in isolation. Concepts are connected to other concepts; they are mental abstractions constructed through experience (Taber, 2019).

Examples

- When revising several units, students write their own linking questions, share them and attempt to answer each other's questions.
- Concept mapping can be used to summarize the content of a unit. The visible thinking routine "Generate–Sort–Connect–Elaborate" can be used to structure the activity (Project Zero, 2015).
- Frayer model graphic organizers help to clarify the meaning of a concept, and to identify correct and incorrect examples of the concept.
- Visible thinking routines such as those used in "The Explanation Game" or "The Ways Things Can Be Complex" (Project Zero, 2015) can be used, for example, to discuss the concept of energy and the perspectives on it.
- A simple grid can be used to organize ideas about the similarities and differences of gravitational, electric and magnetic fields. Why are they all called "fields"? What is the essence that they share?

Grid for organizing ideas on similarities and differences between different kinds of fields

	Gravitational	Electric	Magnetic
Gravitational	Differences / Similarities		
Electric		Differences / Similarities	
Magnetic			Differences / Similarities

Local and global contexts

Setting learning in context gives relevance to the curriculum and allows students to connect their learning to their own experiences and the world around them. Observing their surroundings through a different lens may help students understand these from a different perspective, an important component of international-mindedness and various learner profile attributes.

Physics has many abstract concepts that, even though they describe the natural world, are not easily "seen" or represented in it. Concepts such as momentum, energy and fields are models and abstractions used to explain what students see around them. When presented with a particular context in which these concepts arise naturally, students begin to grasp the concept and appreciate its value and utility.

The scientific investigation, the collaborative sciences project and the extended essay are all excellent opportunities for students to delve into an application of physics. Applications should be emphasized by weaving many examples of local and global contexts into the course. New examples of local and global contexts may arise throughout the course. In some cases, they can be planned into teaching well ahead of time (e.g. particle accelerators in understanding quantum physics). In others, local or global news items related to physics may spark interesting conversations spontaneously.

Context can be introduced at different points in a learning sequence; it can lead into the teaching of a concept, or be used after concepts are taught (Turner, 2019). After a concept has been explained, students can be asked to apply it to a particular context or case study to reinforce the concept and transfer it to a less familiar setting.

Examples

- Discussing physics-related news items, considering:
  - relevant theoretical concepts
  - the quality of scientific communication
  - examples of ethical, environmental, economic, cultural and social impacts.
- Asking students to prepare a five-minute presentation on an application of physics of their choice.
- Contributing to physics-related data collection projects at the global level (citizen science).
- Sharing examples from teachers' own university and employment experiences.
- Inviting students' relatives with physics-related careers to present to the class.
- Featuring prominent physicists in class when relevant, connecting their actions to the IB learner profile.

- Using authentic stimuli to generate class discussions or as assessment instruments.
- Setting the introduction of new concepts in contexts where they are particularly relevant.
    - Introducing the concept from the aim of determining the final speed in a two-body collision.
    - Introducing the concept from the aim of explaining what happens to kinetic energy in free fall.
    - Introducing gas laws from the aim of understanding why a hot air balloon rises.
    - Introducing angular momentum and moment of inertia from the aim of determining how to spin faster in ice skating.
    - Introducing Lorentz transformations from the aim of making Maxwell's equations covariant (can be done from a qualitative standpoint).

Effective teamwork and collaboration

This pedagogical principle aims to encourage collaborative relationships to create a positive and dynamic learning environment. It covers collaboration between students, and between students and their teacher. In science, it also echoes the aspects of NOS that acknowledge science as a collective endeavour.

In physics, the collaborative sciences project stands out as one of the course requirements that specifically aims to develop collaboration skills in students. Collaborative tasks can vary significantly in terms of time and configuration. Their duration can range from short pace-changers in a lesson to extended teamwork such as the collaborative sciences project. The size of collaborative groupings also varies, from pairs of students to whole-class endeavours.

Students benefit from opportunities to articulate their thinking, which can help to clarify lines of reasoning and even reveal knowledge gaps. It is also advantageous to practise using appropriate scientific vocabulary, irrespective of whether students are fluent in the language of instruction or not. Academic language is cognitively demanding, and collaborative tasks provide spaces for students to practise using correct vocabulary, building their academic fluency.

Teamwork and collaboration also encourage a learning environment in which students share their perspectives, but also consider and integrate the views of others. For example, peer feedback is valuable for both parties. The student receiving the feedback gains from acting on the suggestions for improvement given by their peer. For the student giving the feedback, it is an opportunity to practise commenting constructively.

For students to benefit fully from collaborative tasks, behavioural expectations and the nature of effective group work need to be made explicit. For example, collaboration is permitted in the early stages of the scientific investigation. Teachers must therefore be vigilant, clarifying where necessary the difference between acceptable collaboration and collusion.

Examples

Teamwork and collaboration are possible in a variety of ways.

- The collaborative sciences project
- Solving a numerical problem individually and then explaining reasoning to a partner
- Collaboratively collecting experimental data and then comparing results obtained by processing and analysing that data, e.g. measuring the speed of sound in a standing wave
- Working in small groups to solve a problem or explain a situation, e.g. deducing the Doppler effect equation by considering what happens in some situations where either the source or observer is at rest and the other moves at the speed of sound
- Using visible thinking routines that encourage students to explain their reasoning, e.g. "Think, Pair, Share", and connecting learning to prior knowledge, e.g. "Connect, Extend, Challenge" (Project Zero, 2015)
- Short collaborative research leading to a presentation with a competitive element. For example:
    - In small groups, students research one method of electrical energy generation (e.g. wind, solar, hydroelectric). They should explain how it works, its advantages and disadvantages, and make a

case for why that particular method of energy generation should be invested in by any given country or region. A brief presentation/pitch is then delivered by every group. The class should decide, through a simple vote or any other means, which pitch was most convincing

Removing barriers to learning

IB approaches to teaching aim to help students set challenging and appropriate personal learning goals. Differentiation to remove barriers to learning is understood to relate to four interconnected principles. The central principle is to affirm students' identities and build self-esteem. Surrounding this are the principles of valuing prior knowledge, scaffolding learning and extending learning.

In IB programmes, language is recognized as having a vital role in learning and teaching, permeating almost all aspects of a learning environment. All IB teachers are therefore regarded as language teachers.

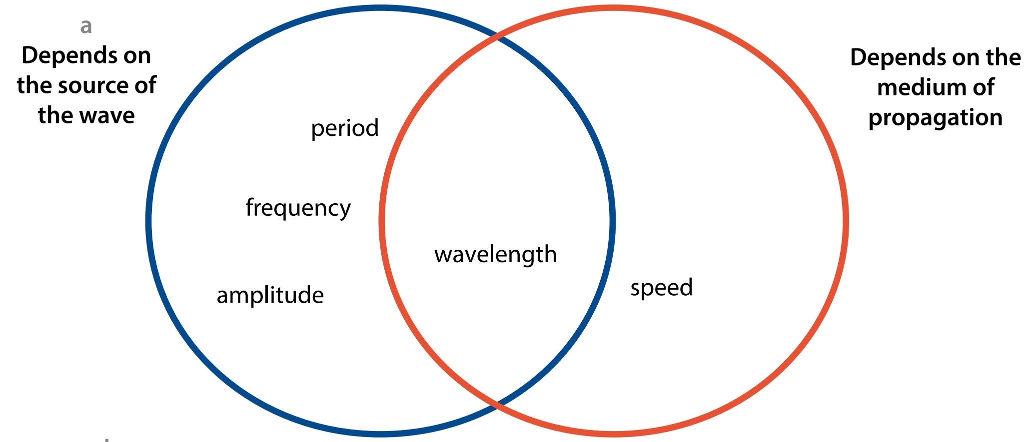
Many terms used when explaining physics concepts have subtleties that are not usually considered in everyday contexts. Examples are the difference between speed and velocity, or the definition of heat and temperature. Teachers should be mindful of this and make definitions explicit for students, helping them to understand how context may influence the meaning of a word.

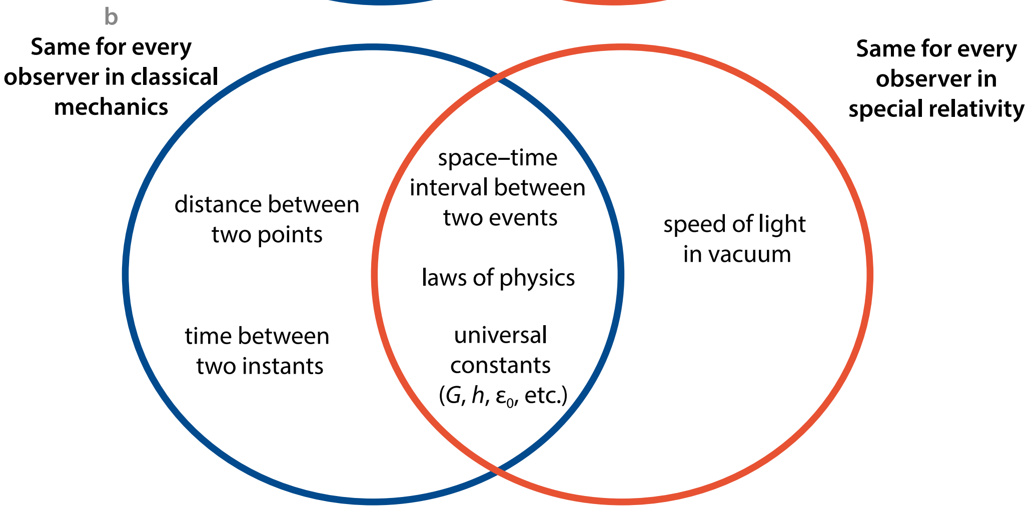
Examples

There are numerous ways to remove barriers to learning.

- Affirming identity and building self-esteem
  - Asking students to construct glossaries containing definitions in their preferred language, as well as the language of instruction (if this is different)
  - Reducing cognitive load in practical instructions by minimizing textual elements and maximizing diagrammatic elements
- Valuing prior knowledge
  - Identifying prior knowledge through diagnostic quizzes or mind mapping
  - Activating prior knowledge through linking questions
- Scaffolding learning
  - Using simulations and animations to help students visualize concepts that are less easy to grasp
  - Using graphic organizers to represent processes or relationships
    - Flow charts for processes
    - Venn diagrams for similarities and differences

*Venn diagram summarizing (**a**) dependence of different wave characteristics on either source or medium and (**b**) differences and similarities between classical mechanics and special relativity*



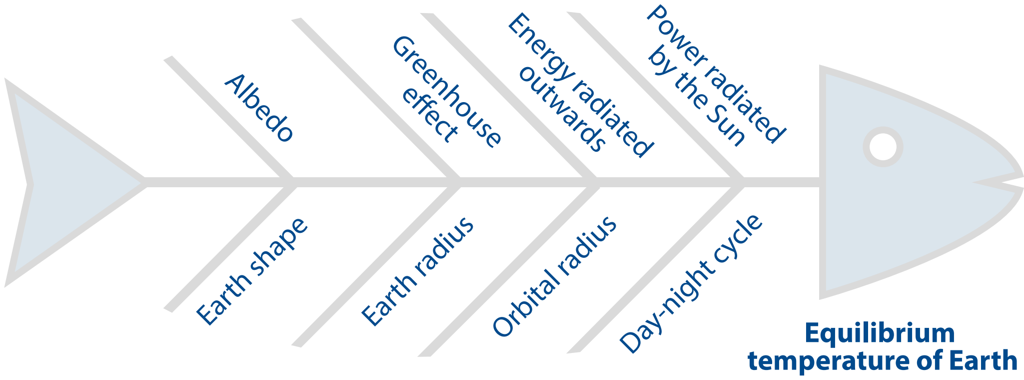


- Fishbone diagrams examining the causes leading to an effect

  Downloadable resource

  Blank fishbone template (PDF)

Fishbone diagram analysing the different factors that determine Earth's equilibrium temperature



- Extending learning

- Applying concepts learned in a new, unfamiliar context or use of case studies
- Exploring interdisciplinary links

Assessment

Assessment provides valuable information that supports learning and teaching and therefore should take place continually throughout the course. Assessment feeds back into the teaching process, providing information that facilitates the synchronization of learning and teaching. It is a key two-way process that can be used to improve learning, teaching and assessment. Teachers and students' own peers provide students with feedback on how to consolidate their understanding and move forward. Meanwhile, students provide teachers with feedback on their misconceptions, knowledge gaps, levels of understanding and levels of engagement, all of which inform the teacher's subsequent decisions.

Throughout the DP and CP, students work towards demonstrating the course assessment objectives through formative assessments. Some assessment tasks will be dedicated to measuring student learning and will inform predicted grades as well as internal reporting of student progress. Assessment of learning should be aligned with the course assessment objectives and grade descriptors. In physics, this involves providing opportunities for the students to develop the skills and techniques required to undertake the scientific investigation and exposing them to questions of the style and type they will encounter in external examinations.

- Multiple-choice questions
- Short-answer questions
- Extended-response questions
- Data-based questions

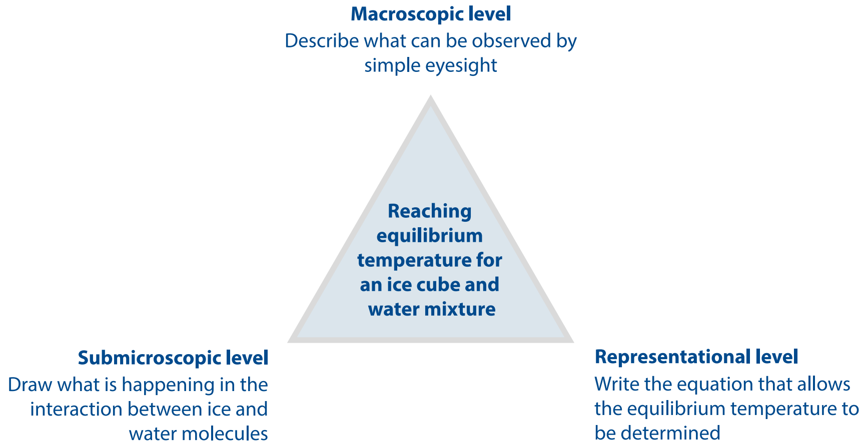
These types of questions assess connections between concepts-, NOS- and skills-related knowledge, and will be set in a contexts such as experimental work and day-to-day applications of physics.

Examples

Assessment in physics can take many forms.

- Students practising data-based questions
- Using multiple-choice questions to uncover student misconceptions
- Students assigning a level of confidence to their responses to multiple-choice questions (5 for "absolutely certain", 3 for "I think this is correct", 1 for "guess"), and applying positive and negative marking. Students can also be encouraged to justify their reasoning for each response
- Students exploring and researching an application of physics, then presenting this in a variety of formats. Examples include a formal research paper, a scientific poster, an article for the school newspaper, a video or podcast, a presentation or assembly and an infographic
- Sharing the internal assessment criteria with students and asking them to analyse an example of student work against the criteria
- Students doing peer and self-assessment using the internal assessment criteria
- Students doing self-assessment using rubrics and markschemes
- Using mini-whiteboards to assess student understanding
- Students formulating conclusions from experimental data
- Setting short report tasks on practical experiences
- Setting a task requiring a video, poster, blog post, infographic or similar that briefly explains a complex everyday technology or idea such as electromagnetic induction
- Delving into students' understanding of a concept by asking them to consider it on multiple levels, as suggested by Johnstone (1991), e.g. macroscopic observations, submicroscopic particle behaviour and symbolic representations

Graphic organizer using Johnstone's triangle (1991) to delve into students' understanding



International-mindedness

The IB aims to develop "inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through education that builds intercultural understanding and respect". International-mindedness recognizes similarities and affirms differences between communities, peoples and nations. Knowledge and understanding of similarity allow for the construction of common foundations, while recognition and affirmation of difference encourage a celebration and valuing of diversity.

With this in mind, teachers of DP physics should provide opportunities for students to foster international-mindedness within the context of the course, underpinned by a focus on global engagement. Global engagement represents a commitment to address humanity's greatest challenges in the classroom and beyond. Such challenges may relate to the environment; development; conflict, rights and cooperation. One of the aims of the course is to model solutions to local and global problems in a scientific context. DP physics students and teachers are therefore expected to explore local and global issues relating to the content of the syllabus. There is a close connection between international-mindedness and the IB learner profile attributes, which underpin, and are central to, understanding what it means to be internationally minded.

Along with their exposure to international-mindedness elsewhere in the DP, students should be prepared to be successful global citizens of the future.

Engaging with international-mindedness

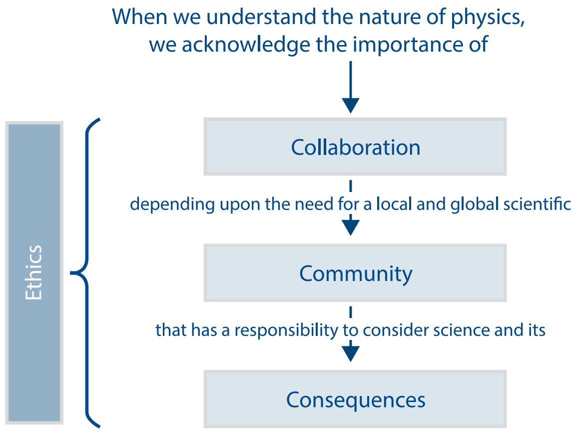
Teachers are not expected to address international-mindedness as a stand-alone topic, but instead to integrate it within the teaching of the subject.

This teacher support material (TSM) supports the teaching and learning of physics and includes a number of ideas and suggestions. The aim is to aid all IB teachers in addressing the need to include international-mindedness in their delivery of the course. These ideas and suggestions are by no means mandatory nor exhaustive and teachers are encouraged to generate alternative approaches and share ideas as they plan and deliver the content.

The "Physics and international-mindedness" section of the *Physics guide* highlights the international nature of science and might be a good starting point to consider the role of a scientist in a global community.

For practical purposes, it might be useful here to break down the term *international-mindedness* into specific concepts that are particularly relevant in the context of science: *collaboration*, *community*, *consequences* and *ethics*. Please note that a consideration of ethics can provide valuable overlap with the IB theory of knowledge (TOK) course.

International-mindedness through the lens of collaboration, community, consequences and ethics



A focus on these concepts throughout the course can help design learning engagements that develop international-mindedness. The table below provides scaffolding questions that might be used to unpack these concepts.

Scaffolding questions to help develop international-mindedness

This table contains a list of possible scaffolding questions that can be used to develop international-mindedness. They can also be applied to specific real-life contexts.

Concept	Scaffolding questions for developing international-mindedness
Collaboration	• Why is collaboration necessary? • What scale of collaboration is required in science? • What does scientific collaboration look like?
Community	• Who is involved in the scientific community? • What structures and organizations might be found in the scientific community?
Consequences	• How might new scientific knowledge impact future scientific research? • Which areas of society might be impacted by scientific knowledge? • How significant are the consequences of science on other areas of society? • Does every society respond similarly to scientific research?
Ethics (note overlap with the TOK course)	• What responsibilities do individual scientists possess in carrying out their own research? • What responsibilities do journals, research facilities and scientific organizations possess? • Who is responsible for the communication of science within the public domain? • Should scientific research be subject to ethical constraints?

Exploring international-mindedness

Real-life context	International-mindedness connections
Russian and US scientists collaborate at the Joint Institute for Nuclear Research near Moscow to synthesize and prove the existence of element 118, oganesson.	High cost of and need for advanced technology limits progress without collaboration. Collaboration can occur on an international level.
The International Space Station (ISS) is a multinational project currently involving five space agencies. Research carried out on the ISS has led to many advancements in many areas of science that may not have been possible on Earth.	Collaboration can occur on an international level. Scientific progress is rarely dependent on the work of a single scientist. This is an example of contributions from different nationalities, although the question of why certain nations are represented more than others is a valid question.
Role of World Health Organization during the COVID-19 pandemic.	A good example of a scientific organization responsible for supporting and advising national health policies across the globe.
The Surgisphere COVID-19 scandal involved the publishing of two papers in well-respected scientific journals that were later found to be based on highly suspicious and possibly false data.	An example of a major failing in the peer-review process with global implications in how governments dealt with the COVID-19 pandemic.
The influence of big data companies in scientific progress during the COVID-19 pandemic.	Commercial companies can impact the scope of scientific progress. Ethical questions can be raised regarding the access and use of personal medical data.
Research on vaping and its interplay with politics. US and UK policy have significant differences.	This is an example of how scientific information can be interpreted and used differently when it enters the political domain.

Examples

The following tables have some general structures that could be used to integrate international-mindedness development in lessons or sections of lessons.

Research and discussion

Suggested timing (25 minutes)	Example content (for a focus on collaboration and consequences)
5 minutes	Presentation of a real-life context, e.g. the synthesis and proof for the existence of element 118, oganesson.
10 minutes	In groups, students are asked to research the real-life context using the following prompts. • Who collaborated? • Was the collaboration on a local or global level? • Why was the collaboration necessary? • What are the consequences of this new knowledge?

Suggested timing (25 minutes)	Example content (for a focus on collaboration and consequences)
	(It may also raise interesting questions about the independence of scientific collaboration beyond political tensions between Russia and the US.)
10 minutes	Groups share their findings.

Mini-presentations

Suggested timing (40 minutes)	Example content (for a focus on community and consequences)
5 minutes	Present students with a number of national and international scientific organizations. • International Atomic Energy Agency (IAEA) • Intergovernmental Panel on Climate Change (IPCC) • International Committee for Weights and Measures (CIPM) • CERN (European Organization for Nuclear Research) or SESAME (Synchrotron-Light for Experimental Science and Applications in the Middle East) • International Space Station (ISS) • International Campaign to Abolish Nuclear Weapons (ICAN) • National physics-related organization relevant to your school context
15 minutes	Individually or in small groups, students are asked to research one of the organizations using the following prompts. • What does it do? • Where does it work? • Who funds it? • What are the consequences of its work? • How might it be relevant to you?
20 minutes	Individuals or groups make presentations (2–3 minutes) on their findings.

Debate

Suggested timing (45 minutes)	Example content (for a focus on ethics)
5 minutes	Brief outline of an ethical issue. An understanding of atomic physics began at the end of the 19th century. Because of the Second World War, great effort was made to develop a nuclear bomb, leading to the Manhattan Project. Following the end of the war, research in atomic physics continued with the development of nuclear power. Students place anonymous initial votes on whether they support, oppose or are unsure of the motion: *Funding for scientific research should be used for war efforts.* The class is split into two teams and assigned to support or oppose the motion. It can be interesting to manipulate the groups so that they are arguing against their initial thinking.

Suggested timing (45 minutes)	Example content (for a focus on ethics)
20 minutes	Students are given time to research and build their lines of argument. The level of scaffolding prompts can be adapted to meet the needs of the class. Example prompts • What is the ethical issue? • What are the consequences of this issue? • What evidence might support your argument? • What might the opposite team try to argue? • How can you dismantle opposition arguments?
20 minutes	Debate • Each group selects one or two speakers to briefly (1–2 minutes) summarize their argument. • The debate is opened to the floor—a “speaking stick” can be used to prevent students talking over each other. This can be controlled by the teacher or students. • One or two different speakers briefly (1–2 minutes) summarize their arguments. • Second vote: students place final individual anonymous votes on whether they support or oppose the motion. These results can be compared to the initial votes to identify the winning team.

Introduction

The Diploma Programme (DP) physics course has no prescriptive sequence for coverage of the concepts and topics. Teachers are completely free to plan their own route through the course according to their circumstances. This section gives ideas for some contexts and possible routes, which may help teachers to develop their own course outlines. As it is expected that experimental work and teaching of the skills are included regularly throughout the course, extensive ideas are included for laboratory-based experimentation and applications of technology to help teachers to plan their experimental programme.

Pathways through the course

Standard level (SL) roadmap

The course has been split into eight sections. Each section has questions and ideas that link each topic in the unit together, as well as questions that connect to the next topic in the course.

Further authentic examples of routes through DP physics will be published in due course.

Unit	Linked topics	Rationale
Motion	A.1, A.2, A.3	The student begins with the concepts of linear and circular motion, forces, and conservation of energy and momentum. This is an ideal opportunity to introduce work on graphing, uncertainties and vectors.
High speed motion	D.1, C.5	The student combines forces, linear and circular motion to examine motion of objects at high speeds, including planetary orbits, gravitational forces and measurement of high speeds using the Doppler effect.
Waves	C.1, C.2, C.3, C.4	In units 1 and 2, the student explores models with one or two particles. In unit 3, the multiparticle model is introduced by focusing on wave properties of particulate matter.
Thermal physics	B.1, B.3	Combining the multiparticle model with concepts from unit 1, such as forces and energy, thermal energy is described and gas laws are developed, furthering the idea that observable properties can be described by microscopic behaviour.
Electricity	B.5, D.2, D.3	Through discussion of gas laws, the student is now familiar with the atom as a particle. In this section of the course, the particles that make up the atom will be examined, beginning with the electron, its interaction with electromagnetic fields and analogy with gravitational fields in unit 2. History to include historical development in physics by J. J. Thomson and Millikan.
Atomic physics	E.1, E.3	Developments in the understanding of physics continued with work from Rutherford, Geiger and Marsden, allowing students to focus on the nucleus and subatomic particles.
Nuclear power	E.4, E.5	Student links micro world of subatomic with macroscopic observations such as fission, fusion and observation of stars.

Unit	Linked topics	Rationale
Earth	B.2	Greenhouse effect allows discussion from a nature of science (NOS) perspective. This links with topics from the previous unit and acts as a quantitative and qualitative examination of themes throughout the course and, for the student, the world around them.

The following shows how linking questions can be used to develop pathways through the course. In brackets after the linking question is a reference to the topic(s) to which a connection could be made.

Unit 1: Motion

A.1 Kinematics

How effectively do the equations of motion model Newton's laws of dynamics? (A.2)

When can certain types of problems on projectile motion be solved by applying conservation of energy instead of kinematic equations? (A.3)

How does the motion of a mass in a gravitational field compare to the motion of a charged particle in an electric field? (D.1, D.3)

A.2 Forces and momentum

How are concepts of equilibrium and conservation applied to understand matter and motion from the smallest atom to the whole universe? (Ideas of equilibrium and conservation permeate throughout the course, including NOS.)

Why is no work done on a body moving along a circular trajectory? (A.3)

How does the application of a restoring force acting on a particle result in simple harmonic motion? (C.1)

What assumptions about the forces between molecules of gas allow for ideal gas behaviour? (B.3, NOS)

How can knowledge of electrical and magnetic forces allow the prediction of changes to the motion of charged particles? (D.2)

A.3 Work, energy and power

How do travelling waves allow for a transfer of energy without a resultant displacement of matter? (C.1, C.3, C.4)

Which other quantities in physics involve rates of change? (A.1, A.2, B.1, skills)

How is the equilibrium state of a system, such as the Earth's atmosphere or a star, determined? (B.1, B.2, B.4, E.5)

Unit 2: High speed motion

D.1 Gravitational fields

How can the motion of electrons in the atom be modelled on planetary motion and in what ways does this model fail? (E.1, NOS)

How is uniform circular motion like—and unlike—real-life orbits? (A.2)

How is the amount of fuel required to launch rockets into space determined by considering energy? (A.3)

What are the benefits of using consistent terminology to describe different types of fields? (D.2, NOS)

C.5 Doppler effect

How can the Doppler effect be utilized to measure the rotational speed of extended bodies? (D.1)

What gives rise to emission spectra and how can they be used to determine astronomical distances? (E.1)

Unit 3: Waves

C.2 Wave model

How can light be modelled as an electromagnetic wave? (D.2)

What happens when waves overlap or coincide? (C.3, C.4)

How are waves used in technology to improve society? (NOS)

C.1 Simple harmonic motion

How can the understanding of simple harmonic motion apply to the wave model? (C.2, NOS)

How can greenhouse gases be modelled as simple harmonic oscillators? (B.2)

How can circular motion be used to visualize simple harmonic motion? (A.2, D.1, D.3, E.1)

How does damping affect periodic motion? (A.3)

C.4 Standing waves and resonance

How can resonance be explained in terms of conservation of energy? (A.3)

What is the relationship between resonance and simple harmonic motion? (C.1)

How can the idea of resonance of gas molecules be used to model the greenhouse effect? (B.2, NOS)

C.3 Wave phenomena

What evidence is there that particles possess wave-like properties such as wavelength? (C.2, NOS)

Unit 4: Thermal physics

B.1 Thermal energy transfers

What role does the molecular model play in understanding other areas of physics? (NOS)

How can the phase change of water be used in the process of electricity generation? (D.2)

What applications does the Stefan-Boltzmann law have in astrophysics and in the use of solar energy? (E.5)

B.3 Gas laws

How does the concept of force and momentum link mechanics and thermodynamics? (A.2, A.1)

What other simplified models are relied upon to communicate the understanding of complex phenomena? (E.5, NOS)

Unit 5: Electricity

B.5 Current and circuits

What are the parallels in the models for thermal and electrical conductivity? (B.1, NOS)

In what ways can an electrical circuit be described as a system like the Earth's atmosphere or a heat engine? (A.3, B.2)

How are fields in other areas of physics similar to and different from each other? (D.1, D.2)

What are the advantages of cells as a source of electrical energy? (B.2)

D.2 Electric and magnetic fields

How are electric and magnetic fields like gravitational fields? (D.1)

What are the relative strengths of the four fundamental forces? (A.2, D.1, D.2, E.3)

D.3 Motion in electromagnetic fields

How are the properties of electric and magnetic fields represented? (NOS)

What causes circular motion of charged particles in a field? (A.2, D.1, NOS)

How can conservation of energy be applied to motion in electromagnetic fields? (A.3)

Unit 6: Atomic physics

E.1 Structure of the atom

How is the distance of closest approach calculated using conservation of energy? (A.3)

How can emission spectra allow for the properties of stars to be deduced? (E.5, NOS)

How can emission spectra be used to calculate the distances and velocities of celestial bodies? (C.5)

Under what circumstances does the Bohr model fail? (D.2, NOS)

E.3 Radioactive decay

Are there differences between the photons emitted as a result of atomic versus nuclear transitions? (E.1)

Which areas of physics involve exponential change? (B.1)

How does equilibrium within a star compare to stability within the nucleus of an atom? (E.5)

Unit 7: Nuclear power

E.4 Fission

How is binding energy used to determine the rate of energy production in a nuclear power plant? (A.3)

To what extent is there a role for fission in addressing climate change? (B.2, NOS)

E.5 Fusion and stars

How is fusion like—and unlike—fission? (E.4)

How can the understanding of black-body radiation help determine the properties of stars? (B.1)

How can gas laws be used to model stars? (B.3, NOS)

How do emission spectra provide information about observations of the cosmos? (C.5, E.1)

Unit 8: Earth

B.2 Greenhouse effect

What relevance do simple harmonic motion and resonance have to climate change? (C.1, C.4)

How do different methods of electricity production affect the energy balance of the atmosphere? (B.1, B.3, NOS)

Unit planners

Sample unit planners

All DP teachers are required to engage in explicit planning. However, the IB does not prescribe a particular format of unit planner that teachers should use. Nonetheless, the process of planning may be supported by using one of the template DP unit planners developed for DP teachers. These DP unit planners are not intended to mandate or restrict what DP teachers can or cannot do. Rather, they are intended to inspire and support teachers to think more about not only what they are teaching, but also how they are teaching.

Examples of DP unit planners are provided in the resource *Approaches to teaching and learning in the Diploma Programme*. This section of this support material also includes examples of completed unit plans for the DP sciences. These examples are intended to help teachers to reflect on their own planning and are not intended to be model plans or to prescribe how unit planning should be undertaken.

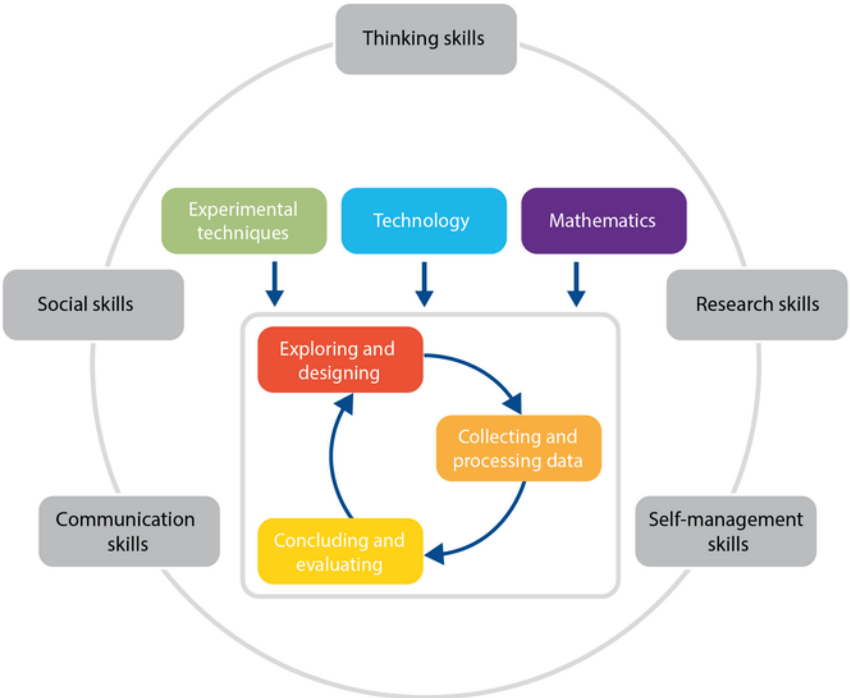
Downloadable resources

DP physics sample unit planner 1: Nuclear and quantum physics (PDF)

DP physics sample unit planner 2: The greenhouse effect (PDF)

Skills-based activities

Overview of skills in the study of physics



Tools

Tool 1: Experimental techniques

Skill: Addressing safety of self, others and the environment

Description
Recognize and address relevant safety, ethical or environmental issues in an investigation.
Activities
Risk assessments should be produced for all experiments, planned or completed, and include potential risks and mitigations. Local safety requirements should always be observed. The IB has produced a document, *Managing safety in science laboratories and workshops,* which gives guidelines on safety. Further resources and recommendations can be found online. Major physics specific hazards include: • radioactive materials • lasers • any use of chemicals

• electrical risks (mains equipment, specific electrical experiments) • unstable structures/heavy weights • wires under tension. The “Research design” internal assessment criterion requires safety to be considered in planning the experiment to investigate the research question. Methodological considerations must include the recognition of any safety, ethical or environmental issues that need to be taken into account. To prepare for this, it is recommended that students have the opportunity to practise risk assessments, including risk identification and mitigations in most experimental work. Safety and ethics should be addressed in the different practical work experiences students undergo in the course. Safety regarding electrical equipment or handling of hot water/materials may be particularly important for physics.
Example opportunities for integration into the physics programme
B.1 Thermal energy transfers: considering safety measures to handle hot objects in an experiment. B.5 Current and circuits: considering safety measures to handle devices with a flowing current or a high voltage. E.4 Fission: considering the ethical implications of the work on nuclear reactions (i.e. nuclear bomb and nuclear energy).

Skill: Measuring variables

Description
Understand how to accurately measure the following to an appropriate level of precision. • Mass • Time • Length • Volume • Temperature • Force • Electric current • Electric potential difference • Angle • Sound and light intensity
Activities
Most of these variables can be incorporated into a range of standard experiments, for example: • gravitational mass in a Hooke’s law experiment with a spring balance • inertial mass in a lab applying Newton’s second law using technology • length in parabolic motion experiments • volume in density experiments of regular and irregular shapes • temperature in specific heat capacity experiments • force in potential risk and mitigation, as well as in equilibrium experiments with static situations • current and potential difference in Ohm’s law, resistivity or internal resistance experiments • angle in refractive index experiments • sound and light intensity in interference experiments or variations of intensity with distance.

Common instruments and sources of uncertainty should be addressed when measuring different variables. Through practical work students should look for more efficient and accurate ways to measure variables.
Example opportunities for integration into the physics programme
A.1 Kinematics: measuring time is usually not very accurate. Using a video with a slow camera can be a big upgrade. A.2 Forces and momentum: students should become familiar with analogue dynamometers to measure forces. C.2 Wave model: students should address how to reduce background noise when measuring sound and light intensity, and consider appropriate materials for isolation.

Tool 2: Technology

Skill: Applying technology to collect data

Description
• Use sensors. • Identify and extract data from databases.
Activities
There are a large number of possible activities using sensors such as: • temperature • pressure • position (ultrasound) • photogate/wireless smart gate • dynamics trolley fitted with sensors (measure force, position, velocity, three axes of acceleration, and three axes of rotational velocity) • force • rotational motion sensor • light (see "Experiment: Modelling albedo", downloadable PDF) • sound (see "Experiment: Modelling reverberation time", downloadable PDF) • current • voltage • magnetic field. Other sensors are available depending on budget; however, this list will facilitate a wide range of investigations. Students should engage in practical work and be allowed to use a range of different measuring sensors. In some cases where practical work is not feasible, databases can provide a source of data for students to work on. They should be able to extract relevant data from a table.
Example opportunities for integration into the physics programme
B.2 Greenhouse effect: working with databases can be a good way to see the theory in action, e.g. when exploring the greenhouse effect. There are many experimental simulations available on the internet, such as PhET.

Description
• Generate data from models and simulations.

Activities
Modelling generally involves using spreadsheets at this level although students can also write their own code. Models can be developed to investigate physical situations such as: • motion • momentum changes • energy flow • electrical circuits • power transfer • fields • three-body interactions • electromagnetic induction • radioactive decay • nuclear reactions. Simulations can provide a useful environment to carry out experiments that are not possible in a school setting.
Example opportunities for integration into the physics programme
A.5 Galilean and special relativity: a large number of resources are available on the internet, including games and applications, that amplify the effects of special relativity. D.1 Gravitational fields: there are several gravitation simulations online that can be used to gather data. For example, Kepler's third law can be tested with one of these simulations. E.2 Quantum physics: experiments in quantum physics usually require expensive equipment. There are many online resources that simulate quantum phenomena like the photoelectric effect and can be used to gather data. Some examples to work with are given in the downloadable resource "Drag and terminal speed modelling activity" (Excel). These can be used as templates by teachers or students to develop mathematical models in any aspect of the course.

Description
• Carry out image analysis and video analysis of motion.
Activities
There are datalogging producers available online that not only provide extensive details and worksheets on their websites to support datalogging in general in physics experimental work but also provide video analysis software. A popular free online video analysis application is called *Tracker*, which is used extensively in student internal assessments. Video can be a powerful tool to increase accuracy of various measurements. Students should have the chance to gather data from videos, whether filmed by them or obtained some other way.
Example opportunities for integration into the physics programme
A.1 Kinematics: study of free fall or other movements can gain a lot of accuracy by filming them with a chronometer in the frame to measure time in between events. C.1 Simple harmonic motion: the position of a simple harmonic motion is usually too quick to measure as a function of time. A video of an oscillating body together with a chronometer and ruler/measuring tape in frame can allow students to build a position vs time graph for a simple harmonic motion.

Skill: Applying technology to process data

Description
• Use spreadsheets to manipulate data. • Represent data in a graphical form. • Use computer modelling.
Activities
Spreadsheets are important tools in the recording and analysis of data. Ideally, students should be familiar with spreadsheet use by the time they start a DP physics course. However, it is recommended that time is set aside in class to ensure students have at least a basic understanding so they can: • record data • manipulate and process data • plot appropriate graphs • construct lines of best fit • use uncertainty bars. Computer modelling is discussed above as spreadsheets are excellent tools for mathematical modelling. Some students will be able to code and will therefore be able to create very useful simulations, perhaps to support an internal assessment or an extended essay. Students may need to carry out calculations of uncertainty propagation, which can be time consuming. Using spreadsheets to do these calculations can greatly reduce the amount of time students work on a laboratory report. Students should know how to build a graph from data in a spreadsheet. This will be particularly useful for their internal assessment. It can be done using the spreadsheet itself, but also using free graphing software available online. Students can also model systems using a computer. It can be done by programming, but also using spreadsheets.
Example opportunities for integration into the physics programme
B.1 Thermal energy transfers: a simple task to introduce uncertainties in data collection and graphing relates to determining the density of modelling clay. Working in pairs, students measure the mass and volume of a small piece of clay, recording their measurements in a shared table. This provides an opportunity to discuss uncertainty in measurement. Using a spreadsheet, students can plot mass (y-axis) vs volume (x-axis), adding uncertainty bars and a line of best fit. The value of the gradient of the line is the density of the clay. Maximum and minimum lines of best fit can be added to allow the students to determine the density of the clay with uncertainty.

Tool 3: Mathematics

Skill: Applying general mathematics

Description
• Use basic arithmetic and algebraic calculations to solve problems. • Calculate areas and volumes for simple shapes. • Carry out calculations involving decimals, fractions, percentages, ratios, reciprocals, exponents and trigonometric ratios. • Carry out calculations involving logarithmic and exponential functions. • Determine rates of change. • Calculate mean and range.

- Use and interpret scientific notation (for example, 3.5×10^6).
- Select and manipulate equations.
- Derive relationships algebraically.
- Use approximation and estimation.
- Appreciate when some effects can be neglected and why this is useful.
- Compare and quote ratios, values and approximations to the nearest order of magnitude.
- Distinguish between continuous and discrete variables.
- Understand direct and inverse proportionality, as well as positive and negative relationships or correlations between variables.
- Determine the effect of changes to variables on other variables in a relationship.
- Calculate and interpret percentage change and percentage difference.
- Calculate and interpret percentage error and percentage uncertainty.
- Construct and use scale diagrams.
- Identify a quantity as a scalar or vector.
- Draw and label vectors including magnitude, point of application and direction.
- Draw and interpret free-body diagrams showing forces at point of application or centre of mass as required.
- Add and subtract vectors in the same plane (limited to three vectors).
- Multiply vectors by a scalar.
- Resolve vectors (limited to two perpendicular components).

Activities

Most of the mathematical requirements outlined here will be covered in pre-DP courses including the Middle Years Programme (MYP), I/GCSE and middle school courses. Some are introduced at DP level in mathematics, often after they have been covered in physics. This section provides good motivation for interdepartmental planning between the physics (or science) and mathematics teams.

Vectors and scalars are covered here. This content should be taught in context (e.g. parabolic motion, conservation of momentum, work–energy, electromagnetic induction, fields).

Algebraic manipulation of equations is part of our day-to-day work in physics. Students should be able to easily solve equations and manipulate expressions algebraically. It is important, however, to see this as a necessary skill in the study of physics, but not as physics itself.

Many physics laws come in the form of a direct or inverse proportionality. Instead of students always thinking of equations, it can be helpful to encourage them to think of proportionalities and proportionality constants. An understanding of these relations should also enable students to predict the behaviour of one variable when another changes.

Example opportunities for integration into the physics programme

D.1 Gravitational fields: Newton's universal law of gravitation can be introduced as a proportionality relation between masses and distances. The universal gravitational constant can be introduced as the proportionality constant in this relation.

D.2 Electric and magnetic fields: Coulomb's law can be introduced as a proportionality relation between electric charges and distances. Coulomb's constant can be introduced as the proportionality constant in this relation.

Representing quantities as vectors is key for an accurate communication of results. Free-body diagrams are a good resource to emphasize the importance to distinguish between vectors and scalars and to represent vectors accurately.

Skill: Using units, symbols and numerical values

Description
• Apply and use International System of Units (SI) prefixes and units. • Identify and use symbols stated in the guide and the data booklet. • Work with fundamental units. • Use of units (for example eV, eVc^{-2}, ly, pc, h, day, year) whenever appropriate. • Express derived units in terms of SI units. • Check an expression using dimensional analysis of units (the formal process of dimensional analysis will not be assessed). • Express quantities and uncertainties to an appropriate number of significant figures or decimal places.
Activities
Measurements in physics is covered here. This content should be taught in context in virtually any part of the course. The importance of scientific communication should be constantly reinforced with the students. Every time a student expresses a quantity it should be in the correct unit and consider significant figures and decimal places. This is particularly important for assessment.
Example opportunities for integration into the physics programme
When introducing a new physical quantity in physics, it can be useful to show how it relates to other quantities using SI units. e.g. Newton, N If we start with $F = ma$, then $\mathrm{N} \Rightarrow \mathrm{kg\,m\,s^{-2}}$ e.g. Joule, J If we start with $W = Fs$, then $\mathrm{J} \Rightarrow \mathrm{N\,s} \Rightarrow \mathrm{kg\,m\,s^{-2}s} \Rightarrow \mathrm{kg\,m\,s^{-1}}$

Skill: Processing uncertainties

Description
• Understand the significance of uncertainties in raw and processed data. • Record uncertainties in measurements as a range (±) to an appropriate level of precision. • Propagate uncertainties in processed data in calculations involving addition, subtraction, multiplication, division and raising to a power. • Express measurement and processed uncertainties—absolute, fractional (relative) and percentage—to an appropriate number of significant figures or level of precision.
Activities
This content should be taught in context in virtually any part of the course where laboratory practical work is done. This will be examined in paper 1 and the internal assessment. Uncertainty processing should be viewed as an inherent part of scientific endeavour. Every practical work experience that students undergo should involve the use and processing of uncertainties.
Example opportunities for integration into the physics programme
The “Uncertainties” section of this teacher support material (TSM) contains example opportunities for integration into the physics course.

Skill: Graphing

Description
• Sketch graphs, with labelled but unscaled axes, to qualitatively describe trends. • Construct and interpret tables, charts and graphs for raw and processed data including bar charts, pie charts, histograms, scatter graphs and line and curve graphs. • Construct and interpret graphs using logarithmic scales. • Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes. • Draw lines or curves of best fit. • Draw and interpret uncertainty bars. • Extrapolate and interpolate graphs. • Linearize graphs (only where appropriate). • On a best-fit linear graph, construct lines of maximum and minimum gradients with relative accuracy (by eye) considering all uncertainty bars. • Determine the uncertainty in gradients and intercepts. • Interpret features of graphs including gradient, changes in gradient, intercepts, maxima and minima, and areas under the graph.
Activities
This content should be taught in context in virtually any part of the course where laboratory practical work is done. This will be examined in paper 1 and the internal assessment. Graphing is usually the goal in a practical experience. Scatter graphs in particular should be seen not only as a way to represent and communicate data, but also as a tool to calculate a given quantity from the slope of a best-fit line. Best-fit lines aim to increase the accuracy of measurements. Students should understand best-fit line as a tool and not just a way to represent the relation between variables in a graph.
Example opportunities for integration into the physics programme
There are many opportunities throughout the DP physics course to incorporate graph work. Students can gain practice in sketching graphs by watching videos of objects moving at both constant and non-constant speed, and by asking them to sketch position–time, velocity–time and acceleration–time graphs.

Inquiry process

Inquiry 1: Exploring and designing

Skill: Exploring

Description
• Demonstrate independent thinking, initiative and insight. • Consult a variety of sources. • Select sufficient and relevant sources of information. • Formulate research questions and hypotheses. • State and explain predictions using scientific understanding.
Activities

There are opportunities to develop all the approaches of learning skills of thinking, communication, social, research and self-management. It is important that students are digitally literate. Resources to promote this are available online, including help developing the "Big6 skills" (Eisenberg, Berkow, 2018). In physics, students should be given opportunities to work independently when developing research questions. The research question should always implicitly state the independent variables (IV) and dependent (DV) variables, however it is formulated. Students should be aware that any other variables should be controlled (CV), e.g. how the mass of an object (IV) affects the terminal velocity (DV) of it when dropped from a height of 1 metre (CV). Students should be encouraged to research the background physics behind the planned investigation using a variety of reliable resources. They should critique the value of each source and compare before deciding which are the most reliable and useful. It is important that students use a range of source types, not just the internet, and it is an IB requirement that all sources be fully referenced. Using their knowledge, students should make predictions such as "The terminal velocity of an item will increase as its mass increases" and should be able to link this to their knowledge (e.g. "As the mass of an object increases, its weight increases and hence when dropped it accelerates for longer before terminal velocity is reached. Therefore, they reach a higher terminal velocity."). This should be supported with equations and students should be able to predict the mathematical relationship between the variables. Students should be given the chance to develop their own methodologies and research questions. This is particularly important when considering the internal assessment. They should learn to do research by consulting different and sufficient sources. This is relevant both to formulate an informed hypothesis and to compare their results with relevant literature. Students should base their predictions and hypothesis in scientific arguments. They should use physics concepts to explain their reasoning.

Skill: Designing

Description
• Demonstrate creativity in the designing, implementation and presentation of the investigation. • Develop investigations that involve hands-on laboratory experiments, databases, simulations and modelling. • Identify and justify the choice of dependent, independent and control variables. • Justify the range and quantity of measurements. • Design and explain a valid methodology. • Pilot methodologies.
Activities
Students should be given numerous opportunities to design and develop their own physical inquiries. Support can be scaffolded to guide them through the process at first, then become more open-ended as they progress. The practical programme should be designed to involve a range of different experimental types to include hands-on laboratory equipment, online simulations and the use of databases. More prescriptive support can be used to develop students' laboratory and data collection skills before allowing students to develop their own research questions in preparation for the internal assessment. Students should be encouraged to design experiments where the equipment is not always available to encourage creativity. Students should also be given the chance to design their own methodologies. This involves the materials to be used, steps to be taken, how to measure, what to measure and what to keep under control. Students should be creative, showing that they are not simply repeating some other measuring technique in a different setting.

Piloting methodologies can be a useful skill to determine whether a methodology can be carried out or not. Students should consider extreme cases (highest and lowest values) to test their methodology.

Skill: Controlling variables

Description
Appreciate when and how to: • calibrate measuring apparatus, including sensors • maintain constant environmental conditions of systems • insulate against heat loss or gain • reduce friction • reduce electrical resistance • take background radiation into account.
Activities
Opportunities for students to calibrate apparatus (e.g. measuring temperature with an unmarked thermometer or a thermistor that can be calibrated first using fixed points). Some sensors require calibration although many modern ones are Plug and Play. Students should be encouraged to ensure that, where possible, friction should be minimized, electrical resistance reduced and heat losses minimized. However, where these cause experimental errors, students should learn how to allow for this and compensate by propagating uncertainties. Students should take intentional action to control the variables that are important in their methodologies. It is important to distinguish between constant quantities and controlled variables.

Inquiry 2: collecting and processing data

Skill: Collecting data

Description
• Identify and record relevant qualitative observations. • Collect and record sufficient relevant quantitative data. • Identify and address issues that arise during data collection.
Activities
Data collection is vital for any scientist as it is through observations and measurements that patterns, rules and mathematical relationships between variables are found. Virtually every practical task will involve the collection of primary data from an experiment or secondary data from an online database. The amount of data collected does depend on the actual experiment carried out. A bouncing ball investigation can be simple. However, an experiment investigating how the diameter of a ball bearing affects its terminal velocity in syrup has more limitations. As a general rule, students should aim for five values of IV, spread over the maximum possible range. For each value of the IV, at least three values of the DV should be collected to allow for random errors. This gives a better estimate of the uncertainty than the limitations of the measuring device. However, students should be aware that if there are turning points (maxima or minima) or similar, then it is wise to collect more data points around this point so it can be located accurately. Data collecting should not be a merely mechanical process. Students should determine how much and what data need to be collected in order to address their research question. Also, students should be able to make decisions as they measure different quantities to improve precision or avoid error.

Skill: Processing data

Description
• Carry out relevant and accurate data processing.
Activities
Processing, in general, will involve averaging the data for each IV and then plotting a graph of the mean value of the DV against the IV. The graphs could be linearized or log graphs could be plotted where appropriate to confirm or determine the relationship between variables. Spreadsheet software, along with experience and good scientific judgement, could be used to determine the relationship between the variables. Students should understand data processing as a tool that allows for further and deeper interpretation. In some cases, data processing may also be the only way to actually get to a variable. For example, it is hard to measure the kinetic energy of any given body. However, it is easier to measure its mass and speed and get the energy from there.

Skill: Interpreting results

Description
• Interpret qualitative and quantitative data. • Interpret diagrams, graphs and charts. • Identify, describe and explain patterns, trends and relationships. • Identify and justify the removal or inclusion of outliers in data (no mathematical processing is required). • Assess accuracy, precision, reliability and validity.
Activities
Graphs will be drawn and interpreted in many physics experiments. Students may linearize the graph using their knowledge and judgement to plot appropriate variables or they may select an appropriate trend line using the spreadsheet software. Sometimes an educated guess is useful. This enables students to determine the relationship between the variables. The use of error bars enables students to make a decision on whether outliers are included or excluded. Students should know how to include suitable error bars and how these may be used to plot graphs of maximum and minimum gradient to determine the uncertainty in the gradient and *y*-intercept, which may well be the results required from the experiment. Students should be able to interpret data, i.e. to bring physics into the discussion. A chart, a table or a graph are merely numbers until some physical meaning is attached to them. Interpretation of results is what allows students to test their hypothesis and answer their questions.

Inquiry 3: Concluding and evaluating

Skill: Concluding

Description
• Interpret processed data and analysis to draw and justify conclusions. • Compare the outcomes of an investigation to the accepted scientific context. • Relate the outcomes of an investigation to the stated research question or hypothesis. • Discuss the impact of uncertainties on the conclusions.
Activities

Students typically find concluding and evaluating challenging and tend to score lower marks in their internal assessment in this section compared with data collection, processing and analysis. Once relationships between variables are determined, the finding should be justified with scientific knowledge. If the student's knowledge contradicts the findings from the data, alternative explanations should be researched. Any conclusion should refer to the experimental uncertainties, which can be used to validate the findings compared to expectations. When concluding a scientific investigation, students should not only consider the answer to their research question, but also a comparison with similar investigations. This also includes comparison with the theoretical framework of their experience. When relevant, students should also consider how uncertainties affected their result. They should be specific, i.e. they should discuss what specific effect one or other source of uncertainty had in their data.

Skill: Evaluating

Description
• Evaluate hypotheses. • Identify and discuss sources and impacts of random and systematic errors. • Evaluate the implications of methodological weaknesses, limitations and assumptions on conclusions. • Explain realistic and relevant improvements to an investigation.
Activities
Evaluating involves considering the strengths and weaknesses of the background information researched, the experimental techniques and methodology, the data collected and the final conclusion. Students should be able to discuss the effect of weaknesses in the data obtained and the conclusions, as well as making several realistic improvements. Most experiments will give better and more reliable results if more data points are measured and if a wider range of data is collected with smaller intervals between the data points. The process of evaluating an experience should be seen as an inherent part of the scientific activity. Identifying sources of uncertainty and suggesting possible ways to reduce them should be a standard practice in physics laboratory experiences.

Uncertainties

What is an uncertainty?

Physics is a quantitative science, and experimental work is based on measurements. There is never a perfect or absolute measurement, and a degree of uncertainty is associated with all measurements. Uncertainties are the result of human involvement in making measurements, the instruments or equipment being used or environmental factors that can be difficult to control during data collection. Care should be taken to recognize and reduce uncertainties. It is important to record all measurements with a corresponding uncertainty.

Human involvement

Subtle differences can be introduced when humans take the same measurement several times. Reaction times for starting and stopping the timer are not always the same nor are they symmetrical, for example. Repeating the timing for the same distance may reveal an uncertainty larger than the basic precision of the measurements. Uncertainties due to reaction time often become apparent through repeated measurements under the same conditions.

Parallax error is caused by reading an analogue device at an angle to the scale markings. Depending on how observations are made, a degree of uncertainty caused by parallax can be introduced. If a measurement on an analogue scale is always taken by looking from the left of the scale, then measurements may be slightly larger than they should be. This can be reduced through good experimental practice and ensuring devices are read in an optimum way. Parallax error may appear as a systematic shift on a graph.

Instruments and equipment

Instruments used to make measurements will have an inherent uncertainty and this is often stated by the manufacturer. Repeated measurements of the same system may show some fluctuations in the data due to the instrument. In addition, measurements of a given quantity using two (or more) devices may show some differences. Any one measurement is not necessarily wrong, but all devices have a degree of uncertainty associated with them.

Environmental factors

Environmental factors could include temperature, air resistance or background radiation. For example, in an experiment to measure how the coefficient of restitution of a squash ball depends on the temperature of the ball, the time lapse between heating the ball and making the measurements will cause a change in the temperature of the ball. While such sources of uncertainty cannot be entirely eliminated, steps can be taken to reduce their impact.

Uncertainties in raw data

Determining the sizes of uncertainties

During the Diploma Programme (DP) physics course, students will develop skills on how to estimate uncertainty. The IB does not prescribe one method and the course allows for a range of approaches to be applied. It is important that when determining the size of any uncertainty, a student should be able to justify their choice based on the measuring device and how well they were able to make the measurement.

Experimental example

As part of an experiment to determine the acceleration of freefall, a student measures the time it takes for a ball to roll a given distance down an incline as 2.3 s. In determining the sizes of the uncertainties, it should first be recognized that there is a limit to the precision of the stopwatch and a limit to the precision of the metre rule.

All measurements involve two reference points. The first reference point for a time measurement would be at 0. The time read-out of 0.0 s could require a brief interval of 0.067 s before it begins timing. That is, the zero reading is really –0.067 s. Or, when the timer starts it could already be at a time of 0.0123 s. It can be estimated that any zero reading has an uncertainty of one-half the least count.

The second reference point is the measurement of the event. A measurement of 2.3 s could have been 2.2876 s rounded up or 2.3210 s rounded down. In either case, the measurement could be off by up to one-half the least count, or ± 0.05 s. However, this uncertainty would be inconsistent with the one-decimal place precision of the measured time.

In the worst possible case, twice one-half the least count equals plus or minus the least count. The timing in this example would be (2.3 ± 0.1) s, as noted in the table on measurement and least count. Uncertainties associated with a single measurement must be expressed to the same degree of precision as the measurement. This least count of the timer is the minimum uncertainty that should be recorded for a single measurement. This is the minimum uncertainty, although often it is greater and this normally becomes evident with repeated measurements.

Measurement and least count

Measurement	Least count
2.3 s	0.1 s
2.34 s	0.01 s
2.345 s	0.001 s

The same rule applies to analogue devices such as a metre rule.

Significant figures in raw data must be recorded precisely and consistently, as seen in the table on correct and incorrect expressions of a length and its uncertainty.

Correct and incorrect expressions of a length and its uncertainty

Correct	Incorrect
(87.4 ± 0.2) cm	(87.4 ± 0.05) cm (87.4 ± 2) cm

Propagation of uncertainties

Processing data may involve several mathematical operations, such as sum and difference, product and quotient, exponential powers, and trigonometric and logarithmic functions. The required basic rules are provided in the *Physics data booklet*.

All processed data should be presented clearly. Basic mathematical operations do not need to be illustrated. More specific and complicated calculations should be illustrated with a sample calculation.

Uncertainties and repeated measurements

The quality of data is revealed by the scatter of data points above and below the best-fit line. These are called "random uncertainties" and they demonstrate that measurements never have zero uncertainty. Repeated measurements are the norm in physics, but repeated measurements do not reduce random errors in the measuring process. Repeated measurements reduce the standard deviation of the mean, but statistical analysis is not expected in DP physics.

When making repeated measurements, the uncertainty of the mean can be determined by taking one-half the range between the maximum and minimum values. Symmetry can be assumed, so that the plus and minus values are the same.

For example, the extended length of a spring under the same tension is recorded five times, as displayed in the table on the length and mean length of a spring.

Data on length and mean length of a string

Length of spring, *L* (cm) **Δ*L* = ± 0.1 cm**	**Mean length of spring,** $\overline{L}$ **/ cm**
11.5	11.16
11.0	
11.1	
11.0	
11.2	

$$\begin{aligned}\text{Range} &= \text{maximum} - \text{minimum}\\ &= (11.5 - 11.0)\ \text{cm}\\ &= 0.5\ \text{cm}\end{aligned}$$

One-half the range is 0.25 cm.

Raw data values, the mean value and the associated uncertainty should be expressed to consistent degrees of precision by recording the value to a consistent number of decimal places. As all raw data are recorded to one decimal place, a second decimal place in the mean and uncertainty is not justified. Thus, the mean and uncertainty are best expressed as (11.2 ± 0.3) cm.

However, if this value is used to plot a graph with uncertainty bars, then the additional decimal place can be retained to avoid compounding rounding errors during data processing. Rounding in preliminary processing steps can distort the resulting uncertainty. It is common practice in physics to record one or more additional decimal place during processing, keep additional decimal places and only round at the end.

If repeated measurements reveal no differences, then the least count should be taken as the uncertainty. If one-half the range reveals an uncertainty that is smaller than the individual raw data uncertainty, then the uncertainty in the mean must be taken as the larger of the two values.

Processing uncertainties with trigonometric functions, exponentials, logarithms and other functions can result in asymmetric uncertainties. In these cases, the uncertainty bar above and below the datum point would not be equal. Each extreme would be calculated [e.g. log $(x + \Delta x)$ and then log $(x - \Delta x)$]. However, for the purposes of internal assessment, this subtle detail is not expected and symmetric uncertainty bars are acceptable.

Significant figures in uncertainties

Most uncertainties should be expressed as a single digit and to the same decimal place as that of the quantity value. However, if the uncertainty begins with 1, then two significant figures are acceptable, as seen in the table on correct and incorrect significant figures in uncertainties.

Correct and incorrect significant figures in uncertainties

Correct	**Incorrect**
(12.2 ± 0.4) m (14.23 ± 0.12) s	(12.2 ± 0.36) cm (14.23 ± 0.1) s

Processed data tables

Quantitative data should be tabulated. It is good practice to include a heading with the name of the quantity (e.g. distance), the symbol of the quantity (d), the unit of the quantity (cm) and the uncertainty for this unit ($\Delta d = \pm 0.2$ cm).

Clear and precise tabulated data can include a combination of processed and raw data to help focus the processing. Explanations of the uncertainty and processing should be provided in the text.

Experimental example

A student measures the period of a simple pendulum of a given length and records these observations in a table.

Controlled variables can be included outside the table, as seen for the table showing an example of properly presented raw and processed data.

An example of properly presented raw and processed data

Pendulum length, L (cm) = 80.0 ± 0.1

Time for 10 periods T_{10} /s **$\Delta T_{10} = \pm 0.01$ s**	**Period T /s** **$\Delta T = \pm 0.001$ s**	**Mean period $\overline{T}$ /s** **$\Delta T = \pm 0.0425$ s**	**Mean period squared $\overline{T}^2$/s** **$\Delta T^2 = \pm 0.1498$ s^2**
17.90	1.790	1.7618	3.1039
17.38	1.738		
18.00	1.800		
17.66	1.766		
17.15	1.715		

$$\frac{\text{Range}}{2} = \frac{\text{maximum} - \text{minimum}}{2}$$
$$= \frac{(1.800 - 1.715)}{2} \text{ s}$$
$$= 0.0425 \text{ s}$$

$$\text{Mean period } \overline{T} = 1.7618 \pm 0.0425 \text{ s}$$
$$= 1.7618 \pm 2.4123\%$$

To determine uncertainty in T^2, the percentage uncertainty in T is doubled.

$$T = 1.7618 \pm 2.4123\%$$
$$T^2 = (1.7618)^2 \pm 4.8246\%$$
$$= 3.1039 \text{ s}^2 \pm 4.8246\%$$
$$= 3.1039 \text{ s}^2 \pm 0.14975 \text{ s}$$
$$= (3.10 \pm 0.15) \text{ s}^2$$

Rounding to appropriate significant figures and precision takes place only at the end of the processing.

Data tables using spreadsheets

A spreadsheet can be used to present and process data, and a screenshot may be included in submitted work. It is good practice to note that a spreadsheet has been used. When using a spreadsheet, it is not always possible to include uncertainties or other details of the measured quantities in the headings. In presenting the data, any missing information can be mentioned in the text close to a screenshot of the spreadsheet data. See, for example, the figure on data processing using a spreadsheet.

An example showing data processing using a spreadsheet

	A	B	C	D	E	F
1	Length / cm	10 periods / s	Period / s	Mean period, T / s	(1/2) Max - Min period / s	Mean T^2 / s^2
2	80.0	17.90	1.790			
3	80.0	17.38	1.738			
4	80.0	18.00	1.800	1.7618	0.0425	3.10393924
5	80.0	17.66	1.766			
6	80.0	17.15	1.715			

Student comments could include the following.

The length uncertainty was ± 0.1 cm and the minimum uncertainty for 10 periods was ± 0.01 s. Using the spreadsheet, the time for 10 periods was divided by 10 to obtain the time of a single period. Then, the mean value of the five measurements was determined to be 1.7618 s. The spreadsheet was used to determine half the range of the individual period measurements.

The "Show Formula" function in Microsoft Excel can also be used to illustrate data processing, as displayed in the figure on the screenshot of this function.

Screenshot of the Show Formula function turned on during data processing using a spreadsheet program

	A	B	C	D	E	F
1	Length / cm	10 periods / s	Period / s	Mean period, T / s	(1/2) Max – Min period / s	Mean T^2 / s^2
2	80	17.9	=B2/10			
3	80	17.38	=B3/10			
4	80	18	=B4/10			
5	80	17.66	=B5/10			
6	80	17.15	=B6/10	=AVERAGE(C2:C6)	=0.5*(MAX(C2:C6)-MIN(C2:C6))	=D2*D2

Graphing uncertainties

Uncertainty in raw data should be propagated and can be shown as uncertainty bars on graphs. Uncertainties in processed data should be considered in the interpretation of the data. When a linear graph is established and the gradient is meaningful, uncertainty bars should be used to establish the uncertainty in the value of the gradient.

Automatic gradient determination

Software that automatically determines gradients may be used, but the student must make clear that they understand the process taking place.

Experimental example

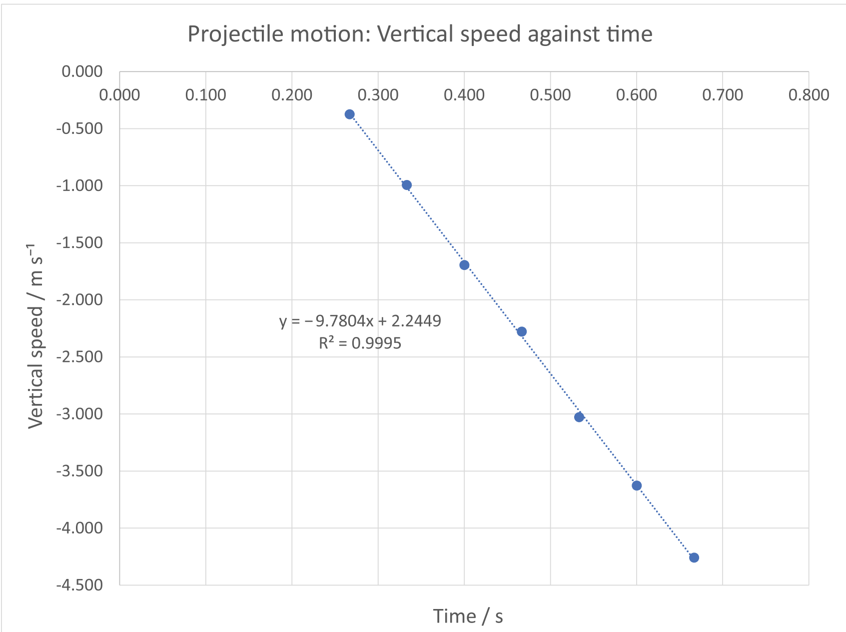
A student conducted an experiment using video to analyse the projectile motion of a ball launched horizontally from a table. The student clicked on the image position for consecutive time intervals. The software determined the speed at each position, as shown in the table on time, X and Y positions and vertical speed. A graph on vertical speed against time was generated automatically, and the gradient was determined by the software. Acceleration due to gravity is the vertical acceleration of the projectile. The student described what was done. An equation or sample calculation is not required for the experimentally determined value of acceleration, but the student must explain how the gradient represents acceleration. Uncertainties should still be addressed and stated in a format consistent with the final value.

The student could use this result as part of an investigation into a factor that affects the acceleration of a falling object.

Determination by software of the speed of the ball at each position

Time (s)	*X* position m	*Y* position m	Vertical speed /m s^{-1}
0.000	−0.001	1.081	0.000
0.067	0.101	1.091	0.149
0.133	0.200	1.084	−0.106
0.200	0.297	1.084	0.000
0.267	0.396	1.059	−0.373
0.334	0.495	0.993	−0.992
0.400	0.594	0.880	−1.694
0.467	0.693	0.728	−2.279
0.534	0.793	0.526	−3.028
0.600	0.893	0.284	−3.628
0.667	0.986	0.000	−4.258

Graph of vertical speed against time



The slope of the line is calculated as follows.

$$m = \frac{\Delta y}{\Delta x} = \frac{\Delta v}{\Delta t} = a$$

$$= -\ 9.7804\,\mathrm{m\,s^{-2}}$$

There is no need to add the R^2 value to graphs.

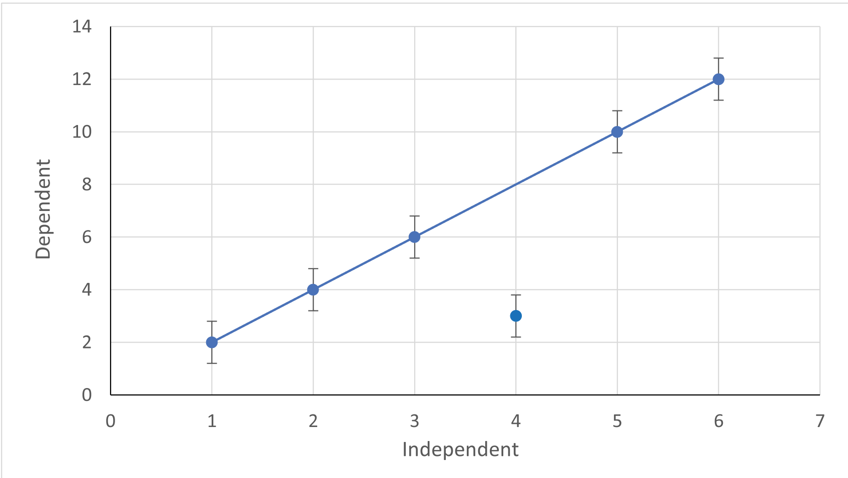
Uncertainty bars

Uncertainty bars are added to the dependent variable on graphs. This can be achieved using graphing software. The size of the uncertainty bar should reflect the size of the uncertainty for that data point and be based on the spread of data obtained from repeated measurements. It is acceptable to assume that uncertainty bars will be symmetrical around each data point.

Data outliers

When processing or graphing experimental data, there may be a data point that does not fit the overall pattern or trend of the other data, as seen in the figure on an example of an outlier on a graph. This is a potential outlier. In physics, outliers are most likely to occur as a result of human error such as a methodological fault or an irregularity in the equipment or environment. These can be recognized and corrected at the time of collecting data. The quantity in question can be remeasured. When adding the best-fit line or best-fit curve, a decision needs to be made whether to include or exclude any possible outliers, and a justification should be provided.

An example of an outlier on a graph

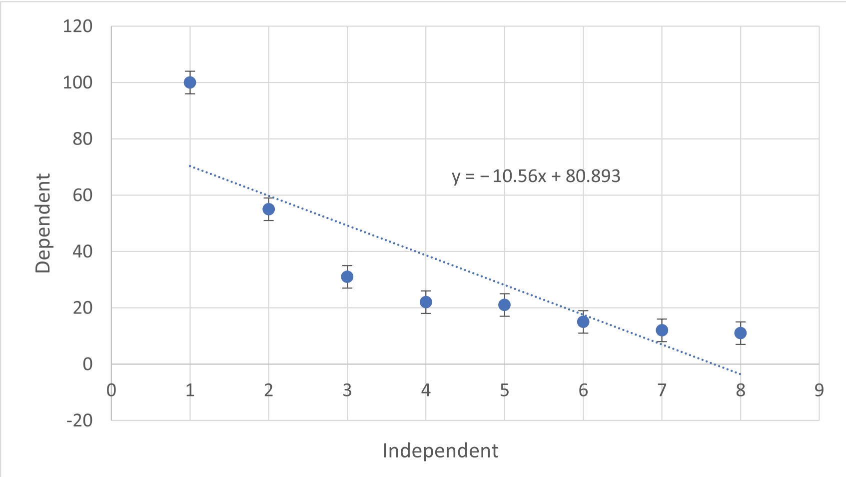


The graph illustrates an example of a genuine outlier. The student reasoned that a linear relationship exists between the variables, and that it did not make sense that one point should be so far off the obvious trend. The approach used in DP mathematics to identify outliers is not required in DP physics.

Best-fit line or best-fit curve

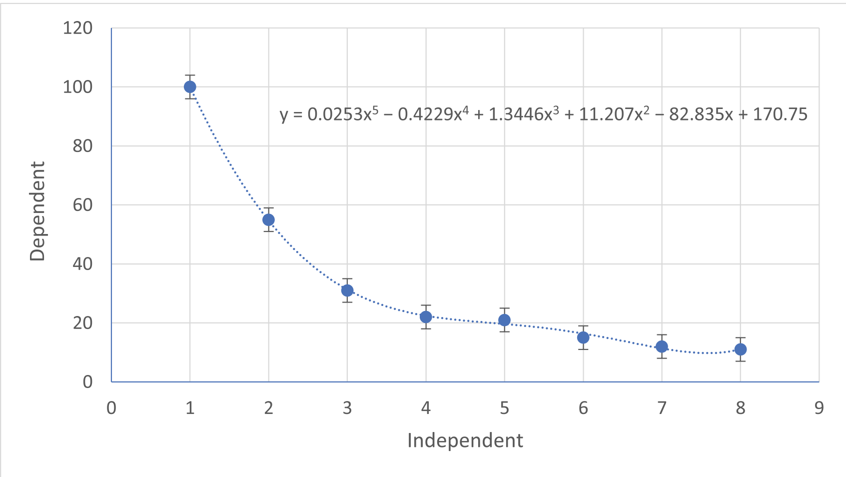
A best-fit line or best-fit curve should be added to all graphs, and the choice should be driven by the relevant physics theory. The best-fit line or best-fit curve does not need to pass through all the data points, but it should pass through—or be close to—all uncertainty bars. Otherwise, the line would not be a best-fit line, as shown in the figure on the inappropriate line added to a graph.

Inappropriate line added to a graph



A polynomial curve that passes very close to all the data points can be added, as seen in the figure on data points joined by a polynomial curve. However, the nature of the curve is unlikely to be supported by the laws of physics.

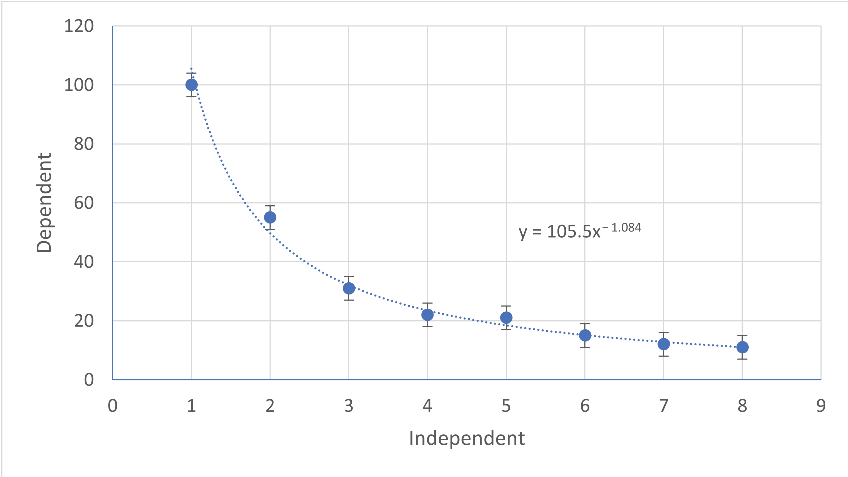
Example of all data points joined by a polynomial curve



The equation of the curve provided by Excel is $y = 0.0253x^5 - 0.4229x^4 + 1.3446x^3 + 11.207x^2 - 82.835x + 170.75$.

The final example shows a curve that passes close to each data point and through the uncertainty bars.

Curve passing through each data point and the uncertainty bars



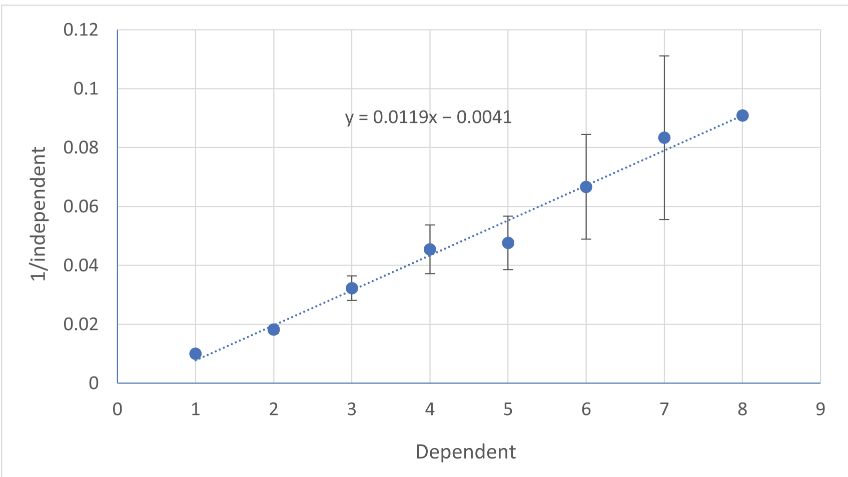
Straight line graphs

In some cases, plotting the experimental data will generate a linear fit. When this occurs, the gradient and intercept can be determined and related to the relevant theory in the conclusion.

A non-zero intercept may suggest a systematic error that should be discussed in the evaluation, or it may relate to a physical quantity (see in "Examples of uncertainties in processed data", example 2).

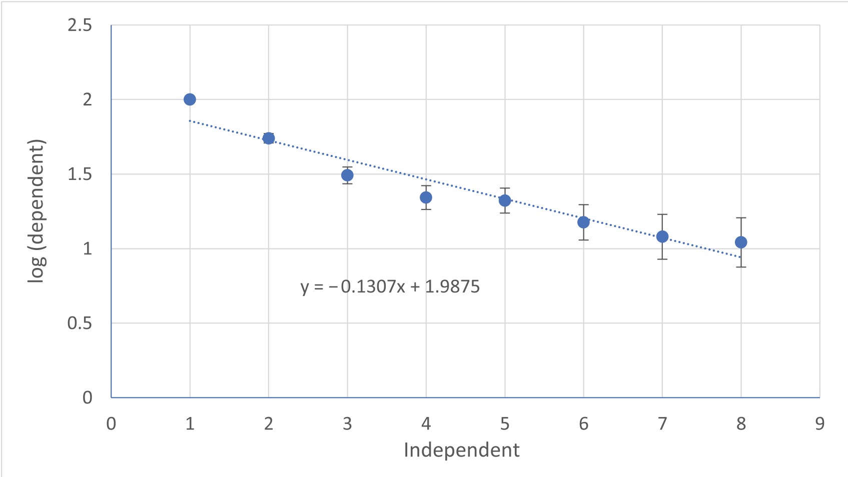
In cases where a best-fit curve has been drawn, the student must decide if the data can be linearized easily. Relevant background theory, for example squaring reciprocals of one variable, or dimensional analysis, can provide direction, although this normally requires ideal data. It should be noted that the linearization of data can be a useful exercise but is time consuming and may not be worth pursuing at the expense of other tasks. For instance, consider the data from the above example. The reciprocal of one of the variables is taken and these data are then plotted. The uncertainties are processed and graphed, as seen in the figure on linearizing data by taking the reciprocal of one variable.

Graph obtained after attempting to linearize data by taking the reciprocal of one variable



An alternative approach also exists, as seen in the figure on plotting the log (dependent variable) versus the independent variable.

Alternative attempt to linearize data by plotting the log of one variable against the other variable



Maximum and minimum lines of fit

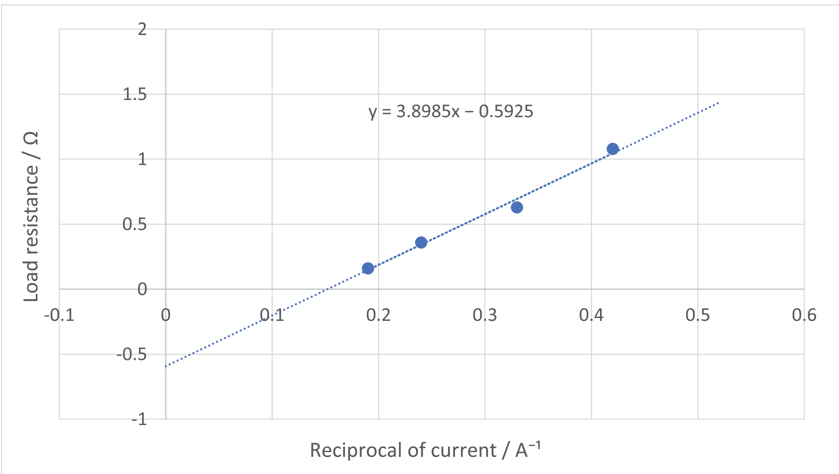
If a straight line has been drawn on a graph, uncertainty bars should be used to draw two further lines: one showing the maximum permissible gradient, and the other showing the minimum permissible gradient. In doing so, all data points and corresponding uncertainty bars should be considered, not simply the first and last points. This allows for the determination of the gradient and intercept with uncertainty.

Examples of uncertainties in processed data

Comparison with literature values (example 1)

Experiment	Indicators
A student investigated the ohmic behaviour of an electrical conducting material. The results were used to determine the resistivity. The experimental value of the resistivity of aluminium was calculated to be $(3.0 \pm 0.5) \times 10^{-8}$ W m.	The accepted value of the resistivity of aluminium is 2.8×10^{-8} W m. A textbook reference or online source must be given for this value. The experimental range of the experimental value includes the accepted value. The percentage difference is calculated as follows. $= \frac{2.8 - 3.0}{2.8} \times 100\%$ $= \frac{0.2}{2.8} \times 100\%$ $\approx 7\%$
Learning opportunities	
Calculate the percentage uncertainty in the experimental result and comment on this in the evaluation. $= \frac{0.5}{3.0} \times 100\%$ $\approx 17\%$	

Comparison with literature values (example 2)

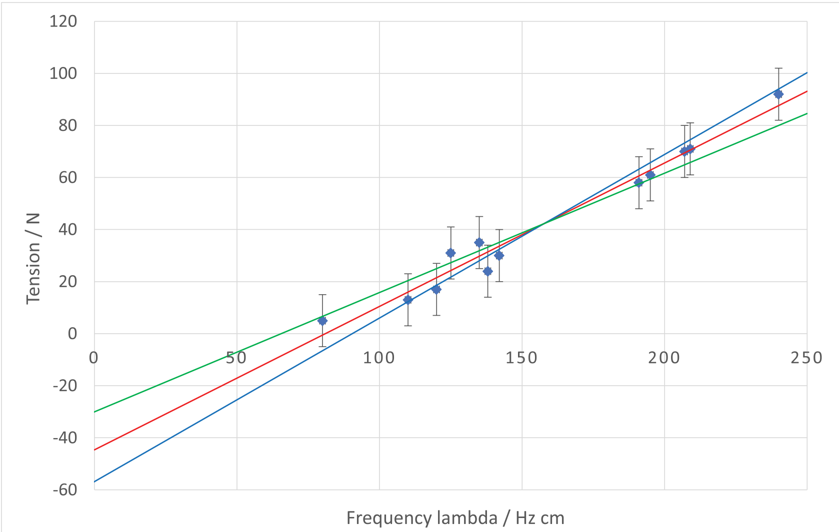
<table>
<tr><th>Experiment</th><th>Indicators</th></tr>
<tr><td>A student investigated the internal resistance of a 6-V battery. They measured the voltage and current with digital meters for a variety of resistance loads. Following relevant theory,
$\varepsilon = I(R + r)$
$\frac{\varepsilon}{I} = R + r$
$R + r = \frac{\varepsilon}{I}$
$R = \frac{\varepsilon}{I} - r$
$R = \varepsilon\frac{1}{I} - r$
$y = mx + c$
The student constructed a graph of the calculated load resistance R against the reciprocal of the current $\frac{1}{I}$. This graph showed only the first four data points so that the view of the y-intercept was enhanced.
Theory indicates that the y-intercept represents the negative of internal resistance.
Uncertainties were determined and propagated correctly but were not visible on the graph.</td><td>The y-axis intercept, corresponding to the negative of internal resistance, is −(0.5925 ± 0.0866) Ω. That is,
$r \pm \Delta r$ = (0.59 ± 0.09) Ω
Note: For clarity, uncertainty bars and max–min lines are not shown on the graph.
The student was able to find the manufacturer’s specification sheet online and discovered that the internal resistance of a new battery would be 0.483 Ω (no uncertainties were listed). Background information states that temperature affects the internal resistance and that the internal resistance increases as the battery is used.
The student speculated that the battery’s internal resistance may have increased over repeated measurements. The experimental value of 0.59 ± 0.09 Ω compared to 0.483 Ω seems reasonable, given this information.</td></tr>
<tr><td colspan="2">Graph

</td></tr>
<tr><th colspan="2">Learning opportunities</th></tr>
<tr><td colspan="2">The experimental value of internal resistance and its uncertainty range did not include the manufacturer’s value (r_{min} = 0.50 Ω > r_{new} = 0.48 Ω). The student’s results were close and of the same order of magnitude,</td></tr>
</table>

and the difference was addressed in a plausible way. However, this aspect should have been noted by the student.

Using theory to determine analysis

Experiment	Indicators
A student conducted a simple sonometer laboratory exercise and quoted the known equations relating frequency *f*, tension *T* and mass per unit length μ. In the background and theory section, the equation $T = v^2 \mu$ was stated.	The student sketched the results in a graph of tension against $f\lambda$, which refers to wave speed. They quoted an R^2 correlation value of 0.985 and thereby claimed that their hypothesis of a "direct relationship between tension and frequency" was 99% certain.

Graph



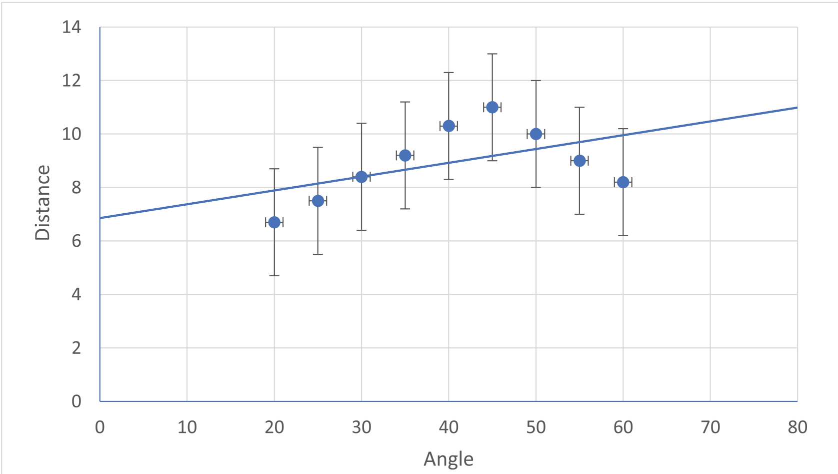
Learning opportunities
While expressing speed in units "Hz cm" is acceptable, there is a contradiction between the known theory, the graphical analysis and the conclusion shown here. If the student had understood the known theory, they would not have forced a linear fit. The student should, therefore, make a comparison to the known theory. No attention was paid to the *y*-intercept other than calculating the gradient range. No attempt was made to explain what negative tension means (not even as a systematic error) and how this would cause a resonating frequency from 0 to about 75 Hz. An explanation of the physical meaning of the results was also missing.

Large uncertainties: potential problems

Experiment	Indicators
A student investigated the relationship of projectile range and launch angle. They obtained a range of angles and propagated uncertainties, as seen in the uncertainty bars.	A graph of launch angle against distance was plotted with uncertainty bars. A single best-fit line was applied to the whole data set, and the student stated that as the launch angle increases, the distance increases.

The student's hypothesis was qualitative and only stated that the range would increase with the angle. In the background research, the student mentioned the textbook theory of maximum range at 45° if there is no noticeable air resistance.	

Graph



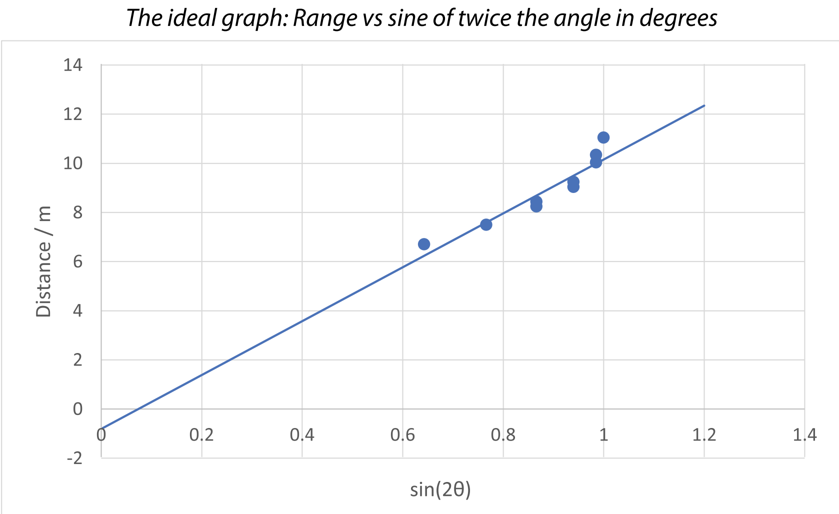
Learning opportunities

At ± 2 m, the uncertainties appear large. While a linear fit lies within the uncertainty bars, this is not justified by theory. Touching all the uncertainty bars is not a justification here, as the data scatter is not linear. If the student had constructed the minimum and maximum gradients, the values could have ranged from positive to negative, including a zero gradient.

The student should have commented about the *y*-intercept at 7 m. How does this relate to the experiment?

The student should have referred to the theory while conducting the analysis. One thing is obvious from the graph: the maximum range was obtained at about 45°.

Further data processing could have been carried out by referring to the textbook equation for projectile range and drawing a graph of range against sin(2θ). The ideal result would be a line with the maximum range at sin(2θ) = 1, which is 45°.



Uncertainties in scientific investigation

Addressing the conclusion criteria

This section concerns addressing uncertainties in the context of the criteria for the conclusion of the scientific investigation.

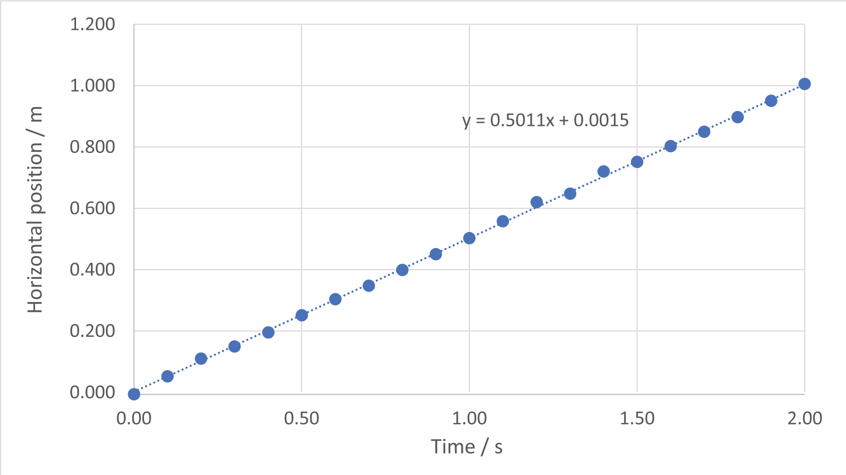
Precision and accuracy

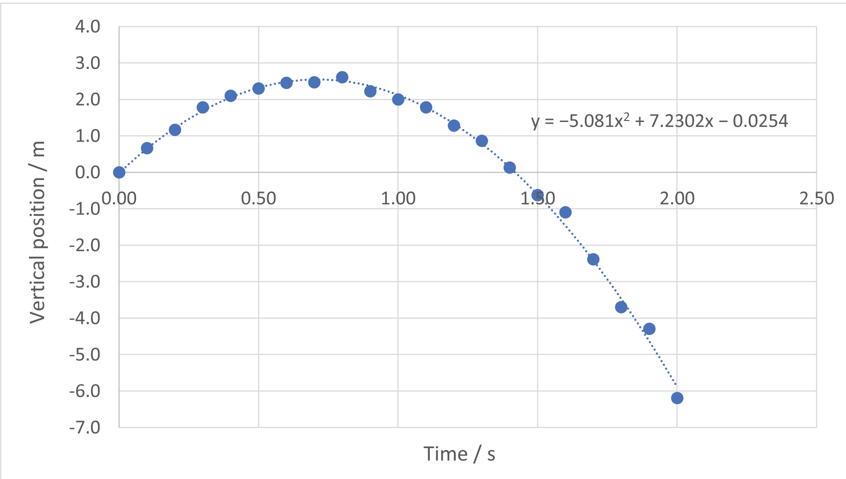
Video analysis of projectile motion

A student analysed projectile motion using video analysis, as shown in the figure on horizontal and vertical positions versus time. The results were satisfactory, but the methodology contained some limitations or assumptions.

Students should be familiar with resolution, frame rate or timing, scale and parallax. Students must address any issues pertaining to their research questions, aspects that become apparent once they have analysed the data.

Analysis of horizontal and vertical projectile motion using video





Possible sources of uncertainty include the following.

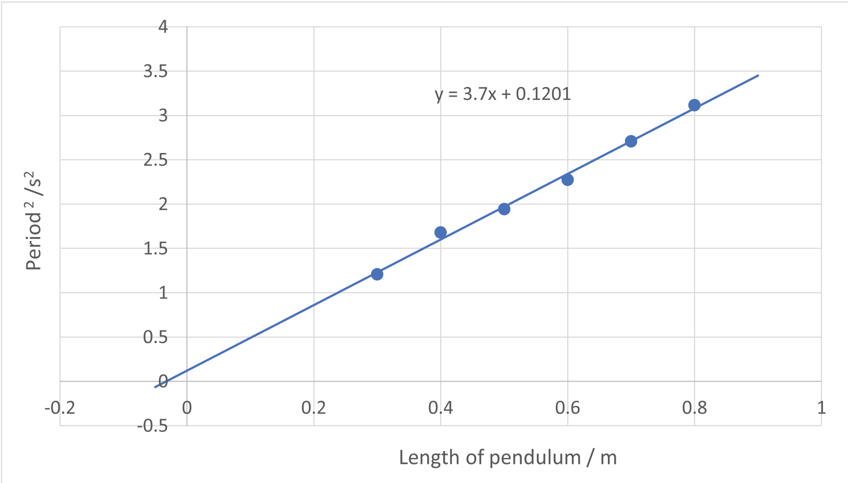
- The camera had a fixed position, and there were parallax issues (leading to a lack of accuracy) when the ball's path moved from the left to the right of the camera. Increasing the distance away from the projectile path would reduce the parallax, but this would make the object smaller and make it more difficult to locate a fixed point.
- The projectile path was assumed to be in a single plane. In real life, this is not the case, and this resulted in a lack of accuracy. A second and third camera could record the other two dimensions and determine if the motion out of a single plane was significant.
- The images revealed fuzzy edges of the ball. The limit of resolution affected the precision of the measurements. An increased frame rate would improve the precision.

Due to the random error exhibited on the graph, it was clear that the last issue noted here would be the most significant.

Pendulum: A systematic shift

In a simple pendulum investigation, the student graphed the period against the square root of the length and obtained a straight line. However, the line did not go through the origin as expected, as shown in this figure.

Graph depicting systematic shift



The student should appreciate the size and direction of the systematic shift in the data and consider this aspect in the evaluation section.

The student should consider either of the following.

- The y-intercept is 0.1201 s^2, or there is a systematic shift in the time of 0.346 s, which suggests that all measured times are approximately 0.35 s shorter than they should be.
- The x-intercept is –0.0325 m (found by solving for x when $y = 0$), which suggests that all measured lengths are approximately 3.3 cm shorter than they should be.

Addressing the evaluation criterion

This section concerns addressing uncertainties in the context of the evaluation criterion of the scientific investigation.

As part of the evaluation, the student must refer to issues identified as weaknesses or limitations. These are issues that can apply to the quality of the data or the specific details of the student's research question and methodology. Based on these weaknesses or limitations, the student should suggest improvements. Generalities such as "take more measurements" or "improve precision" should be avoided as the context is missing. Issues about the quality of data and sources of uncertainties should be addressed. Any suggested improvements must be plausible and specific.

The following is a detailed example where the student explains the impact of methodological weaknesses and offers realistic improvements relevant to these weaknesses.

Refractive index

A student investigated how the temperature of water affects the refractive index of light. A standard textbook method was followed. A fish tank with a water heater was set up, and a laser was secured at a 45° angle above the water surface. A ruler was fixed at the bottom of the tank (under water), and the distance from where the laser beam hit the ruler was read off.

The water depth was measured and, using the two perpendicular lengths, the angle of refraction was determined. The 45° incident angle remained fixed for all temperatures. This method was repeated for every 5°C for a temperature range from 5°C to 90°C, as seen in the table on temperature versus experimental value of refractive index.

The measured distances were a few centimetres, with a claimed precision of 1 mm. The incident angle was measured with a protractor with an uncertainty of 1°, and the refracted angle was calculated.

The student discovered that the refractive index of water decreases as temperature increases, as displayed in the table on temperature versus experimental value of refractive index. The results were feasible and suggested a curve that resembled known theory.

Temperature vs experimental value of refractive index for water (only selected data are shown)

Temperature / °C	Experimental value of refractive index ± 0.02
5	1.238
⋮	⋮
20	1.287
⋮	⋮
90	1.192

Upon closer examination, however, the student began to question their methodology and the results.

The textbook value of the refractive index of water at 20°C is 1.333. The accepted value was not included in the experimental range. The student believed an error must have occurred in the either method or the data analysis.

The student noted that other factors cause a variation in the refractive index, including:

- the wavelength of light
- effect of atmospheric pressure on the refractive index
- purity of water.

For all these factors, only the fourth and fifth decimal places would be affected.

The student calculated the range of their refractive index values. The results showed a change in the index of $n_{90°} - n_{5°} = (1.192 - 1.238) = -0.046$. In contrast, the theoretical change for the same temperature range should have been only –0.012. The student's range of refractive index was nearly four times greater than the theoretical range. They realized that the problem was not a systematic error.

The following is a list of weaknesses in the method and relevant improvements.

Methodological weaknesses	Improvements
The uncertainty in the distance was stated as 1 mm.	Aligning the zero end of the ruler while under water required the zero point to be directly below the interface point on the surface of the water. The laser beam itself was a few millimetres wide. Looking through the water revealed some distortion of the image. These issues suggest that a larger uncertainty should be considered.
Precision is low when calculating the refractive index from a single set of angles.	Vary the incident angle and, with the corresponding refracted angle, use a graph to determine the best-fit line that represents the refractive index value. This would improve precision.
The use of a fish tank and the low precision of the angle measurements are also weaknesses.	Replace the fish tank with a hollow transparent prism on a turntable. Measure the laser beam deviation several metres across the room. The uncertainty would be a significantly smaller percentage of the actual measurement.
A polynomial best-fit curve of refractive index against temperature is only qualitatively related to known theory.	Relate the refractive index to the water density and look for a linear function. With an improved method and precision, a more accurate result might be obtained.

Methodological weaknesses	Improvements
	Graphing theoretical and experimental values on the same graph will highlight any issues.
Heating requires agitation of water to equalize temperature throughout the tank. This affects the surface of the water and the incident laser beam.	Start with hot water and let it cool slowly to room temperature. Then, start with cold water and let it warm up to room temperature. Do not agitate the water and keep the thermometer in a fixed position.
A non-linear systematic error could occur in the index calculations. Some unidentified quantity affects all the calculations but in an increasing amount. The fish tank method did not consider the slight change in water depth, which was assumed not to change during the experiment. This wrong assumption could be the source of the non-linear error.	A revised method (with a prism and turntable) should be used to measure multiple data sets to find the index at a given temperature and eliminate the compound error.

Teacher and student responsibilities

This section outlines the actions and responsibilities of both teachers and students during the scientific investigation. The teacher is the mentor who provides guidance and support to students during the process, so that students can demonstrate the necessary inquiry skills described in the sections "Approaches to learning", "Approaches to teaching" and "Skills in the study of physics".

Teachers are encouraged to accompany and guide students in this journey, allowing them to make their own decisions with confidence, replicating the processes undertaken by scientists. Topics that have some personal significance will encourage students into more innovative approaches.

Teacher responsibilities

General responsibilities

Teachers must provide "non-decision-making" guidance and support. They must develop a range of strategies to ensure ongoing authenticity of the student work, which may include:

- discussing with students their initial proposals and the investigative methods to be used
- being present and supervising students during data collection
- discussing the content of the work with students and the conclusions being drawn
- scrutinizing the draft and final versions of the work, e.g. by comparing a student's writing style with that of their other work, or using web-based applications to detect plagiarism.

Specific responsibilities

While facilitating the scientific investigation, teachers have the following responsibilities.

Prior to student development of a research question, teachers must:

- explain the aims and requirements of the scientific investigation, ensuring that the criteria are well understood by students
- ensure that students have developed the required skills for their scientific investigation and for authoring their reports
- encourage students to explore ideas and ask questions that relate to topics studied during the course
- remind students that different types of investigation could be carried out, e.g. hands-on investigations, fieldwork, use of databases and online simulations
- ensure that approximately 10 hours are allocated for the design and implementation of the scientific investigation.

During student development of a research question, teachers must:

- discuss with students the appropriateness of their research question for a report with a 3,000-word limit
- counsel students on whether the projected research is suitable for the physics course and feasible in terms of time, resources, and safety, ethical and environmental considerations
- ensure that each student develops their own research question
- ensure that the investigative method proposed by each student is adequate to obtain valid and sufficient data.

During initial collaborative work, teachers must:

- guide students in organizing themselves into groups

- ensure that each group consists of no more than three students.

In this phase, the school, the teacher and the students share responsibility for ensuring that each student's input is assessed only on the work they carry out for their own investigation.

During the investigation, teachers must:

- supervise the work and data collection carried out by students. If students are collecting data outside the classroom, sufficient steps should be established to ensure authenticity of student work
- monitor student progress in data collection and processing
- where necessary, show students how to operate equipment, or guide them in the steps needed to carry out tasks such as graphical analysis and navigating a database. However, the teacher should not choose equipment, the method of analysis, or the database for the students.

During report writing, teachers must:

- remind students of the requirements of the written report—it should be relevant and concise, with references—and of the assessment criteria
- ensure that students understand concepts related to academic integrity, e.g. authenticity and intellectual property. In the case of collaborative work, the difference between collaboration and collusion must be made clear
- read and comment on students' draft investigative reports. The teacher's comments should aim to help students identify issues and shortfalls according to the assessment criteria, but they must not directly offer solutions
- ensure that the internally assessed work is entirely that of each student, and that any information incorporated from external sources is appropriately cited and acknowledged.

Student responsibilities

General responsibilities

- First and foremost, the work submitted must be a student's own.
- Individually, each student must:
    - formulate a research question
    - establish a research methodology
    - identify variables
    - collect and analyse the data
    - draw conclusions.
- Students must also understand and actively apply concepts related to academic integrity, such as authenticity, respect for intellectual property, and citing and referencing according to accepted systems.

Specific responsibilities

Prior to the development of a research question, students must:

- understand that the internal assessment is compulsory for both standard level (SL) and higher level (HL) students
- read and understand the assessment criteria.

During development of a research question, students must:

- choose a suitable topic in physics for the scientific investigation
- formulate and develop their own research question, even if working in small collaborative groups
- consult with the teacher to ensure that the proposed scientific investigation is feasible. The research question must be focused, non-trivial and testable

- design a method that is suitable to address the research question and allows collection of valid and sufficient data
- seek teacher guidance to learn how to set up and use equipment, and to be sure that their methodology is appropriate considering the time and resources available.

During the investigation, students must:

- follow experimental guidelines, and local ethics, safety and environmental regulations
- follow school and teacher recommendations and stipulations
- record all observations and measurements.

During the report writing phase, students must:

- present a concise draft version of the report to the teacher
- use subject-specific terminology and conventions
- acknowledge all sources of information, with adequate references
- consider teacher recommendations regarding the draft version of their report, before submitting the final version
- confirm that the report submitted is their authentic work, and constitutes the final version of that work.

Scheduling and planning the internal assessment

As stated in the *Physics guide*, "the internal assessment should, as far as possible, be woven into normal classroom teaching and not be a separate activity conducted after a course has been taught".

Each school is free to decide the stage of the course most appropriate to carrying out the scientific investigation, when students have developed sufficient skills and subject content.

Factors to consider in scheduling and planning include:

- the experimental skills and concepts to be developed during the two-year course
- the 10 hours to be allocated to the work, e.g. when these should be scheduled
- the number of students being assessed, all of whom will need guidance and supervision
- coordination with teachers of other Diploma Programme (DP) subjects, to avoid excessive student workload
- school calendars, local regulations and other DP assessment activities
- accessibility to any outdoor environment (if applicable)
- the types of investigation chosen by the students:
    - laboratory work
    - fieldwork
    - investigations using simulations, databases and modelling
- the IB submission deadline indicated in *Diploma Programme Assessment procedures* (updated annually).

Student preparedness

Over the course of their studies, student preparedness for the internal assessment is developed through multifaceted learning opportunities.

Developing approaches to learning skills in physics

Table 3 in the *Physics guide* describes the approaches to learning skills that students must experience during the course. Through these experiences, the approaches to learning skills—thinking, communication, social, research and self-management—can be practised and developed before the scientific investigation is attempted.

Formative practical experiences

The section "Skills in the study of physics" in the *Physics guide* describes the experimental techniques, technology and skills that students must attain to support the inquiry process. Students develop their scientific skills and techniques, and their understanding of scientific methodologies, using a range of active learning processes through which they experience the syllabus content. Throughout the course, this involves carrying out different formative practical activities, investigations, experiments, fieldwork and assignments. It is essential that students are given the opportunity to ask a range of research questions with differing methodologies. These experiences will be applied to the scientific investigation through the inquiry process, which includes the stages of designing the investigation, collecting and processing data, concluding and evaluating. This is also an opportunity to reinforce the *IB sciences experimentation guidelines* and academic integrity guidance, as well as giving guidance on how to cite and include references.

Presenting and explaining the internal assessment criteria

The internal assessment criteria are introduced in class activities throughout the first year of the course. Applying the criteria to smaller assignments, whether individual or collaborative, is another way to familiarize students with the criteria. Students should have sufficient opportunities to unpack the requirements for each criterion.

Student planning

An important success factor for the internal assessment is for students to organize themselves according to the time and resources available. For example, major tasks can be broken down into stages, each one with an agreed deadline. A staged process may involve the following.

Ideation sessions

Ideation sessions can be very useful for students to develop a culture of asking questions based on personal interests, observations and subject content within the syllabus. Ideation sessions can also be valuable in revising the *IB sciences experimentation guidelines*.

Students should be encouraged to choose a topic of interest for the scientific investigation.

Developing a research question

Each student should read about their topic of interest to gather background information that will lead to meaningful study. They should record details of all the websites and literature they consult.

Students can then formulate a focused research question identifying the relevant variables, including those that need to be controlled. After a question is formulated, the teacher spends time with each student to verify that the research question is testable, and that variables have been correctly identified. For example, it may be necessary to select a suitable range of values for the independent variable.

Deciding on a methodological procedure

Each student decides on the most appropriate method to ensure the collection of relevant and sufficient data that address the research question and allow for a valid conclusion to be drawn. Each student provides a list of materials and equipment required for the investigation.

The teacher evaluates the suitability of the student's proposed methodology to answer the research question. If asked, teachers may (for example) need to show how equipment is used, how a technique should be followed, or how a graphical analysis is carried out.

Collecting data

Each student agrees with the teacher when and where data are to be collected. The teacher should verify that all safety, ethics, environmental and experimental guidelines are followed. They should also monitor the progress of the investigation and supervise the work being carried out by the student as part of the ongoing authenticity check.

For large cohorts of students, a staggered process could be organized.

Writing a draft report

Each student agrees with the teacher on the handover deadline for a draft report. The teacher reads it and provides holistic feedback on the work, without editing the draft. Teacher comments should be broad and general. This is the last opportunity for the teacher to:

- emphasize the importance of a relevant and concise report
- emphasize the correct use of references
- ensure that the work is commensurate with the level of the course
- ensure that the work meets the criteria against which it will be assessed.

Delivering the final report

The student agrees with the teacher on the final handover deadline. Students should revise the contents of the work and make any necessary amendments or improvements before submitting the final version.

Each student must confirm that the scientific investigation is their own authentic work and is their final version. As stated in the *Physics guide*, "the requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that is submitted to the IB for the purpose of moderation".

Internal assessment deadlines

Further work is necessary after the students have submitted their final report. Teachers must therefore take the following steps into consideration while scheduling the work.

Assessment of the reports

The final report from each student about their work must be read, assessed using the internal assessment criteria and authenticated by the teacher.

It is strongly recommended that comments are made on the work. This aids in awarding the correct level for each criterion. During the process of external moderation, comments help examiners understand the reasoning behind the marks given by the teacher.

Internal standardization

Internal standardization is essential to ensure that works are marked consistently within the school for a given examination session. If only one teacher is teaching physics, standardization across science subjects is recommended.

Submission of marks to the IB

After the marks of all the students are entered, a randomized set of works are selected for moderation. Teachers work with heads of department and DP/Career-related Programme (CP) coordinators to make sure marks are submitted prior to the deadline published in *Diploma Programme Assessment procedures* (updated annually).

Submission of works to the IB

The works of the students chosen by the IB for external moderation must be uploaded before the deadline, following the procedures indicated in *Diploma Programme Assessment procedures.*

Activities to develop skills for the inquiry process

Asking questions worth answering

The process of investigating is an opportunity for students to use time and resources to answer a research question. It is the teacher's responsibility to give students opportunities to ask meaningful questions and to steer them away from trivial ones.

Teachers must challenge students to ask questions:

- that are not easily answered using an online search engine
- that are not versions of previously written practical reports
- for which answers are not found in their textbook
- for which the answers are not self-evident from the syllabus.

Some strategies for teaching students to ask questions worth answering include the following.

Exploring unanswered questions

Try asking questions and leading the discussion. For example:

- Does the diameter of a tube affect the amount of end correction required when determining the speed of sound using resonance in an open-ended tube?
- Small insects can walk on the surface of water due to surface tension. How does the concentration of a solute affect the surface tension?

Collecting stories

Stories can help to develop students' skills for the inquiry process. They can act as real-world inspiration that helps students think of areas to explore.

Running a "skills circus"

A session involving different activities can help refresh and develop students' practical inquiry skills. Here are two examples.

Activity 1—For different laboratory experiments that students have carried out over the past year, gather the apparatus and other materials they used and set it out on laboratory benches. Students then try to use the apparatus to refresh their memories of investigations they undertook. They can use any resource to refresh their memories.

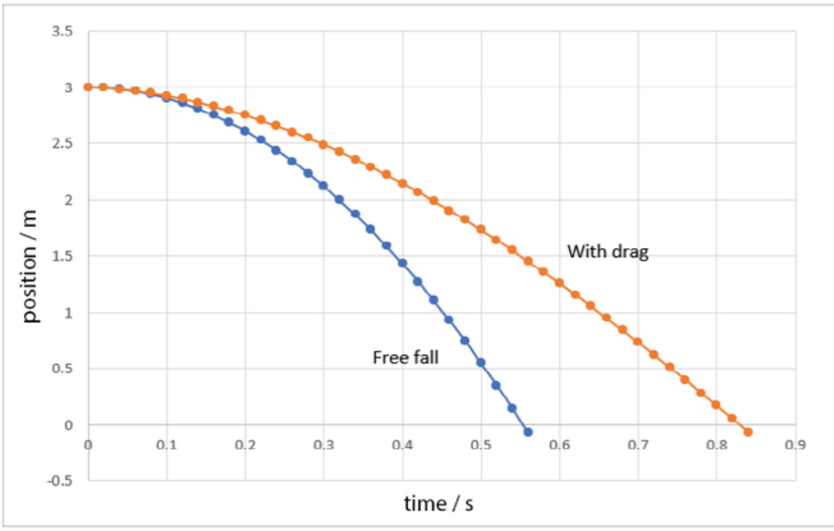
For experiments, also ensure students follow the guidance given in *IB sciences experimentation guidelines* and *Managing safety in science laboratories and workshops*.

Activity 2—Each student receives a graph of experimental results. Their challenge is to set up the correct apparatus and other materials that would be needed to replicate the results shown on the graph.

For example, if given the graph below, students would release two objects from a given height, measuring the vertical position above the ground as they fall using a motion detector.

The blue line shows how the position of a small, massive object changes over time as it falls 3 metres. The orange line shows how a larger, lighter object (such as an inflated balloon with paper clips attached) falls from the same height.

Graph of experimental results



Playing a variable lotto

Variable lotto is a low-stakes, high-feedback exercise. The following example involving chance choice with scientific variables aims to develop experimental design skills.

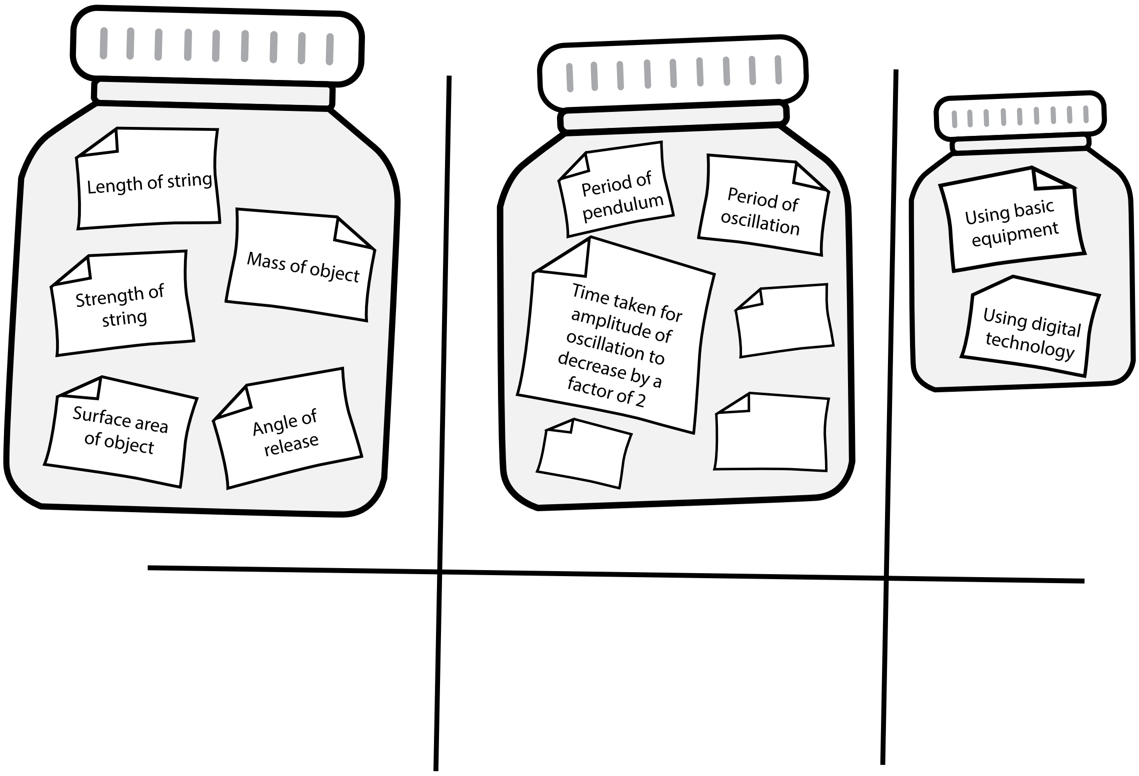
Prepare three beakers or jars containing folded pieces of paper (see the figure) marked with:

- a range of possible independent variables (jar 1)
- various dependent variables (jar 2)
- the letters A and B, referring to different methodologies (jar 3).

Students take a piece of paper from each jar. This shows them the laboratory experiment they will need to design for the next lesson.

An example of a variable lotto

Variable lotto



Examples of lotto outcomes

- Effect of surface area (of the bob) on the period of a pendulum using technology
- Effect of the angle of release on the time taken for the amplitude to decrease by a factor of 2 using simple equipment

Describe, explain, evaluate, predict

For a graph or set of graphs, students take turns describing what they observe, then explain the results. They then evaluate other factors, such as possible weaknesses in the study, or how the data is presented. Finally, they attempt to make predictions from the data given, or extrapolate to suggest how the experiment that produced the data could be extended further.

For each graph, students:

1. suggest an explanation
2. suggest an alternative explanation
3. design experiments to eliminate the alternative explanation.

Using mentor texts when writing the scientific investigation

Mentor texts can be an effective tool to help students learn the specific requirements of disciplines and subject-specific tasks. Teachers know that each discipline has its own specific demands. Students will enter DP physics classes with some writing skills, but teachers will still need to find ways to familiarize students with the internal assessment criteria. They will also need to introduce students to specific conventions expected in science writing, and teach them some of the subject-specific vocabulary required for this task (Pytash, Morgan, 2014).

Mentor texts are often pieces of work that students can read to identify very specific sentences or phrases, and whether they were effective or ineffective. They can then "integrate what they learned from this process into their own writing" (Thompson, Reed, 2019). A mentor text will show students, not just tell them, how to write well, allowing them to envision the kind of writer they can be as they develop their skills (Dorfman, Cappelli, 2017).

One way this exercise varies from the use of mentor texts with younger students is that it does not use a "perfect" exemplary piece of work. Students are invited to find strengths and weaknesses in the mentor text based on teacher clarification of the rubric.

Sample mentor text lesson

In this lesson, taught over two days, students will read two unrelated investigations from the *Physics assessed student work*. While neither of these investigations is perfect, they scored highly enough that students will be able to identify strengths, as well as areas for improvement.

This lesson is best taught after students have collected some data in a laboratory experience, for example a simple pendulum experiment that generated data for which they can draw a conclusion.

The activity, "Assessing mentor texts" (PDF), guides teachers and students through these texts and marking rubrics specifically for the "Conclusion" and the "Evaluation" criteria, but the lesson format is fairly straightforward and can be modified to include other sections.

1. The teacher introduces each internal assessment criterion individually by going over the rubrics, the clarifications and then some more focused points.
2. Students read an assigned section of the mentor text, usually no more than two or three pages of student work. Individually, they mark up where they believe aspects of the conclusion criterion have been achieved, or where they believe there are omissions.
3. Students discuss their findings in groups and give feedback to the class about what markband they would assign this student for that criterion.
4. The teacher then uses a marked-up copy of the mentor text to go over what makes an effective conclusion.
5. Students then spend 15 minutes writing their own conclusions individually.
6. The next day, students continue reading, discussing and marking the evaluation section. The teacher then uses the marked-up copy of the mentor text to go over what makes an effective evaluation.
7. Students then spend 15 minutes writing their own evaluations individually.

General advice

Calculating the overall criterion mark

Deciding on an overall mark for a criterion can seem challenging, but it is less so when a clear methodology is used.

- When marking a student's report, read the complete report first to get a general impression of the work before deciding on the marks to be awarded.
- Evidence for a single criterion will inevitably appear in several places in a report—it is not expected that students will respond to the criteria in a linear or standard way. Read the report several times, marking the report overall against each criterion.
- A best-fit approach must be used to decide the appropriate mark for each criterion. The overall mark awarded for a criterion is *not* an arithmetic mean of the different strands. Rather, it is a holistic judgement reflecting the overall standard of work the student has demonstrated for that criterion.
- Read the level descriptors for each criterion (starting with the lowest level) until you arrive at a descriptor that most appropriately describes the level reached by the student's work.
    - If a piece of work seems to be between two descriptors, read both descriptors again. Choose the descriptor that more appropriately describes the student's work.
    - Consider how well the application of command terms has been addressed, as described in the *Physics guide*.
- It is not necessary that all level descriptors are met within a single markband for a mark to be awarded.
- Mark positively—give credit for what the student has done; do not penalize what they could have done or should have done. Record only whole numbers when giving marks; partial marks (fractions and decimals) are not acceptable.

Markbands, level descriptors and strands for the "Research design" criterion

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Marks	Level descriptor
0	The report does not reach the standard described by the descriptors below.
1–2	• The research question is stated without context. • Methodological considerations associated with collecting data relevant to the research question are stated. • The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced.
3–4	• The research question is outlined within a broad context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions.
5–6	• The research question is described within a specific and appropriate context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced.

First strand

In this "Research design" criterion there are three **strands**.

The first strand concerns the research question. The second and third strands are the next two items in the markband.

Each strand repeats in each markband, incrementally differentiated each time.

In "Research design" the three strands appear three times each, in markbands 1–2, 3–4, 5–6.

Awarding zero for a criterion

It is rare that a student's report should be awarded a zero, but there are specific circumstances in which this is appropriate.

- In the case of an incomplete report if there is no evidence at all for a criterion, a zero is awarded.
- If there is some evidence of some effort to address a criterion, the work should only be awarded zero if the response is incomprehensible or totally irrelevant to the criterion.

If one strand of a criterion scores a zero when the other strands do not—If a strand is not addressed at all, or the student's work does not reach the required standard for scoring in that strand, the appropriate score is zero. However, if the other strands are found to match the higher markbands, the overall mark for the criterion should reflect the student's achievement, that is, not over-penalizing the zero-scoring strand.

Investigations not focused entirely on physics

The internal assessment is not an opportunity for an interdisciplinary study—the focus should be on physics.

If a teacher is concerned about the focus of the investigation proposed by a student, they can visit My IB to consult other experienced teachers and examiners for clarification. It remains the teacher's responsibility to make sure each student's internal assessment report is appropriate for assessment in physics.

Collecting sufficient data

Designing the collection of sufficient data

Students should be creative or demonstrate initiative in the design, implementation or presentation of their investigation. It is not expected that every investigation will generate a lot of data. The data collected should be commensurate with the 10 hours' work required for the scientific investigation overall. Student guidance is necessary, especially at the outset of the scientific investigation.

There is no single standard for determining that data collected in an investigation is insufficient: some physics investigations will generate data more quickly than others. The amount of data collected that addresses a methodology will be determined by the nature of the investigation and the time available. The number of repeats should be selected with a clear rationale.

For example, an investigation to determine the coefficient of restitution of a bouncing ball will usually generate data more quickly than an investigation into heat loss.

Some limitations may only become apparent during data processing. It is strongly recommended that the student considers the appropriateness of data as they are being collected. Carrying out rough processing while collecting data may help the student identify issues. This allows them to modify the range, interval or frequencies as well as collect additional data.

The report should be an account of what happened, and the outcomes may not be those predicted. The report should include details of problems encountered when collecting data. It should also describe issues faced by the student during their trials and how the student responded to them. One possibility is that a potentially feasible investigation fails to provide sufficient data, through no fault or inexperience of the student. The data may be rough and possibly inconclusive. The student should be adaptable, and express this in their account of the method.

Sufficient data are necessary for adequate processing to be evidenced. Interpreting the results and arriving at a conclusion will require care and attention if the results are inconclusive.

The impact of the amount of data collected on other criteria

Insufficient data and poor consideration of uncertainties may impact students' marks for all the criteria.

The amount of data collected will impact the type of processing that can be done.

If, through no fault of the student, insufficient data are collected, the only viable processing may be to calculate the mean and the range. If the processing carried out is commensurate with the level expected to address the research question, the work could achieve the highest marks available.

Insufficient data will impact on the conclusion and the evaluation of the investigation. It is important to look for evidence in the report that the student is aware that the amount of data is limiting the conclusion. Note too that if the data are limited the processing will also be limited, and the interpretation will be impacted too. The teacher should counsel the student to follow a process that will be productive with the time and materials available. If there is no good reason why more data could not have been collected, the mark for data analysis could be impacted.

Propagation of uncertainties is expected, rather than the use of standard deviation or statistical analysis. Not all data processing is equally complex. Students who have extensive data, or whose data require complex processing, may be more likely to make mistakes. In the case of large data sets, carefully consider what the student has done, rather than penalize minor errors in the processing. Major errors in processing may influence interpretation and the conclusion.

Using databases, simulations and models

For work involving databases, simulations and models, the same design rules apply. The source of the data needs to be identified clearly, its reliability established, and its sufficiency and relevance to answering the research question considered. Students using databases and simulations should provide the necessary screenshots, including web addresses or the program name, to clearly demonstrate appropriate data collection and manipulation in support of their methodology. Databases and simulations that are free or behind paywalls are acceptable.

When using secondary data sources, more independent variables can be included, because sufficient data can be collected rapidly.

The student will need to explain how the data sampling is controlled and how it is extracted or filtered. They should explain their selection and the decisions taken for extracting data, and consider using a series of screenshots to illustrate the method. When using databases and simulations, the student must include screenshots or pictures to illustrate the methodology.

Investigations based on tables found in published articles are rarely suitable, because the authors have often already made decisions that the students themselves should make.

Repetitions that result in the same value each time receive minimal credit. In this case, the student can use additional simulations or databases to gather sufficient data to answer the research question. The student must explain how and why the specific simulation was used, and the methodology for collecting data.

Investigations based on computational analysis should include tools that calculate properties accurately, rather than those limited to visual representations.

Communication style and report length

The structure of the internal assessment report is the student's responsibility. The IB offers no guidelines here, except that the report should be clear, concise and focused, and demonstrate relevant scientific skills. A cover page and a table of contents are often distractions and should not be included. A clear and informative title reflecting the research question and a first paragraph should inform the reader about the investigation.

There is no fixed style for presenting the method. Both prose and recipe style are acceptable. This is a physics investigation, not an assessment of language skills. The use of the passive voice or a personal style should not impact the marks given. Neither should errors of expression, spelling and grammar, unless these result in ambiguity, contradictions, or amount to incomprehensible content. The structure, scientific relevance and conciseness of the report are more important than the language used. This is particularly important considering that many students are not working in their preferred language.

Assessment is always based on evidence from the student's report, and this evidence needs to be clearly communicated in scientific terms. Effective communication is not a criterion on its own; it is an essential part of all four criteria.

- Effective communication is explicit in the research design criterion. The student needs to communicate the methodology (the purpose and practice) and the context of their investigation.
- Effective communication is an aspect of the data analysis criterion, where the recording and processing of data should be clear, precise and accurate in relation to the research question.
- Effective communication is also implicit in the conclusion and evaluation criteria, where an answer to the research question must be justified and where evidence of an evaluation needs to be expressed.

The report should be a maximum of 3,000 words. The word count does not include data tables, sketches, graphs, headings, references or bibliographies. Where a large amount of data has been collected, only a sample of the data should be included. If a report is clear, concise and focused, 3,000 words (maximum) will be more than adequate. If the report exceeds this limit, examiners are not compelled to read further.

Citations, bibliographies and academic integrity

If the student is quoting broadly accepted facts or theories, citations are generally not needed. However, if a specific fact is quoted, a citation would be expected. For example, students do not need a citation when stating Newton's second law of motion, but the value of the coefficient of static friction between two surfaces would require a citation.

Citations can be in-text, in footnotes on each page, in endnotes, or written as references in a bibliography. The citations should allow sources to be traced, for example the URL and retrieval dates for online sources. They should be limited to sources that have been used in the investigation, either for ideas, content quoted or images copied. The style of citation is up to the student, but they should follow a clear and consistent method of referencing. The bibliography can be used to record the full reference details.

Academic integrity is important to IB educational philosophy and, indeed, to any academic pursuit. Honesty is the hallmark of scientific inquiry. When writing their reports, the student must clearly distinguish between their words or ideas and those of others.

If a teacher believes some of a report's content may have been taken from a source without adequate citation, this may be a case of malpractice. The teacher must discuss this with the student, to clarify how and why the content came to be presented in the report.

If an examiner is not satisfied that the report is the student's own work, the IB will instigate an inquiry on suspected malpractice.

For further guidance, refer to the IB's *Academic integrity policy* and *Effective citing and referencing*.

Appendices

All information relevant to the investigation must be presented within the report. Appendices will not be read by the examiner. The only appendices permissible and sometimes necessary are consent forms for students participating in data collection.

The full raw data is no longer required in an appendix if there is too much to fit in the actual report. The teacher should have seen the full raw data and made a comment in the work to that effect. The sample data used in the report should be taken at regular intervals so it covers the range of the independent variable.

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Research question and context

The teacher should check that the:

- research question is unique to the student
- independent variable is present
- dependent variable or derived dependent variable is present
- variables are quantifiable
- background context or theory is relevant and focused
- context of the independent and dependent variables is relevant and focused
- choice of data sources, in the case of databases, is explained and their reliability is commented on.

Deciding on the research question

The research question needs to be unique to the student. In the case of group work, the teacher should verify this. Both the research question and the background context provided need to be considered.

All students (whether standard level (SL) or higher level (HL)) can explore topics outside the syllabus. Students should avoid research questions where the answer is known to them beforehand.

The research question may not necessarily include the actual dependent variable but a derived value. For example, for the question "What is the effect of X on the rate of change of Y?", the rate of change would be derived from measured values. The link between the dependent variable and the investigation—the context—would need to be established in the background. This may not be the case for simulations that may result in derived values such as rates. In these cases, the rate would be the raw data.

When a more general research topic is being investigated, the student needs to express it in a form that clearly states the quantities and their relationship, thus guiding an appropriate investigation method.

General accounts of the broad area of study will not achieve the highest marks (e.g. a general overview of electric circuits). Students should focus their background reading on the exact research question. The background may provide information that will lead the student to identify variables.

An appropriate context needs to be described when formulating the research question. The context should help with understanding the specific details of the research question and with the implementation of the investigation. This context includes the scope and limitations of the known theory or phenomenon, as well as assumptions about the quality of the data.

If the investigation's background is too broad and/or lacks specifics, the student's work will not reach the top markband in the first strand.

Students are permitted to present more than one independent variable, but there must be a clear link between them. They should also carefully consider if including more than one variable will allow the investigation to reach the expected depth, considering the word limit.

Students are permitted to formulate a hypothesis for the outcome of the investigation, though this is not obligatory. A hypothesis can help to set the research question in context. A hypothesis allows students to relate the variables more formally, and to provide an indication of the nature of the relationship. Typically, there will be some known theory that is used to develop the relationship between the variables. In other cases, there may be no answer. For instance, a student might investigate how the frequency of the applied voltage to a transformer relates to the overall efficiency. The phenomenon of transformer efficiency would set guidelines for what is reasonable and what range of efficiency might be expected. If a hypothesis is included, it must be addressed in the conclusion.

Methodological considerations

The teacher should check:

- that the method can generate data that may answer the research question
- the type of data collected
- the protocol for collecting relevant data
- that a preliminary or trial investigation is described and assessed
- the description of measuring the dependent variable
- the range and intervals of the independent variable
- the sampling rate
- the method of controlling or monitoring each variable
- the discussion of other factors that would need to be controlled
- the techniques used to ensure adequate control (fair testing)
- the use of control experiments
- the quantity of data collected, including sufficient repetitions given the nature of the system investigated
- that provision is made for qualitative observations.

Protocols, methods and procedures

The protocol will be a record of the method used, including an account of trialling. It should not be a proposed plan. Students will probably use standard protocols for determining the dependent variable; the protocols should be cited.

The method employed will depend on the nature of the investigation and may be limited by time or materials. The student's method needs to make reasonable provision for the collection of sufficient data to answer the research question in a 10-hour period of investigative work. This 10-hour period may include a certain amount of designing and trialling, followed by redesign, which could be time consuming. The quantity of data collected needs to be realistic. The student must consider time constraints during design. If the investigation requires more time than that allocated, the teacher should provide the necessary scaffolding.

The reader needs to understand how the methodology and procedures were implemented, and how the equipment and other materials were used. There needs to be enough information so that the reader could, in principle, repeat the investigation. The procedure should be clear and detailed enough to be reproduced. Details of equipment, and measuring instruments and their sizes, must be included to assess their suitability and the stated uncertainties.

Defining and explaining variables

A table can be used to list and explain the variables. It is not necessary for the variables to be identified explicitly and separately (e.g. using subheadings).

The dependent variable needs to be accurately defined and explained. If the investigation is looking for a trend, a minimum of five data points is expected for the independent variable. In some exceptional cases, four may be accepted.

The rationale for the range and intervals used for the independent variable needs to be explained in the context of the investigation. In many experiments the sampling rate needs to be considered to ensure that meaningful but not excessive data are collected. This can often be best determined during trialling.

The method should identify which variables can be controlled and how this is achieved. It should also identify which variables cannot be controlled but need to be monitored (confounding variables).

Room temperature may not vary very much during an experiment, but in temperature-sensitive investigations it needs to be recorded. Merely setting the room's thermostat or air conditioning is not sufficient to control room temperature for an experimental set-up.

In physics, stating that gravity needs to be kept constant in a simple pendulum investigation is unnecessary. However, starting with the same amplitude for each trial is important, and how this is achieved needs to be clearly described.

Repeats are a standard expectation, to ensure the validity of the results. A student whose work indicates several trials should not be penalized for not mentioning repeat measurements in their methodology.

Students should reflect on the quality of the data while carrying out the investigation, including some rough data processing to detect issues that can be addressed.

Risk assessment

The teacher should check for:

- safe handling of chemicals or equipment
- application of *IB sciences experimentation guidelines*
- judicious consumption of materials
- appropriate disposal of waste
- consideration of impact and safety on field sites
- consideration of safety and environmental concerns.

Teachers have a responsibility to ensure that their students carry out safe, ethical investigations and that the students also consider the environmental impact of these.

Risk assessment is an important part of experimental design. However, issues concerning safety, ethics and environmental impact may not apply to the same degree for each investigation. The impact of risk assessment on the mark awarded for the criterion will depend on whether there are significant safety, ethical and environmental factors that are, or need to be, considered by the student. It should be clear that these risks have been mitigated. Stating an issue indicates the student is aware of it, but not necessarily that the issue has been addressed. If an investigation has no safety, ethics or environmental considerations, the student should include a statement to this effect.

For work with databases, simulations or modelling systems, safety and environmental concerns will not be relevant. However, ethical issues can arise for the use of databases, and it is to the student's credit if they are raised.

Examiners who encounter experimental set-ups that constitute a severe risk to safety or the environment will refer these to the IB. The relevant school may then be contacted.

Describing the data collection method

The teacher should check for:

- a logical sequence
- the presence of essential information
- unnecessary repetition
- the sketches, diagrams, charts and photographs used to illustrate the investigation
- the use of screenshots to explain how the data were captured (in the case of investigations using databases and simulations)
- correct use of scientific terms (spelling is not penalized if there is no ambiguity)
- the selection of measuring instruments and their sizes
- brand names of items used as variables.

Students need to present information in enough detail for the reader to understand readily how the methodology was implemented, such that they could, in principle, repeat the investigation.

Illustrations and lists

Students should consider illustrating their investigation using annotated sketches, diagrams, charts and photographs of the experimental set-up. These can help to describe the investigation, with minimal impact on the word count.

Illustrations should only be included when they add value. For example, diagrams of balls, rulers and stopwatches out of context are superfluous.

A list of materials is useful but not obligatory. Details of the materials can be included in the method if appropriate.

Data analysis

This criterion assesses the extent to which the student's report provides evidence that the student has recorded, processed and presented the data in ways that are relevant to the research question.

Communication of the recording and processing of data

The teacher should check for:

- collection of sufficient and relevant data to address the research question
- appropriate qualitative observations (images/drawings correctly labelled)
- concise presentation (of text, tables, calculations, graphs, other illustrations)
- use of correct scientific units and their symbols
- appropriate formatting of data: units are correct and uncertainties are identified; consistent number of decimal places or significant figures
- clear and precise processed data that addresses the research question
- a sample calculation or the use of screenshots where appropriate
- relevance of graphs (e.g. with best-fit lines or curves).

Units and decimal places

International System of Units (SI) or other metric units (e.g. mL or cm^3, L or dm^3 for volumes) are acceptable. Non-decimal system units (e.g. °F, cups, inches) are not appropriate and should be converted.

SI units are expected for base quantities (e.g. time in seconds, distance in metres) and derived quantities (e.g. force in newtons or energy in joules). Non-SI units (e.g. eV, u, ly) are acceptable if the scientific context makes them relevant.

A correct and consistent number of decimal places, based on the degree of precision, is expected. Minor errors in data tables can be accepted if, overall, the student is trying to maintain consistent decimal places between the raw data, any degrees of precision expressed and the processed data.

Recording and processing data

The presentation of the analysis will depend upon the data-processing tools being used. Percentages, means, standard deviations or ranges at the end of the column or row of data they represent are sufficient evidence of processing. For more complex processing (e.g. using spreadsheets), screenshots including the formula used are acceptable. For other less orthodox processing, a worked example is necessary.

Providing examples of full calculations is superfluous or irrelevant when using dedicated software programs. However, the processing and reasoning must be clear so that the validity of the calculations and interpretations can be verified.

Note: Interpretation of the data as it relates to the research question is assessed in the "Conclusion" criterion.

Correctly tabulated data should have appropriate titles and numbers, or they should be set in a context that makes them unambiguous. Within the text of the report, they should be referenced using, for example, Figure 1 or Graph 1. Where relevant, there should be concise column headings and units in the column headers with their uncertainties. It is not necessary to provide separate tables for raw data and processed data.

If large amounts of data have been collected, students are permitted to present only a representative sample of the raw data, to facilitate comprehension. Data taken directly from an electronic device are raw data and require further processing to constitute processed data. For example, a device that determines "rate" produces raw data. If software automatically constructs a graph, the graph itself is acceptable as raw data. Details about how results were obtained, and information about quantities, units and precision, should be mentioned in the text. The gradient of or area under the graph may then be used for further calculations.

Inadequate labelling of a graph (axes, legends, titles) will impact data analysis. The type, size, proportions and scaling of the graph impact not only presentation, but also the graph's usefulness in data analysis.

Both axes must be labelled with the names of quantities. Names can be spelled out in full or using the symbols already included in the report. For example, labels for a graph of time squared against distance might be "d / cm" for the x-axis and "t^2 / s^2" for the y-axis. Note that quantity symbols are styled in italics and units are not. The standard for expressing the units for quantities is to separate the quantity symbols from the unit with a solidus (forward slash), "/". There is no penalty if units appear in parentheses (e.g. "d (cm)").

Descriptions of qualitative observations are expected to accompany the raw data where applicable. Their importance will depend on the nature of the investigation.

Considering uncertainties

The teacher should check for:

- degrees of precision in the instruments used
- consideration of errors and uncertainties
- consistency in the reported uncertainties
- variation in the results, as shown by propagation of uncertainty, uncertainty bars, maximum and minimum lines of best fit
- ranges (maximum value minus minimum value)
- an appropriate response to outlier data.

Note: The processing of data to obtain an uncertainty value is assessed in the third strand (relevant processing of data) of the "Data analysis" criterion. Consideration of the impact of uncertainties is assessed in the "Conclusion" criterion because (in part) this criterion assesses the relevance of the conclusion to the analysis.

It is not expected that students will necessarily cover all of the above parameters. This is merely a guide to the ways a student may evidence that they have considered the impact of uncertainty on the analysis.

Uncertainties in measurements

Measurement uncertainties can be obtained from an instrument's graduations, manufacturer specifications (for electronic devices) or the read-out for least count. The realistic use of an instrument also needs to be considered. For example, a handheld stopwatch used to measure the time of an event will not have a precision of 0.001 seconds, even if the stopwatch can provide such a read-out—human reaction times are not this fast. Students should justify the size of uncertainty based on the nature of the experiment. Repeating a measurement for the same event often reveals an uncertainty larger than the precision of the instrument.

Uncertainties associated with single measurements must be expressed to the same degree of precision as raw data. Using the least count, the uncertainty could be expressed as 0.1 for 2.3 s, 0.01 for 2.34 s and 0.001 for 2.345 s. This is the minimum uncertainty, but often the uncertainty is greater. For example, measurement of a length could be (87.4 ± 0.2) cm. Expressions such as (87.4 ± 0.05) cm or (87.4 ± 2) cm are inappropriate.

Where relevant, measurement uncertainties should appear in the column headings along with the units, unless there is reasonable justification for data to have different values of uncertainty within a column. Uncertainties are also expressed graphically using scatter plots with trend lines. Graphs should include uncertainty bars. Uncertainties that are present but too small to be visible should be noted in the report. Uncertainty bars can be different for each data point, or each point can have the same absolute uncertainty. Uncertainty bars are usually only drawn for the dependent variable.

Propagation of uncertainties involves mathematical operations using the non-statistical rules provided in the Diploma Programme (DP) *Physics data booklet*. Other processes, including trigonometric and logarithmic functions, should take account of the range of values and be illustrated by a sample calculation.

For repeated measurements, the uncertainty of the mean can be determined by using one-half of the range between the maximum and minimum values. It is acceptable to assume symmetry here so that the plus and minus values are the same. It is important that the raw data values, the mean value and the associated uncertainty are expressed to the same number of decimal places.

Most uncertainties should be expressed as a single digit. However, if the uncertainty begins with a "1" then two significant figures are acceptable, for example 87.4 ± 1.2.

If repeated measurements reveal no differences, then the least count remains the uncertainty. If one-half of the range reveals an uncertainty that is smaller than the individual raw data uncertainty, then the uncertainty in the mean must remain the larger value.

The minimum and maximum lines should simply be estimated while considering all the uncertainty bars. They should not be lines drawn using just the first and last data point uncertainty bars. The minimum and maximum lines are not required to touch or include all the uncertainty bars. Students only need to consider their location by eye based on a reasonable judgement, not a mathematical procedure.

Outliers

Data identified as possible or probable outliers should not be systematically omitted from calculations. Outliers are actual measured results and therefore need to be considered. Removing them so that the results "fit better" with expectations or with a general model is not good practice. This is manipulation of data and it is unscientific. Instead, students could consider presenting the outcome with the outliers included and excluded, thereby revealing their impact.

Outliers are most likely to occur as the result of human error, methodological flaws, or irregularity in the equipment or environment. Often, the quantity in question can be remeasured. The scientific method requires rigour and integrity in gathering data, while the IB requires academic integrity from students. Both of these are more important than attempts to make data appear consistent. Therefore, being cautious when rejecting data is essential, and **data exclusion requires a justification**. Students should never reject two or more data as this distorts the true quality of their data sets. Although there is no single agreed method for rejecting outliers, common sense and careful analysis are always helpful.

Processing of data

The teacher should check for:

- processing that is efficiently presented and at the DP level for the topic
- appropriate processing tools
- realistic trend lines in presented data
- appropriate graphing techniques including adequate scale, title and labelled axes
- correct calculations and graphing.

Processing is the transformation of raw data to arrive at a conclusion. Mathematical skills are important, and this is stressed in the nature of science (NOS) aspect of this course; however, this is not a mathematics course.

Graphing, even that of raw data, is part of processing, especially if it is used to derive values such as gradients for rates.

Graphing raw data when the graphing of *processed* data would be more appropriate can be considered insufficient, or even irrelevant; but it is not wrong.

The types of graphs produced by the student should be appropriate to the data being analysed.

To be confident that a trend line can be drawn on data points, sufficient data need to be obtained. A trend line may be used to show how the limited data collected fit a given model.

An appropriate best-fit line or curve is common practice and should be guided by theoretical considerations, known equations or dimensional analysis. Students should not assume a linear fit unless it is justified. If a best-fit line is justified by theory and experiment, the scatter of data points above and below the best-fit line should be approximately equal, demonstrating that the variation is genuinely random.

The purpose of a graph is to reveal the trend or mathematical function between the quantities graphed. This means looking for a continuous line or curve approximating the data scatter. The best-fit line or curve should never connect data point to data point, as this would not reveal a mathematical function. Nor should the best-fit line assume a zero–zero origin—this would disguise any systematic shift. Extrapolating to the axis origin and beyond the maximum value provides additional evidence that the chosen line or curve makes physical sense.

There is no requirement that graphs should be linearized. However, if a linear graph line is established, minimum and maximum lines can be used to determine the uncertainty in the gradient and intercept. Approaches to linearization include using the known theory, dimensional analysis or logarithms.

Conclusion

This criterion assesses the relevance of the conclusion to the research question, to the analysis presented and to the accepted scientific context.

Relevance of the conclusion

The teacher should check for:

- a valid explanation of trends in the results or correlations of the results
- a conclusion that addresses the research question in the proposed context
- evidence that sense has been made of the data and/or results, leading to a conclusion that is realistic
- references to a hypothesis (if one has been stated)
- a discussion of the impact of uncertainties
- a discussion of the reliability of the data (which may indicate an appreciation of the strengths of the data)
- whether the data supports any hypothesis that has been proposed.

The student must discuss whether the data address the research question or not. The data collected and processed may not demonstrate clear patterns or trends. The data may also be inconclusive. For some investigations, the data may partially support a conclusion, but not necessarily lead to a strong one.

Students should ensure they do not introduce bias in the interpretation to form conclusions that are not supported by their data.

The conclusion should include an explanation of the trend line using mathematical terms correctly, such as "linear" (positive or negative gradients), "directly proportional", "inversely proportional", "exponential" (negative or positive). Where relevant, terms such as "optima", "maxima" (plateau) and "intercepts" should be used.

Considering uncertainties in the conclusion

Measures of variation, such as the range or the standard deviation, can indicate the reliability of the results.

A valid conclusion needs to express not only the resulting value but also an experimentally acceptable range of values. A student should, for example, conclude that the specific heat capacity of aluminium is (932 ± 15) J kg^{-1} K^{-1}. In this way the result is justified as being accurate enough to agree with the accepted value of 921.095 J kg^{-1} K^{-1}. Stating the percentage difference and percentage uncertainty is also good practice.

The student should comment on the presence of random and systematic errors as shown in any graphs, and on their effect on any conclusions. The direction of any systematic error should be stated.

The conclusion and the scientific context

The teacher should check for:

- a relevant scientific context, with references from the literature that help explain the investigation's outcomes
- reliable scientific sources, referenced with sufficient detail to be traced (e.g. retrieval dates for online sources)
- comparison with general models and a proposed explanation in the context of physics.

There may be no accepted value for comparison (e.g. the spring constant of a large rubber band). In this case, the student must determine if the result is reasonable and physically plausible.

In setting up the context, assumptions are made in determining the equation or model used. Physics involves cause-and-effect relationships and theories. Assumptions can be:

- practical—the path of a projectile motion remains in a common plane
- mathematical—the simple pendulum theory assumes a parabolic path, but in fact the motion follows a circular path
- physical—air is treated as an ideal gas.

Evaluation

This criterion assesses the extent to which the student's report provides evidence that weaknesses and limitations in the investigative methodology have been assessed, and improvements have been suggested.

Methodological weaknesses and limitations

The teacher should check for:

- methodological and procedural weaknesses and limitations
- evaluation of the relative impact of weaknesses and limitations
- evidence supporting the identified weaknesses and limitations
- a clear understanding of the topic in the suggested context and of the methodology used.

There is no expectation that a student will address all aspects relating to methodological weakness and limitations. Nevertheless, when evaluating the results of an investigation, students should explain the relative impact of those that are significant. They can do this in a qualitative way, identifying minor and major weaknesses by explaining how the issue would affect the results.

Discussion of methodological weaknesses needs to consider both the issues in the methodology and their effect on the quality of the data. Weaknesses do not include errors due to careless manipulation skills or hypothetical events for which there is no evidence.

Discussion of limitations acknowledges that experiments will only go so far in answering the research question. Even if conditions are perfect, an experiment will still have its shortcomings. For example, a simulation may have few methodological weaknesses, but it will have some limitations.

The degree of impact of these weaknesses and limitations on the outcome of the investigation needs to be judged qualitatively.

The reliability of the results needs to be judged in the light of the uncertainties that have been established. The direction of any systematic error should be stated and related to methodological weaknesses and limitations.

Instruments that are faulty or that have not been calibrated correctly cause systematic errors. These errors, which affect accuracy, can also be caused by human error.

Random uncertainties are unpredictable in size and direction. The precision (measurement uncertainty) of instruments varies due to random errors. Judging the degree of impact of each measuring instrument on the results is an important task in science.

In investigations using databases, the student should not refer to the validity of the sources because this should have been done in research design. However, there are issues in the curation of databases, and a reflection in this regard adds value to the conclusion. Problems resulting from experimental and theoretical values present the same challenges.

Issues such as the cause of random uncertainties and systematic errors can be addressed. Limitations relate to the range and frequency of the collected data, procedural issues in data collection, and the precision and accuracy of the data. The student must explicitly consider whether control variables have been adequately dealt with.

The limitations should be consistent with the analysis and interpretation of uncertainties presented in data analysis. They should be supported by evidence instead of speculation. For example, a comment such as "the temperature of the surroundings was not controlled or monitored and may have changed during the extended testing period" has limited value. Limitations such as limited data or procedural weaknesses (e.g. an uncalibrated ammeter) are generic limitations.

Students are often familiar with certain methodological limitations (e.g. heat losses in calorimetry). These are valid limitations but will only add value when the student has tried to minimize their impact during design. For example, if the student worked with an open container without insulation, referring to heat losses in calorimetry is weak evidence of the understanding of this methodological limitation.

An appreciation of the limitations of an investigation can be shown by discussion of the range of data, including a justification of the chosen range of the independent variable.

Graphs may reveal systematic shifts. The student should discuss the size and direction of such a shift, relating it to weaknesses or limitations in the methodology.

Suggesting improvements to the investigation

The teacher should check for:

- realistic and relevant improvements
- a clear understanding of the topic in the suggested context and the methodology used.

Suggested improvements should be realistic and relevant to the investigation. The improvements must be related to the weaknesses or limitations that have been identified, and should be feasible in a school environment or field course. They need to be based on the identified weaknesses that are relevant to the research question and methodology.

The student should avoid generalities such as “take more measurements” or “use a more precise measuring method”. Only if these generic issues are connected to specific issues can they be seen as improvements to weaknesses. The student should also avoid generic comments such as “eliminate friction” or “perform the experiment in a vacuum”.

During the design phase, changing to a more precise instrument may not be an option if the choice of instruments is limited. A student might realize that inserting an ammeter affected the measurement of current in a circuit, or that using a cold thermometer to measure the temperature of hot water affected the results. Taking steps to minimize such effects would be an improvement.

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Updates to the publication

This section outlines the updates made to this publication over the past two years. The changes are ordered from the most recent to the oldest updates. Minor spelling and typographical corrections are not listed.

Changes for November 2024

Planning the teaching of the course > Skills-based activities

"Inquiry 2: collecting and processing data"

Amendment in response to stakeholder feedback.

In the section "Skill: Collecting data", the general rule has been modified from "eight values" to "five values" to align with information in other sections of the teacher support material.

Changes for July 2024

The syllabus > Syllabus structure and features

"Guiding questions"

Correction of error in previous version.

In "Example: E.5 Fusion and stars", "type II supernovae" was replaced with "type Ia supernovae".

Mathematics > Uncertainties

"Propagation of uncertainties"

Correction of error in the previous version.

In the table in "Processed data tables", the second-column value "0.002 s" was replaced with "0.001 s".

Unpacking the internal assessment > General advice

"Collecting sufficient data"

Introduction of revised or improved content.

In the section "Using databases, simulations and models", more guidance was added for teachers to understand the requirements of the internal assessment reports when students have used databases or simulations.

"Communication style and report length"

Amendment in response to stakeholder feedback.

In the section "Appendices", more guidance was added for teachers to understand what should (or should not) be present in an appendix of an internal assessment report.