PHYSICS SYLLABUS

Upper Secondary Express Course

Implementation starting with
2023 Secondary Three Cohort

Ministry of Education
SINGAPORE

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1. INTRODUCTION

1.1 Science Curriculum Framework

The *Science Curriculum Framework* (see **Figure 1.1**) encapsulates the thrust of science education in Singapore, which is to provide students with a strong foundation in science for life, future learning, citizenry and work.

Science for Life and Society at the core of the curriculum framework captures the essence of the goals of science education.

Figure 1.1: Science Curriculum Framework

Our science students are diverse, with different needs, interests and aptitudes for science. Given the diversity of our students and the needs of our country, the twin **goals of science education** are:

- To enthuse and nurture all students to be scientifically literate, which can help them to make informed decisions and take responsible actions in their daily lives.

- To provide strong science foundations for students to innovate and pursue STEM for future learning and work.

Surrounding the core of the framework are the three "IN"s, *inspire*, *inquire* and *innovate,* which represent the **vision of science education**. It encapsulates the desired overall experience of our students in science education:

- INspired by science. Students enjoy learning science and are fascinated by how everyday phenomena have scientific connections and how science helps solve many of our global challenges. They regard science as relevant and meaningful, and appreciate how science and technology have transformed the world and improved our lives. A good number of students see science-related careers as a viable profession to serve the good of society.

- INquire like scientists. Students have a strong foundation in science, and possess the spirit of scientific inquiry. They are able to engage confidently in the Practices grounded in the knowledge, issues and questions that relate to the roles played by science in daily life, society and the environment. They can discern, weigh alternatives and evaluate claims and ideas critically, based on logical scientific evidence and arguments, and yet be able to suspend judgement where there is lack of evidence.

- INnovate using science. Students apply and experience the potential of science to generate creative solutions to solve a wide range of real-world problems, ranging from those affecting everyday lives to complex problems affecting humanity. A strong pipeline of students can contribute towards STEM research, innovation and enterprise.

The outer ring represents the domains that make up the strong science fundamentals: *Core Ideas*, *Practices of Science*, and *Values, Ethics and Attitudes*.

- Core Ideas. Core Ideas are the distilled ideas central to the discipline. The Core Ideas help students see the coherence and conceptual links *across* and *within* the different sub-disciplines of science (i.e. biology, chemistry and physics).

- Practices of Science (POS). The Practices consist of three components:
  (a) Demonstrating Ways of Thinking and Doing in Science (WOTD);
  (b) Understanding the Nature of Scientific Knowledge (NOS); and
  (c) Relating Science, Technology, Society and Environment (STSE).

  They represent the set of established procedures and practices associated with scientific inquiry, what scientific knowledge is and how it is generated and established, as well as how science is applied in society. The Practices serve to highlight that the discipline of science is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories); it is also a *way of thinking and doing*. In particular, it is important to appreciate that the three components representing the cognitive, epistemic and social aspects of the Practices are intricately related.

- Values, Ethics and Attitudes (VEA) in Science. Although science uses objective methods to arrive at evidence-based conclusions, it is in fact a human enterprise conducted in particular social contexts which involves consideration of values and ethics. It is important for our students to be aware of and appreciate the values and ethical implications of the application of science in society. Thus, science education needs to equip students with the ability to articulate their ethical stance as they participate in discussions about socio-scientific issues that involve ethical dilemmas, with no single right answers.

The pair of hands in the Science Curriculum Framework represents the roles of students *as inquirers* in their learning and pursuit of science, supported by *teachers and partners as facilitators* of the students' learning experiences, to impart the excitement and value of science to the students. The partnership of learning and teaching goes beyond the students and teachers to include other partners who can facilitate learning in various contexts to help fuel students' sense of inquiry and innovation, to inspire them and to help them appreciate the application of science in their daily lives, society and the environment.

1.2 21st Century Competencies Framework

The *Framework for 21st Century Competencies and Student Outcomes* (see **Figure 1.2**) helps guide us to prepare our students to be confident people, self-directed learners, concerned citizens and active contributors – attributes we strive to develop in students to thrive in and contribute to a fast-changing and globalised world of the 21st century.

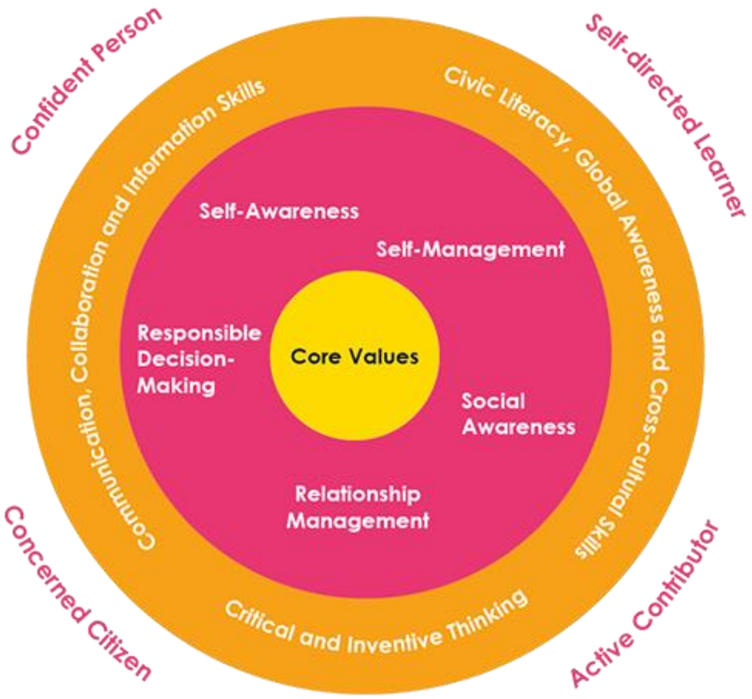

Figure 1.2: Framework for 21st Century Competencies and Student Outcomes

This framework identifies the core values, Social and Emotional Competencies, as well as competencies necessary for the globalised world we live in. In totality, these are referred to as 21st Century Competencies (21CC).

Supporting the Development of 21CC through Science

Science education plays an important role in helping our students understand and address many of the local and global challenges we face in the 21st century. These challenges include climate change, depletion of natural resources, disruptive innovations in technology (e.g. artificial intelligence), and feeding an increasing population. To navigate these challenges, we need to develop scientifically literate citizens who

- possess mindsets and practical knowledge of science and its applications to make informed decisions and responsible actions in their daily lives.
- appreciate science as humanity's intellectual and cultural heritage, the beauty and power of its ideas, as well as participate in socio-scientific issues ethically and in an informed manner.
- are able to apply scientific knowledge and skills, as well as adopt scientific attitudes and mindsets to innovate and push new frontiers.

In this respect, the development of scientific literacy supports MOE's efforts on the development of students' 21CC. As discussed in **Section 1.1**, the development of scientific literacy is necessary to equip students with strong science fundamentals in the three domains of Core Ideas, Practices, and Values, Ethics and Attitudes. The subsequent paragraphs illustrate ideas on how 21CC can be developed through the science curriculum.

Civic Literacy, Global Awareness and Cross-Cultural Skills (CGC)

For students to actively contribute to the community and nation, and develop an awareness of and the ability to analyse global issues and trends, they could be given opportunities to

- explore how science and technology contribute to society, in Singapore and globally, e.g. how applications of new scientific discoveries inspire technological advancements, and motivate scientists to ask new questions in their inquiry.

- participate in ethical discussions that require them to be open-minded when weighing multiple perspectives and develop in them a sense of responsibility for the environment.

Critical and Inventive Thinking (CIT)

For students to generate novel ideas to address issues and solve problems, exercise sound reasoning, use metacognition to make good decisions, and manage complexities and ambiguities, they could be given opportunities to

- engage in the process of inquiry. Students could raise divergent questions about the natural world, develop multiple ways to observe and collect evidence, and explore more than one explanation from their evidence. At the same time, students should exercise healthy scepticism in questioning the assumptions and uncertainties in their evidence and evaluate how these assumptions could influence their explanations.

- recognise that science is an evidence-based, model-building enterprise to understand the natural world through exploring how and why scientific models evolve over time in light of new evidence.

Communication, Collaboration and Information Skills (CCI)

For students to be able to communicate information and ideas clearly, collaborate effectively and manage information thoughtfully and responsibly, they could be given opportunities to

- communicate their ideas clearly and persuasively using the language of science. Students could engage in activities that allow them to express their appreciation for the need and importance of having scientific standards and terminology.

- understand how science is presented in various forms (e.g. orally, written, visual) and media (e.g. print media, social media) and evaluate the effect these forms of communication have on the audience (e.g. identifying fake news).

- collaborate with other students in knowledge construction. Students should present their work and ideas to others, and have healthy discussions and critique. Through collaborative discussions, students could develop social awareness as they are required to discern different perspectives, recognise and appreciate diversity, empathise with and respect others.

1.3 Purpose and Value of Physics Education

Physics is a fundamental science which is concerned with understanding the natural world. A small number of basic principles and laws can be applied to explain and predict a wide range of physical events and phenomena. The fundamental theories of physics form the bedrock of many modern technologies and are responsible for the practical applications and advancement of various fields of science and technology. The subject exposes students to the science process skills of investigation, reasoning, analysis and evaluation, which are transferrable and useful to everyday life. It also develops attitudes and dispositions such as critical thinking and logical analysis, a curious and inquiring mind, and the ability to solve problems and grasp complex concepts.

A unique feature in the study and practice of physics is the extensive use of models, including but not limited to those expressed in mathematical language, to explain observations and make predictions. A model serves as a bridge between abstract scientific theories and the observations and experiences of the real world. Models can be tested through experiments and must be consistent with available evidence. Hence, they can change and evolve with new evidence. The learner is made cognisant of the assumptions and limitations that are inherent in the use of models as they simplify complex real-world phenomena. Knowledge and understanding of the use of models in the learning of physics is transferable to other disciplines, such as modelling of biological processes, weather patterns, earthquakes, and even the movement of people or financial markets.

1.4 Aims

The Upper Secondary Physics syllabus seeks to develop in students the understanding, skills, ethics and attitudes relevant to the Practices of Science, enabling them to

a) appreciate practical applications of physics in the real world,
b) deepen their interest in physics for future learning and work,
c) become scientifically literate citizens who can innovate and seize opportunities in the 21st century, and
d) appreciate that a small number of basic principles and disciplinary ideas can be applied to explain, analyse and solve problems in the physical world.

The Disciplinary Ideas of Physics, the Practices of Science, and the Values, Ethics and Attitudes are elaborated in sections **1.5** to **1.7.**

1.5 Disciplinary Ideas of Physics

The Disciplinary Ideas of physics express overarching ideas that can be applied to describe, explain, and analyse and a variety of phenomena in the physical world. These high-level ideas provide students with a conceptual framework for developing a coherent view and understanding of scientific knowledge, facilitating application to real-world contexts and transfer of learning to novel situations. These ideas are revisited throughout the physics syllabus and form a foundation for further study at higher levels of learning and beyond the schooling years.

The six Disciplinary Ideas are:

1. Matter and energy make up the Universe

2. Matter interacts through forces and fields

3. Forces help us understand motion

4. Waves can transfer energy without transferring matter

5. Conservation laws constrain the changes in systems

6. Microscopic models can explain macroscopic phenomena

1.6 Practices of Science

Teachers are encouraged to provide opportunities for students to develop the Practices of Science. It is important to appreciate that the three components of the Practices are intricately related.

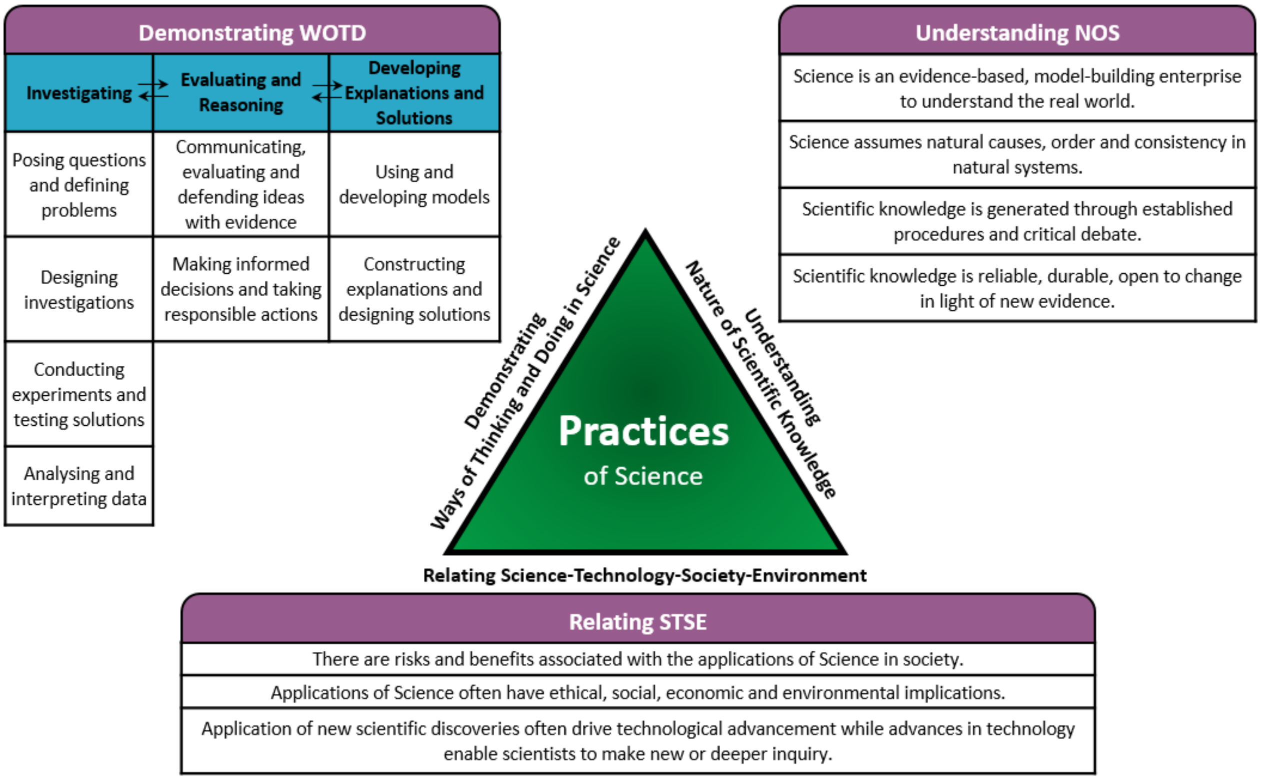

Figure 1.3: Practices of Science

1.7 Values, Ethics and Attitudes

Although science uses objective methods to arrive at evidence-based conclusions, it is in fact a human enterprise conducted in particular social contexts which involves consideration of values and ethics. The intent of fostering an awareness and appreciation of these values in the curriculum is to sensitise our students to the ethical implications of the application of science in society. The challenges that humanity will face in the upcoming centuries will not be overcome by scientific and technological solutions alone. There is a need to consider the impact of these solutions in terms of their benefits to humanity and the ethical issues involved. Thus, science education needs to equip students with the ability to articulate their ethical stance as they participate in discussions about socio-scientific issues[1] that involve ethical dilemmas, with no single right answers.

Values, Ethics and Attitudes	Description
Curiosity	Desiring to explore the environment and question what is found.
Creativity	Seeking innovative and relevant ways to solve problems.
Integrity	Handling and communicating data and information with complete honesty.
Objectivity	Seeking data and information to validate observations and explanations without bias.
Open-mindedness	Accepting all knowledge as tentative and suspending judgment. Tolerance for ambiguity. Willingness to change views if the evidence is convincing.
Resilience	Not giving up on the pursuit for answers / solutions. Willingness to take risks and embrace failure as part of the learning process.
Responsibility	Showing care and concern for living things and awareness of our responsibility for the quality of the environment.
Healthy Scepticism	Questioning the observations, methods, processes and data, as well as trying to review one's own ideas.

[1] Examples of socio-scientific issues are genetic engineering (e.g. cloning and gene therapy), reproductive technology, climate change and the adoption of nuclear energy.

SECTION 2: CONTENT

Measurements
Newtonian Mechanics
Thermal Physics
Waves
Electricity and Magnetism
Radioactivity

2. CONTENT

Content structure

The 20 topics in the Upper Secondary Pure Physics syllabus is organized into six main sections as listed in **Table 2.1**. In this teaching and learning syllabus, a broad narrative is provided for each of the main sections followed by a list of guiding questions, learning outcomes and learning experiences for each of the topics.

Sections	Topics
Measurements	1. Physical Quantities, Units and Measurements
Newtonian Mechanics	2. Kinematics
	3. Dynamics
	4. Turning Effects of Forces
	5. Pressure
	6. Energy
Thermal Physics	7. Kinetic Particle Model of Matter
	8. Thermal Processes
	9. Thermal Properties of Matter
Waves	10. General Wave Properties
	11. Electromagnetic Spectrum
	12. Light
Electricity and Magnetism	13. Static Electricity
	14. Current of Electricity
	15. D.C. Circuits
	16. Practical Electricity
	17. Magnetism
	18. Electromagnetism
	19. Electromagnetic Induction
Radioactivity	20. Radioactivity

Table 2.1: Sections and topics in the Upper Secondary 'O' Level Physics syllabus

Guide to using this section

This is a brief description of the features in **Sections 2.1 – 2.6.**

Section overview

2.1 Measurements

Overview

In order to gain a better understanding of the physical world, scientists use a process of investigation that follows a general cycle of observation, hypothesis, deduction, test and revision, sometimes referred to as the scientific method. Galileo Galilei, one of the earliest architects of this method, believed that the study of science had a strong logical basis that involved precise definitions of terms and physical quantities, and a mathematical structure to express relationships between these physical quantities. To test these relationships and develop physical theories and models, it is essential to collect experimental data through precise measurements. As better tools and techniques for measurement are developed, new or improved measurements can be made, generating data that helps us to better understand and quantify the natural world. Scientific knowledge thus continues to evolve or be generated.

Section narrative - highlights the value of learning the concepts covered in each section and the connections among the topics to guide teachers in making learning relevant and coherent.

Topic overview

TOPIC 1. PHYSICAL QUANTITIES, UNITS AND MEASUREMENTS

- Physical quantities and SI Units
- Measurement
- Scalars and vectors

Guiding Questions

- What are physical quantities and how do we quantify them?
- Why do we use different measuring instruments to measure or determine physical quantities?

Topic Description

Scientists use many skills as they investigate the world around them. They make observations by gathering information with their senses. They often need to make measurements in order to quantify physical properties or changes. This would allow them to test their experiences or observations against others and verify their data by repeated experiments. This forms the basis of the scientific method.

To quantify physical properties well and communicate scientific information effectively, a set of standard units is needed. As early in the 3rd or 4th millennium BC, the need for units of measurement in agriculture, construction and trade was recognised. However, early systems of measurements usually applied to a community or small region, with multiple standards in all. Some of these units were also based on body parts, which varied from individual to individual. With growing importance of trade between communities and countries, it became increasingly critical to standardise units of measurement.

Today, the metric system is known as the International System of Units (**SI Units**), which consists of base units for seven base **physical quantities** – mass, length, time, current, temperature, luminous intensity (out of syllabus) and amount of substance. In this topic, students will learn to select appropriate instruments for the **measurement** or determination of these quantities and explain their choice. They will also learn about **scalar** and **vector** quantities. The implications of vector addition will be discussed in the next section on Newtonian Mechanics.

Guiding questions - highlight the essential takeaways for each topic.

Topic description - highlights the key ideas within each topic and the value of learning them to guide teachers in making learning relevant.

Learning outcomes

Learning Outcomes
(a) show an understanding that physical quantities typically consist of a numerical magnitude and a unit
(b) recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)

2.1 Measurements

Overview

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In this section, students will learn about ***Physical Quantities, Units and Measurements***¸ beginning with a set of base physical quantities and units that can be used to derive all other physical quantities and units. These precisely defined quantities and units, with accompanying order-of-ten prefixes (e.g. milli-, centi- and kilo-) can then be used to describe the interactions between objects in systems that range from celestial objects in space to sub-atomic particles.

A variety of instruments are available for the measurement or determination of these quantities. Students will learn to select appropriate instruments, taking into consideration their precision, range and feasibility. In their course of study, students will also engage in practical activities involving the use of such instruments to collect data and make observations. They will study the limitations associated with the measurement process which can arise from the precision of the instrument chosen, the mechanics of the measuring instrument and the design of the experiment.

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Today, the metric system is known as the International System of Units (**SI Units**), which consists of base units for seven base **physical quantities** – mass, length, time, current, temperature, luminous intensity (out of syllabus) and amount of substance. In this topic, students will learn to select appropriate instruments for the **measurement** or determination of these quantities and explain their choice. They will also learn about **scalar** and **vector** quantities. The implications of vector addition will be discussed in the next section on Newtonian Mechanics.

Learning Outcomes
(a) show an understanding that physical quantities typically consist of a numerical magnitude and a unit
(b) recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
(c) use the following prefixes and their symbols to indicate decimal sub-multiples and multiples of the SI units: nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)
(d) show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth
(e) select and explain the use of appropriate measuring instruments to measure or determine physical quantities listed in 'Summary of key quantities, symbols and units'* taking into consideration the range and precision of the instrument
(f) state what is meant by *scalar* and *vector* quantities and give common examples of each
(g) add two vectors to determine a resultant by a graphical method

*Please refer to Singapore Examinations and Assessment Board website for the Summary of key quantities, symbols and units.

2.2 Newtonian Mechanics

<u>Overview</u>

Mechanics is the branch of physics that deals with the study of motion and its causes. Aristotle, one of the greatest Greek philosophers whose ideas influenced the study of nature for more than two thousand years, wrote extensively on many subjects, including the physical sciences. Aristotle was among the first to propose that abstract principles govern nature and believed in logic and observation.

However, Aristotle's ideas of motion were flawed. He believed that a moving body can only be kept moving by applying a force on it constantly, and that heavy objects would fall faster than lighter ones. He also believed that laws of nature were different on the Earth and in the 'heavens', as planets kept moving without slowing down. Through a careful process of observation, experimentation and tedious measurement, Galileo Galilei overturned these ideas that dominated physics for a long time and proposed basic principles governing the motion of objects that became the precursor to the works of Isaac Newton and Albert Einstein.

The greatest contribution to the development of mechanics is by one of the greatest physicists of all time, Isaac Newton. By extending Galileo's methods and understanding of motion and gravitation, Newton developed the three laws of motion and his law of universal gravitation, and successfully applied them to both terrestrial and celestial systems to predict and explain phenomena. He showed that nature has an amazing simplicity and is governed by a few special rules or laws that can be expressed in mathematical formulae. Indeed, the unifying aspect of physical laws is a theme that recurs throughout the Physics syllabus – from the laws of motion to thermodynamics and electromagnetism. Science, and especially physics, seeks to discover and describe the underlying order and simplicity in nature, and many of the ideas that will be introduced in this syllabus are the result of these efforts. As the scientific endeavour continues, physicists hope to one day find a "unified theory" that connects all of nature's forces and matter.

In this section, students will begin by examining ***Kinematics***, which is a study of motion without regard for the cause. In the topic on ***Dynamics***, students will be introduced to the concept of forces through Newton's Laws and study the conditions required for an object to be accelerated. Subsequently, ***Turning Effects of Forces*** and ***Pressure*** are introduced as other effects of a force. Finally, this section ends off by leading the discussion from forces, which explain changes during interactions, to ***Energy***, which is a quantitative tool for analysing these changes. The amount of energy, which must be conserved in an isolated system, places limitations on possible changes to the system.

TOPIC 2. KINEMATICS

- Speed, velocity and acceleration
- Graphical analysis of motion
- Free fall

Guiding Questions

- How do we communicate to others, the motion of objects (moving in a straight line)?
  a) What vocabulary should we use?
  b) What kinds of representations should we use?
- What sort of motion do bodies falling near the Earth's surface experience?

Topic Description

Kinematics is the study of motion, without addressing the forces that produce the motion. It is important to be able to first characterise the motion of objects. Only then can we appreciate the interactions and forces that drive the motion of these objects.

Kinematics provides us with a "language" to describe, communicate and make predictions about the motion of a body with respect to time. In this topic, specific scientific vocabulary, mathematical and **graphical representations** of a body's position, **speed, velocity and acceleration** are used for describing and **analysing motion** of bodies in a straight line and in **free fall**.

Most objects in the real-world do not move in a perfect straight line (linear motion). Objects can also move with curved paths (e.g., a cannon ball in projectile motion), circular/elliptical paths (e.g., the motion of the Earth around the sun) or experience rotational (e.g., a spinning top) and periodic (e.g., a child swinging back-and-forth on a swing) motion. Nonetheless, linear motion (e.g., a skydiver in free fall, a train travelling on a straight track, a ball rolling down a ramp) provides a foundation for studying more complex kinds of motion.

Learning Outcomes
(a) state what is meant by speed and velocity
(b) calculate *average speed = distance travelled / time taken*
(c) state what is meant by uniform acceleration and calculate the value of acceleration using *change in velocity / time taken*
(d) interpret given examples of non-uniform acceleration
(e) plot and interpret a displacement-time graph and a velocity-time graph for motion in one dimension
(f) deduce from the shape of a displacement-time graph when a body is: (i) at rest (ii) moving with uniform velocity (iii) moving with non-uniform velocity
(g) deduce from the shape of a velocity-time graph when a body is: (i) at rest (ii) moving with uniform velocity (iii) moving with uniform acceleration (iv) moving with non-uniform acceleration
(h) calculate the area under a velocity-time graph to determine the displacement for motion with uniform velocity or uniform acceleration
(i) state that the acceleration of free fall for a body near to the Earth is constant and is approximately 10 m / s^2

TOPIC 3. DYNAMICS

- Types of forces
- Mass, weight and gravitational field
- Newton's laws of motion
- Effects of resistive forces on motion

Guiding Questions

- What are the characteristics of forces and effects of forces on motion of bodies?

Topic Description

Forces cause a body to move, slow down, speed up, stop or change its direction. Hence, forces help us understand motion, which is a disciplinary idea of the syllabus. A force may be exerted through physical contact between bodies or even over distances. The latter is exemplified by the orbiting planets around the Sun, due to mutual gravitational attractions between them.

The concept of force has always fascinated mankind and the scientific knowledge established today is the culmination of the work of several generations of great thinkers. Aristotle was the first to provide a philosophical discussion on the concept of force. Galileo established the scientific method and used it to develop mathematical representations that successfully described motion. His work contributed the initial steps leading to a proper idea of inertia, which became Newton's first law. The collaborative nature of the scientific enterprise is epitomised in these developments, and also captured in Newton's famous quote, "If I have seen further, it is by standing upon the shoulder of giants".

In this topic, students are introduced to the two **types of forces**, namely contact and non-contact (exerted over distance) forces. The concept of gravitational force (weight), how it relates to mass and how it can be quantified are covered under **Mass, weight and gravitational field**.

Following that, students will learn to apply **Newton's laws of motion** in cases where forces are balanced or unbalanced. Whereas Kinematics is a study of motion without regard for the cause, Dynamics is concerned with the motion of objects in relation to the physical factors that affect them. In this topic, students will study the conditions required for an object to be accelerated. At the end of the topic, students will incorporate the effect of air resistance to explain how a falling body achieves terminal velocity under **Effects of resistive forces on motion**.

Learning Outcomes	
(a)	identify and distinguish between contact forces (e.g. friction, air resistance, tension and normal force) and non-contact forces (e.g. gravitational, electrostatic and magnetic forces)
(b)	state that mass is a measure of the amount of matter in a body
(c)	state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction
(d)	define gravitational field strength, *g,* as *gravitational force per unit mass placed at that point*
(e)	recall and apply the relationship *weight* = *mass* × *gravitational field strength* to new situations or to solve related problems
(f)	distinguish between mass and weight
(g)	apply Newton's Laws to: (i) describe the effect of balanced and unbalanced forces on a body (ii) describe the ways in which a force may change the motion of a body (iii) identify action-reaction pairs acting on two interacting bodies (stating of Newton's Laws is not required)
(h)	identify forces acting on a body and draw free body diagram(s) representing the forces acting on the body (for cases involving forces acting in at most two dimensions)
(i)	solve problems for a static point mass under the action of three forces for two-dimensional cases by a graphical method
(j)	recall and apply the relationship *resultant force* = *mass* × *acceleration* to new situations or to solve related problems
(k)	show an understanding that mass is the property of a body which resists change in motion (inertia)
(l)	explain the effects of friction on the motion of a body
(m)	describe the motion of bodies with constant mass falling in uniform gravitational field with or without air resistance, including reference to terminal velocity

TOPIC 4. TURNING EFFECTS OF FORCES

- Moments
- Equilibrium
- Centre of gravity and stability

Guiding Questions

- When does a force cause something to turn?
- What keeps an object from toppling?

Topic Description

A force can cause a turning effect. This is experienced in many everyday situations, such as when we open a door, pedal on a bicycle, or try to maintain our balance while standing in a bus. Turning effects of forces are also essential for many machines to function as levers and gears rely on them to provide a mechanical advantage. In fact, the principle of moments was derived from the operating principle of the lever which was discovered by Archimedes.

In this topic, students will begin by learning about **moments** of a force as a measure of its turning effect, and how this is seen in everyday life. They will study how the moments about a pivot must be 'balanced' to achieve (rotational) equilibrium, much like how forces on a body must be balanced to achieve (translational) equilibrium. Thus, for a body to be in **equilibrium**, both the resultant force and the resultant moment on the body must be zero. Finally, students will apply their understanding of moments to examine how the **stability** of an object is affected by the position of its **centre of gravity** and its base area.

Learning Outcomes
(a) describe the moment of a force about a pivot in terms of its turning effect and relate this to everyday examples
(b) recall and apply the relationship *moment of a force (or torque) = force* × *perpendicular distance from the pivot* to new situations or to solve related problems
(c) state the principle of moments for a body in equilibrium
(d) apply the principle of moments to new situations or to solve related problems
(e) show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity
(f) describe qualitatively the effect of the position of the centre of gravity on the stability of objects

TOPIC 5. PRESSURE

- Pressure
- Density and fluid pressure

Guiding Questions

- What is pressure?
- How is force transmitted through an enclosed liquid?
- How is the height of a column of liquid used to measure pressure?

Topic Description

A component of our sense of touch comes from numerous tiny pressure sensors in our skin. We often experience the pressure due to a force rather than the force itself. For example, our sensation of pain is related to the **pressure** exerted when someone wearing high heel shoes steps on us or when we accidentally cut our skin with the thin edge of a piece of paper. In such situations, it is important to consider whether the force is "concentrated" over a small area or "spread out" over a large area. In the same way, an engineer needs to calculate not only the total force exerted by structures on a building, but also the pressure in terms of how forces are distributed over the entire floor area.

We also experience pressure when a force is transmitted through fluids (e.g., atmospheric pressure). This topic builds on the ideas developed by Pascal about **density and fluid pressure**. Pascal allegedly demonstrated what is known as Pascal's barrel experiment that the difference in pressure between two points within a fluid column depends on the difference in elevation between those two points. He also discovered that the pressure in an enclosed (incompressible) liquid is transmitted equally to all parts of the liquid. This is known as Pascal's law and is the basis of many applications in the modern world, ranging from hydraulic systems used in elevators and vehicle brakes to the measurement of blood pressure.

Learning Outcomes	
(a)	define pressure in terms of force and area
(b)	recall and apply the relationship *pressure* = *force* / *area* to new situations or to solve related problems
(c)	describe and explain the transmission of pressure in hydraulic systems with particular reference to the hydraulic press
(d)	recall and apply the relationship *density* = *mass* / *volume* to new situations or to solve related problems
(e)	recall and apply the relationship *pressure due to a liquid column* = *height of column* × *density of the liquid* × *gravitational field strength* to new situations or to solve related problems
(f)	describe how the height of a liquid column may be used to measure the atmospheric pressure
(g)	describe the use of a manometer in the measurement of pressure difference

TOPIC 6. ENERGY

- Energy stores and transfers
- Work, power and efficiency
- Energy resources

Guiding Questions

- How can energy be transferred from one energy store to another during interactions?
- How do we apply the principle of conservation of energy to perform energy analysis?
- Which energy resource(s) should we use to meet our energy demand?

Topic Description

Energy is one of the most fundamental concepts in physics but also one of the hardest to define. Its representation as an abstract mathematical quantity is important, however, as it provides useful information about the state of a system without delving into the physical processes that are involved. For example, we can estimate the maximum height of the rocket without the need to probe into the complexity of the mechanisms and processes within the rocket that make the motion possible.

In layman terms, the idea of energy "being used up" is often talked about. However, energy has the remarkable property of never being "used up", only transferred from one store to another. These energy transfers can occur through the following ways: mechanically, electrically, by heating, and by propagation of waves. In the real world, these transfers are never 100% efficient, leading to a decrease of energy in stores that are useful to us. Nevertheless, the total energy of an isolated system will always remain constant. Being central to the discipline, the concept of energy naturally transcends domains in physics. As such, students can expect the revisit of energy concepts in other parts of this syllabus.

Under **Energy stores and transfers**^, students will learn that energy can be transferred between stores, the sum of energy in these stores remains unchanged. They will then explore mechanical work, one of the ways of energy transfers, under **Work, power and efficiency**. Students will also learn to apply the definition of power, which is the rate of energy transfer, and to calculate the efficiency of energy transfer. Finally, energy as an essential resource will be discussed under **Energy resources**. In it, students will learn about renewable and non-renewable resources and the considerations involved in the choice of energy resources.

^Do note that "x energy" may henceforth be used as a shorthand for "energy in x store".

Learning Outcomes
(a) show an understanding that there are energy stores, e.g. kinetic, potential (gravitational, chemical, elastic), nuclear and internal, and that energy can be transferred from one store to another: (i) Mechanically (by a force acting over a distance) (ii) Electrically (by an electric current) (iii) By heating (due to a temperature difference) (iv) By propagation of waves (both electromagnetic and mechanical)
(b) recall and apply the relationships for kinetic energy ($E_k = ½\, mv^2$) and gravitational potential energy near the Earth's surface ($E_p = mgh$) to new situations or to solve related problems
(c) state the principle of the conservation of energy and apply the principle to new situations or to solve related problems
(d) recall and apply the relationship *work done* = *force* × *distance moved in the direction of the force* to new situations or to solve related problems
(e) recall and apply the relationship *power* = *energy transfer* / *time taken* to new situations or to solve related problems
(f) calculate the efficiency of an energy transfer using the formula *efficiency* = *useful energy output* / *total energy input*
(g) discuss the use of non-renewable energy resources such as fossil fuel and nuclear fuel, and renewable energy resources such as biofuel, wind, tides, hydropower, geothermal reservoirs and solar to generate electricity in terms of efficiency of energy transfer, cost, reliability and their environmental impact

2.3 Thermal Physics

Overview

When asked to describe the most valuable scientific information in a single sentence, Richard Feynman's response was, "All things are made of atoms — little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence ... there is an enormous amount of information about the world." (Six Easy Pieces, p.4)

The ***Kinetic Particle Model of Matter*** cuts across biology, chemistry and physics. It can be used extensively to explain how different types of matter exhibit certain physical properties, how chemical reactions occur and how processes like diffusion and osmosis, which are important in biological systems, occur. The section begins with an introduction of this model. The model is then used to explain and predict the physical properties and changes of matter at the microscopic level in relation to energy transfer.

In the next topic, three ***Thermal Processes*** for energy transfer are examined – conduction, convection and radiation. These processes result in a net transfer of energy from a region of higher temperature to a region of lower temperature until thermal equilibrium is achieved. Radiation, which is also a type of energy transfer by propagation of waves, will be revisited in the next section on Waves.

The relationship between energy transferred and temperature of the substance, and how energy affects the particles in matter is further explored in the topic of ***Thermal Properties of Matter***. When energy is transferred to matter, the temperature of matter may rise or it may experience a change in state. This topic discusses how much energy is required for a change in temperature or state, drawing upon the knowledge from Kinetic Particle Model of Matter and Thermal Processes.

TOPIC 7. KINETIC PARTICLE MODEL OF MATTER

- States of matter
- Kinetic Particle Model

Guiding Questions

- Why do different states of matter exhibit different behaviours?
- How are macroscopic physical quantities of matter such as temperature and pressure (of a gas) explained at the microscopic level using the Kinetic Particle Model of Matter?

Topic Description

Scientists and philosophers have contemplated the exact nature of matter since a long time ago. The idea that matter is built of discrete building blocks, which is called the particulate theory of matter, was first put forward by the Greek philosophers Leucippus and Democritus in the 5th century BC. Democritus proposed that matter is composed of tiny particles which he called *atomos*, or “indivisible”. However, this atomic theory was a philosophical one, rather than a scientific one. It was not based on measurements or experiments, and was not tested. These ideas were developed into a scientific theory more than two millennia later, starting in the 17th century, and major advances were made by the English chemist John Dalton and Italian scientist Amedeo Avogadro in the early 1800s.

A significant development came when Scottish botanist Robert Brown, known for his pioneering use of the microscope, observed a curious phenomenon. In 1827, while examining pollen grains under his microscope, he noticed minute particles moving continuously in a jittery manner. He thought the motion was due to life processes within the pollen, but later discovered that even pollen from plants that had been dead for a long time exhibited the same behaviour, which came to be known as Brownian motion. Some years later, physicist James Clerk Maxwell came up with an explanation for Brownian motion using the kinetic particle theory of matter. Albert Einstein further analysed Brownian motion, and came up with a mathematical model to make quantitative predictions based on the kinetic particle theory. His analysis was experimentally verified by French physicist Jean Perrin, further validating the theory and putting an end to doubts about the existence of atoms and molecules as actual physical entities. The development of the kinetic particle theory of matter epitomises the nature of science as an evidence-based, model-building enterprise concerned with understanding the natural world. A model or theory that is created to explain observations has to make predictions, and the model or theory is accepted as valid if its predictions are correct as verified by experiments.

In this topic, students will learn about the **Kinetic Particle Model**, which helps us understand what matter is made of, and why different **states of matter** exhibit different behaviours. They will be introduced to important ideas relating the random motion of the particles to the temperature of the body and the pressure exerted by a gas. These concepts will provide a foundation for understanding the ideal gas laws at higher levels and for future learning in Thermodynamics and Statistical Mechanics.

Learning Outcomes	
(a)	compare the physical properties of solids, liquids and gases
(b)	use the kinetic particle model to describe the different states of matter (solids, liquids and gases), relating their physical properties to the arrangement and motion of the particles (e.g. molecules, atoms) and the forces and distances between particles
(c)	infer from a Brownian motion experiment the evidence for the random movement of molecules in a liquid or gas
(d)	relate the rise in temperature of a body to the increase in average kinetic energy of all the particles in the body
(e)	explain the pressure of a gas in terms of the motion of its particles

TOPIC 8. THERMAL PROCESSES

- Thermal equilibrium
- Conduction
- Convection
- Radiation

Guiding Questions

- What is thermal equilibrium?
- How do we describe the process of energy transfer through different materials?

Topic Description

Until the middle of the 19th century, "heat" was thought to be a fluid called caloric fluid. Objects like wood or coal were thought to be able to store the fluid and released "heat" upon combustion. However, this explanation could not explain why friction produced a heating effect. In the 1840s, James Prescott Joule conducted experiments in which falling weights were used for heating water. He obtained values relating the decrease in gravitational potential energy of the falling weights to the amount of "heat" produced. This formed a strong argument for thinking of *heating* as a process of energy transfer.

It is important to note that "heat" is not a substance. Energy is transferred from one body to another when there is a temperature difference and this can cause the internal energy of each body to change – *heating* is what we call that process of energy transfer, while internal energy is the energy store that gets filled up or depleted during this process. This process of heating or energy transfer continues until the two bodies are at **thermal equilibrium**, that is, they are at the same temperature.

Three processes for energy transfer are explored in this topic – **conduction**, **convection** and **radiation**. Our understanding of these different mechanisms enables us to control and make use of them in many appliances and machines. Radiation, which is also a type of energy transfer by the propagation of electromagnetic waves, will be revisited in the topic of Electromagnetic Spectrum. At higher levels, the rate and quantity of energy transfer by conductive, convective and radiative processes may be quantified.

Learning Outcomes
(a) show an understanding that energy is transferred (by heating) from a region of higher temperature to a region of lower temperature until thermal equilibrium is achieved between the two regions
(b) describe, in microscopic terms, how conduction occurs in solids (via vibration of atoms/molecules and movement of electrons)
(c) describe, in terms of density changes, how convection occurs in fluids
(d) explain that energy transfer by electromagnetic radiation does not require a material medium and that this rate of energy transfer to/from a body is affected by its: (i) surface colour and texture (ii) surface temperature (iii) surface area
(e) apply the concepts of conduction, convection and radiation in everyday examples

TOPIC 9. THERMAL PROPERTIES OF MATTER

- Internal energy
- Specific heat capacity
- Melting, boiling and evaporation
- Specific latent heat

Guiding Questions

- How do we describe the behaviour of different materials when energy is transferred by heating?
- Why does a change in state occur without a change in temperature?

Topic Description

Until about 1850, the subjects of thermodynamics and mechanics were considered two distinct branches of science. This started to change when experiments performed by the English physicist James Prescott Joule (1818 – 1889) and others showed that there is a quantitative relationship between the amount of work done on a system, the energy transferred by heating, and the change in internal energy of the system.

As mentioned in the topic of Thermal Processes, a major distinction must be made between internal energy and energy transferred by heating. *Heating* is a process, mechanism or pathway by which energy is transferred from one store to another, while **internal energy** is an energy store made up of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles in the system. When matter undergoes *heating*, its internal energy may increase. Heating may result in an increase in temperature (average kinetic energy of all the particles increases), or a change in state (potential energy of the particles increases). For the former, the amount of temperature increase is dependent on the material's specific heat capacity. For the latter, the energy required for the change in state is known as the latent heat.

In this topic, students will learn to describe **internal energy** as an energy store. They will explore the thermal properties of matter, including the **specific heat capacity** and **specific latent heat** of materials, and use them to calculate the amount of energy transfer required for a change in temperature or state. They will also learn about some processes involving changes in states of matter, such as **melting**, solidification, **boiling**, condensation and **evaporation**.

Learning Outcomes	
(a)	describe internal energy as an energy store that is made up of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles in the system
(b)	define *heat capacity* and *specific heat capacity*
(c)	recall and apply the relationship *energy transfer (by heating) = mass* × *specific heat capacity* × *change in temperature* to new situations or to solve related problems
(d)	describe melting/solidification and boiling/condensation as processes of energy transfer without a change in temperature
(e)	explain the difference between boiling and evaporation
(f)	define *latent heat* and *specific latent heat*
(g)	recall and apply the relationship *energy transfer (by heating for a change of state) = mass* × *specific latent heat* to new situations or to solve related problems
(h)	explain latent heat in terms of behaviour of particles in a body
(i)	sketch and interpret a cooling curve

2.4 Waves

Overview

All waves have properties in common and a wave model can be used to explain many phenomena, both natural (like water waves and sound) and artificial (like many forms of electromagnetic waves). The ability of waves to transfer energy at great speed provides valuable propositions.

Much of our current understanding of wave motion comes from the study of acoustics, which is the science of sound. Many of the ancient Greek philosophers were interested in music and they hypothesized that there was a relation between waves and sound, that vibrations were responsible for sounds. Pythagoras observed in 550 BC that vibrating strings produced sound, and eventually determined the mathematical relationship between the length of strings and the tones they produced.

Scientific theories of wave propagation became more prominent in the 17th Century, when Galileo Galilei published a finding that connected vibrating bodies to the sounds they produced. In 1640, Robert Boyle's classic experiment on the sound produced by a ticking watch in a partially evacuated glass vessel provided evidence that the production and transmission of sound required a medium.

The mathematical theory of sound propagation began with Isaac Newton, who thought of sound as being "pressure" pulses transmitted through neighbouring fluid particles. In the 18th Century, French mathematician and scientist Jean Le Rond d'Alembert discovered the one-dimensional wave equation. It was a mathematical description of waves, which laid the foundation for other scientists to study and describe wave phenomena.

This section seeks to explain the general characteristics of the two main types of waves, longitudinal and transverse waves, using examples of waves that are mechanical and electromagnetic in nature. The topic of ***General Wave Properties*** looks into distinguishing the two types of waves in the way they travel and how their exhibited properties of frequency, speed and wavelength are related.

The topic of ***Electromagnetic Spectrum*** delves further into electromagnetic waves. Students will learn about the implications and applications of the various components of the electromagnetic spectrum, allowing them to appreciate the role of electromagnetic waves in modern world technology, while not forgetting the dangers of over-exposure to ionising radiation.

Light, a component of the electromagnetic spectrum, takes centre-stage as the last topic of the section. The ray model is used to illustrate the phenomena of reflection, refraction and formation of images by mirrors and lenses. In this topic, students will encounter the intriguing occurrence of total internal reflection as light travels between media and learn how it is applied in modern day technology.

TOPIC 10. GENERAL WAVE PROPERTIES

- Describing wave motion
- Wave properties
- Sound

Guiding Questions

- How can we describe wave motion?
- How can we describe the characteristics and propagation of sound?

Topic Description

17th century scientists were convinced that all physical phenomena could eventually be explained by considering matter and its motion. However, as they continued their study, scientists found that the molecular model was not the only way to understand the behaviour of matter. Many phenomena (e.g., sound and light) could also be interpreted in terms of wave motions in matter. It is thus important to understand the nature of waves as it adds to our understanding of how the world works.

In this topic, waves are described as a disturbance that travels from one location to another location without the transfer of any material. In **describing wave motion**, the behaviour of particles in a medium (physical back and forth oscillation) is contrasted with the transfer of energy in the direction of propagation of a mechanical wave. Mechanical waves introduced in this topic include those generated by vibrations in ropes and springs, as well as water waves and sound waves. Displacement-time and displacement-distance graphs are used to represent and analyse **wave properties** such as their wavelengths, amplitudes and frequencies.

Sound will be highlighted as an example of a longitudinal wave. When sound waves are transmitted through a medium, particles in the medium oscillate in the direction of wave propagation, forming regions of compressions and rarefactions. Sound waves travelling through a medium may change their behaviour when they encounter a barrier, e.g., reflection. Students will learn how this phenomenon (echoes) can be used in applications such as ranging and medical diagnostics.

Learning Outcomes	
(a)	describe what is meant by wave motion as illustrated by vibrations in ropes and springs and by waves in a ripple tank (including use of the term wavefront)
(b)	show an understanding that waves transfer energy without transferring matter
(c)	define and use the terms *speed*, *frequency*, *wavelength*, *period* and *amplitude*, including graphical representation
(d)	recall and apply the relationship *speed of wave* = *frequency* × *wavelength* to new situations or to solve related problems
(e)	compare transverse and longitudinal waves and give suitable examples of each
(f)	show an understanding that sound can be produced by vibrating sources and a medium is required for the transmission of sound
(g)	describe the longitudinal nature of sound waves in terms of the processes of compression and rarefaction
(h)	relate loudness of a sound wave to its amplitude and pitch to its frequency
(i)	describe how the reflection of sound may produce an echo, and how this may be used for measuring distances
(j)	describe and explain how ultrasound is used, e.g. including sonar and medical scanning of soft tissue

TOPIC 11. ELECTROMAGNETIC SPECTRUM

- Properties of electromagnetic waves
- Applications of electromagnetic waves
- Effects of electromagnetic waves on cells and tissue

Guiding Questions

- How are electromagnetic waves arranged in the spectrum?
- How do electromagnetic waves affect our lives?

Topic Description

Electromagnetic waves are transverse waves produced by simultaneous oscillations of electric and magnetic fields**.** The electromagnetic spectrum is divided into 7 regions. In ascending order of frequency of oscillations, they are: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays. High frequency electromagnetic waves such as X-rays and gamma rays are high-energy ionising radiation that can remove electrons from neutral atoms. Overexposure to such electromagnetic waves can have harmful **effects on living cells and tissues** and may destroy or modify them.

Electromagnetic waves have many important **applications** in communication, home appliances, medical and industrial use. Although electromagnetic waves have a variety of different applications, common **properties of electromagnetic waves** include: the ability to propagate through empty space where there is no material medium, and the speed of 3×10^8 m/s when travelling in vacuum. As more forms of radiation are introduced, there is a need to distinguish between nuclear radiation which may include the transfer of charged particles, and electromagnetic and thermal radiation, which transfers energy only. Beyond energy transfer, an increasingly important dimension of electromagnetic waves for further reading is the transfer of information.

Learning Outcomes
(a) state that all electromagnetic waves are transverse waves that travel with the same speed in vacuum
(b) describe the main regions of the electromagnetic spectrum in order of wavelength and frequency
(c) state examples of typical uses of the following regions of the electromagnetic spectrum: (i) radio waves (e.g. radio and television communication, astronomy and RFID tags) (ii) microwaves (e.g. mobile (cell) phones, microwave oven and satellite television) (iii) infrared (e.g. infrared remote controllers, intruder alarms and thermal imaging) (iv) visible light (e.g. photography, optical fibres in medicine and telecommunications) (v) ultraviolet (e.g. sunbeds, bank note authentication and disinfecting water) (vi) X-rays (e.g. medical radiology, security screening and industrial defect detection) (vii) gamma (γ) rays (e.g. sterilising food, detection of cancer and its treatment)
(d) describe how over-exposure to electromagnetic waves can have hazardous effects (e.g. heating and ionising effects of radiation) on living cells and tissue

TOPIC 12. LIGHT

- Reflection of light
- Refraction of light
- Thin converging lenses

Guiding Questions

- What happens when light reflects off a surface?
- What happens when light interacts with different optical media?

Topic Description

We need light to be able to see. Understanding the behaviour of light can help explain how we see and why we see images. For example, why do we see reflections even in transparent objects like glass or water, and why is the floor of a pool deeper than how it looks from the surface? The human eye has a small lens which enables sharp images to form at the back of the eye. This lens is capable of changing curvature and shape to help us focus on near and far objects.

The nature of light is more complex than it seems. It is part of the electromagnetic spectrum, which implies that it has wave properties: transferring energy from a source (like the sun) to a target (like our eyes). It may undergo reflection and refraction when it encounters another medium. In further studies of physics, students may encounter experiments which show that light also behaves like a particle. This will lead on to studies of quantum physics, which paved the way for the development of lasers and computers which are so prevalent in our lives today.

In this topic, students will use the ray model of light (also called geometric optics) to describe phenomena such as the **reflection** and **refraction of light.** These showcase the change in behaviour of light when it encounters a barrier (e.g., mirror) or when it is transmitted into another medium respectively. Students will extend their understanding of refraction to describe the action of **thin converging lenses.** They will use ray diagrams to describe the formation of images and their characteristics.

Learning Outcomes
(a) recall and use the terms *normal*, *angle of incidence* and *angle of reflection* to describe the reflection of light
(b) state that, for reflection, the angle of incidence is equal to the angle of reflection and use this principle in constructions, measurements and calculations
(c) recall and use the terms *normal*, *angle of incidence* and *angle of refraction* to describe the refraction of light
(d) recall and apply the relationship sin *i* / sin *r* = *constant* to new situations or to solve related problems
(e) define *refractive index* of a medium in terms of the ratio of speed of light in vacuum and in the medium
(f) explain the terms *critical angle* and *total internal reflection*
(g) apply total internal reflection to the use of optical fibres in telecommunication and medicine, stating the advantages of such use
(h) describe the action of a thin converging lens on a beam of light
(i) define the *focal length* for a converging lens
(j) draw ray diagrams to illustrate the formation of real and virtual images of an object by a thin converging lens
(k) describe the characteristics of images (e.g. *real*/*virtual*, *magnified*/*diminished*, and *upright*/*inverted*) formed by a thin converging lens

2.5 Electricity and Magnetism

Overview

Electricity is an essential for modern life. It powers many devices that we use daily. Electricity generation typically relies on principles of Electromagnetism. More fundamentally, the electromagnetic force is one of the four fundamental interactions in nature, alongside the strong interaction, weak interaction and gravitational forces. Understanding electricity, magnetism and electromagnetism is thus important in laying the foundation for understanding the physical world.

Electricity and magnetism have been known for a long time. Thales of Miletus, a Greek philosopher, mathematician and astronomer, made a series of observations on static electricity around 600 BCE. The ancient Mediterranean cultures of that time knew that certain objects, such as amber rods, could be rubbed with cat's fur to attract light objects like feathers. The history of magnetism also dates back to 600 BCE. Magnetism was most probably first observed in lodestones, which could attract other pieces of the same material and iron.

However, it was only after nearly two thousand years that the phenomena of electricity and magnetism were investigated systematically using scientific methods. In 1600, the English scientist William Gilbert published a book explaining years of his research and experiments on electricity and magnetism. In this book, he described many important discoveries and contributions, including coining the word "electricus", inventing the first electrical measuring instrument and discovering that the Earth itself was magnetic.

It was only in 1802 when a phenomenon establishing a relationship between electricity and magnetism was discovered. The Danish physicist Hans Christian Ørsted discovered, accidentally, that a magnetic needle was deflected when the current in a nearby wire varied. While it had been a chance discovery, the strong observational skills of a scientist were necessary for it to be noticed. However, this discovery was overlooked by the scientific community until 18 years later, when André-Marie Ampère conducted a series of experiments to elucidate the exact nature of this relationship. Ampère showed that two parallel wires carrying electric currents magnetically attracted each other if the currents were in the same direction and repelled if the currents were in opposite directions. This discovery heralded the study of Electromagnetism. Further works by Michael Faraday reinforced the magnetic effect of a current and introduced the idea of a 'field' of action to explain why electricity and magnetism had an 'area of activity'. James Clerk Maxwell, a mathematical physicist, provided mathematical tools and equations to describe Faraday's ideas of the field. His works went on to prove that electromagnetic fields have wave-like properties which was a very important discovery in physics.

The section begins with a discussion of electric charges that are static, i.e. not moving, in the topic of ***Static Electricity***. Next, students will study the phenomena associated with moving charges and the concepts of current, electromotive force, potential difference and resistance in the topic of ***Current of Electricity***. They will also study how these concepts are applied to simple circuits and household electricity in ***D.C. Circuits*** and ***Practical Electricity***. Thereafter, they will study the laws of magnetism to pave the way for the study of the relationships between electricity and ***Magnetism***. The phenomenon in which a current interacts with a magnetic field is studied in ***Electromagnetism***, while the phenomenon in which a current or electromotive force is induced in a moving conductor within a magnetic field is studied in ***Electromagnetic Induction***.

TOPIC 13. STATIC ELECTRICITY

- Electric charge
- Electric field
- Dangers and applications of electrostatic charging

Guiding Questions

- How can we describe the interaction between charged bodies?
- What are dangers and applications of electrostatic charging?

Topic Description

Unlike charges attract and like charges repel. This phenomenon may seem trivial, but it has far-reaching applications. For example, this principle is used in electrostatic precipitators for removal of particles (mainly unreacted carbon) from waste gas, which can otherwise damage buildings and cause breathing difficulties if released untreated into the atmosphere. Understanding electrostatics also helps in designing precautionary measures to prevent charge build-up, which can be hazardous in the presence of inflammable substances.

In this topic, students will learn that there are two types of **electric charge** (positive and negative), and uncharged bodies consist of equal quantity of each type. Electrical insulators and conductors can become electrically charged by rubbing and induction respectively. Charged objects either have a deficit or surplus of electrons and thus contain a net charge. Under **Electric field,** students will learn that movement of an isolated charge is determined by the direction and strength of the electric field where it is located. And under **Dangers and applications of electrostatic charging**, students learn about the risks and benefits of electrostatic charging via examples such as an electrostatic precipitator.

Learning Outcomes
(a) state that there are positive and negative charges and that charge is measured in coulombs
(b) state that unlike charges attract and like charges repel
(c) describe an electric field as a region in which an electric charge experiences a force
(d) draw the electric field of an isolated point charge and recall that the direction of the field lines gives the direction of the force acting on a positive test charge
(e) draw the electric field pattern between two isolated point charges
(f) show an understanding that electrostatic charging by rubbing involves a transfer of electrons
(g) describe experiments to show electrostatic charging by induction
(h) describe examples where electrostatic charging may be a potential hazard
(i) describe the use of electrostatic charging in an electrostatic precipitator, and apply the use of electrostatic charging to new situations

TOPIC 14. CURRENT OF ELECTRICITY

- Conventional current and electron flow
- Electromotive force and potential difference
- Resistance

Guiding Questions

- How do we describe the energy transfer in an electric circuit?
- What is the difference between electromotive force and potential difference?
- What are the factors affecting electrical resistance?

Topic Description

Although electricity powers almost every aspect of our modern lives, myths about electricity are pervasive even among physics students. Some misconceptions about electricity include: a battery supplies the same current, regardless the circuit in which it is used, and a battery stores or provides charge.

In this topic, students learn about the flow of charge due to an electric **potential difference** and that **electromotive force** is the work done by a source in driving a unit charge around a complete circuit. In an electrical system, charge may be carried by electrons in a metal, ions in an electrolyte, or by both ions and electrons (such as in an ionised gas). **Conventional current flow** describes the flow of current from a point of higher to lower electric potential, and it is opposite in direction to **electron flow**.

Students learn that that the **resistance** of an electrical component is the ratio of the p.d. across the component (V) to the current (I) flowing through it. Ohm's Law states that the ratio of V against I for a metallic conductor at constant temperature is constant. However, as temperature increases, resistance of a metallic conductor increases. I-V graphs for a filament lamp and semiconductor diode do not obey Ohm's law. For a wire, the resistance depends on its length, cross-sectional area and type of material.

Learning Outcomes	
(a)	state that current is the rate of flow of charge and that it is measured in amperes
(b)	distinguish between conventional current and electron flow
(c)	recall and apply the relationship *charge* = *current* × *time* to new situations or to solve related problems
(d)	state that the electromotive force (e.m.f.) of a source is the work done per unit charge by the source in driving charges around a complete circuit and that it is measured in volts
(e)	calculate the total e.m.f. where several sources are arranged in series
(f)	state that the potential difference (p.d.) across a component in a circuit is the work done per unit charge in driving charges through the component and that it is measured in volts
(g)	state that *resistance* = *p.d.* / *current*
(h)	apply the relationship $R = V / I$ to new situations or to solve related problems
(i)	recall and apply the relationship of the proportionality between resistance and the length and cross-sectional area of a wire to new situations or to solve related problems
(j)	describe the effect of temperature increase on the resistance of a metallic conductor
(k)	sketch and interpret the I-V characteristic graphs for a metallic conductor at constant temperature (ohmic conductor), for a filament lamp and for a semiconductor diode

TOPIC 15. D.C. CIRCUITS

- Circuit diagrams
- Series and parallel circuits
- Action and use of circuit components

Guiding Questions

- How does the arrangement of electrical components affect the current, potential difference and resistance of the circuit?

Topic Description

Direct Current (D.C.) circuits are electrical circuits in which current flows in one direction only. Many of the devices that we rely on today, such as mobile phones and laptops, use direct current.

In this topic, students will learn to draw **circuit diagrams** of common power sources and circuit components. They will discover how **series** and **parallel** arrangement of circuit components affect the current, potential difference and resistance of the circuit, and apply the laws of conservation of energy and charge to understand the relationships. A change in any part of the circuit affects all other parts almost instantaneously. By using various **circuit components**, various **actions** or specific **uses** (e.g., turning on a lamp when the surrounding is dark) could be achieved. In this topic, we are only interested in circuits that have reached a steady state – that is, the current at each point in the circuit does not change with time.

Learning Outcomes
(a) draw circuit diagrams with power sources (cell, battery, d.c. supply or a.c. supply), switches, lamps, resistors (fixed and variable), variable potential divider (potentiometer), fuses, ammeters and voltmeters, bells, light-dependent resistors, thermistors and light-emitting diodes
(b) state that the current at every point in a series circuit is the same and apply the principle to new situations or to solve related problems
(c) state that the sum of the potential differences in a series circuit is equal to the potential difference across the whole circuit and apply the principle to new situations or to solve related problems
(d) state that the sum of the currents in the separate branches of a parallel circuit is equal to the current from the source and apply the principle to new situations or to solve related problems
(e) state that the potential difference across the separate branches of a parallel circuit is the same and apply the principle to new situations or to solve related problems
(f) recall and apply the formulae for the effective resistance of a number of resistors in series and in parallel to new situations or to solve related problems
(g) recall and apply the relevant relationships, including $R = V / I$ and those for current, potential differences and resistors in series and in parallel circuits, in calculations involving a whole circuit
(h) describe the action of a variable potential divider (potentiometer)

Learning Outcomes	
(i)	describe the action of negative temperature coefficient (NTC) thermistors and light-dependent resistors and explain their use as input transducers in potential dividers
(j)	solve simple circuit problems involving NTC thermistors and light-dependent resistors

TOPIC 16. PRACTICAL ELECTRICITY

- Electrical working, power and energy
- Dangers of electricity
- Safe use of electricity in the home

Guiding Questions

- How do electrical circuits transfer energy to our homes and how are we charged for electricity consumption?
- How do we use electrical appliances and components safely?

Topic Description

Electricity is an essential part of modern homes. It is used for various purposes like heating, lighting, cooling and more.

With the prevalent use of electricity in our homes, it is important for students to understand the safe use of electricity, recognize the hazards and poor practices that can endanger their lives and know about safety features to protect themselves. At the same time, they should be cognizant of the basic specifications of appliances like their operating voltage, power consumption, so that they can make informed choices on the type of appliances to use at home.

In this topic, students will learn to derive electrical consumption of common appliances and calculate the cost of electricity use, based on **electrical power** rating and time of usage. They will proceed to learn about the **dangers of electricity** and their causes. The topic concludes with detailed articulation of devices and practices that help to promote **safe use of electricity** at home.

Learning Outcomes
(a) describe the use of the heating effect of electricity in appliances such as electric kettles, ovens and heaters
(b) recall and apply the relationships $P = V I$ and $E = V I t$ to new situations or to solve related problems
(c) calculate the cost of using electrical appliances where the energy unit is the kW h
(d) state the hazards of using electricity in the following situations: (i) damaged insulation (ii) overheating of cables (iii) damp conditions
(e) explain the use of fuses and circuit breakers in electrical circuits and of fuse ratings
(f) explain the need for earthing metal casings and for double insulation
(g) state the meaning of the terms *live*, *neutral* and *earth*
(h) describe the wiring in a mains plug
(i) explain why switches, fuses, and circuit breakers are fitted to the live wire

TOPIC 17. MAGNETISM

- Laws of magnetism
- Magnetic properties of matter
- Magnetic field

Guiding Questions

- How can we describe and represent the interaction between magnets, and between magnets and magnetic materials?
- How can a magnetic field around a magnet be determined?

Topic Description

Magnets are used in a wide range of devices, ranging from minute-sized ones in high-precision equipment to mega-sized ones in heavy industries. The unique characteristics of magnets make them capable of storing data in hard disks, converting electronic signals into sound inside speakers and generating motion using electricity and vice versa in motors and generators.

In this topic, students will learn about the unique characteristics of permanent magnets under **laws of magnetism** and **magnetic properties of matter**. They will learn to use magnetic field lines to represent **magnetic fields**, a region surrounding a magnet, in which a body of magnetic material experiences a magnetic force.

Learning Outcomes
(a) state the properties of magnets
(b) describe induced magnetism caused by placing magnetic material close to a strong magnet or within a current-carrying solenoid
(c) distinguish between temporary magnets (e.g. iron) and permanent magnets (e.g. steel) in terms of their properties and uses
(d) describe how a bar magnet (e.g. a compass) can be used to determine the direction of a magnetic field
(e) draw the magnetic field pattern around a bar magnet and between the poles of two bar magnets

TOPIC 18. ELECTROMAGNETISM

- Magnetic effect of a current
- Force on a current-carrying conductor
- The d.c. motor

Guiding Questions

- How are electric currents and magnetic fields related and how do they interact?
- How does a d.c. motor work?

Topic Description

Understanding how electric currents interact with magnetic fields allows us to design electrical systems that control and respond to changes in physical systems. These include electric motors, circuit breakers and speakers.

In this topic, students will firstly learn about the **magnetic effect of electric current** and describe the magnetic field patterns due to electric currents flowing in straight wires. Students will learn how to determine the direction of **force on a current-carrying conductor** that is placed in a magnetic field, using Fleming's left-hand rule. Students will also learn about applications of electromagnetism, such as in a circuit breaker and in a simplified (two-pole, single-coil) **d.c. motor** with a split-ring commutator.

Learning Outcomes
(a) draw the pattern of the magnetic field due to currents in straight wires and in solenoids and state the effect on the magnetic field of changing the magnitude and/or direction of the current
(b) describe the application of the magnetic effect of a current in electromagnets (e.g. circuit breakers)
(c) describe experiments to show the force on a current-carrying conductor, and on a beam of charged particles, in a magnetic field, including the effect of reversing (i) the current (ii) the direction of the field
(d) deduce the relative directions of force, field and current when any two of these quantities are at right angles to each other using Fleming's left-hand rule
(e) explain how a current-carrying coil in a magnetic field (e.g. in a motor) experiences a turning effect and that the effect is increased by increasing (i) the number of turns on the coil (ii) the current
(f) describe the action of a split-ring commutator in a two-pole, single-coil motor and the effect of winding the coil on to a soft-iron cylinder

TOPIC 19. ELECTROMAGNETIC INDUCTION

- Principles of electromagnetic induction
- The a.c. generator
- The transformer

Guiding Questions

- What is electromagnetic induction and how does it work?
- How does an a.c. generator produce an electric current?
- How is electricity transmitted over long distances?

Topic Description

Experiments conducted by Michael Faraday showed that a changing magnetic field could induce an electric current in a circuit. The results of his experiments led Faraday to construct the first electric generator. This remains the basis for electricity generation in many power plants throughout the world today.

In this topic, students will learn about Faraday's experiments and the **principles of electromagnetic induction**. Students will learn how this principle is applied in a simple **a.c. generator** and the factors which affect the output of the a.c. generator. They will also learn how the principle is applied in a **transformer** to step-up and step-down the voltage to reduce power losses when electricity is transmitted over long distances.

Learning Outcomes
(a) deduce from Faraday's experiments on electromagnetic induction or other appropriate experiments: (i) that a changing magnetic field can induce an e.m.f. in a circuit (ii) that the direction of the induced e.m.f. opposes the change producing it (iii) the factors affecting the magnitude of the induced e.m.f.
(b) describe a simple a.c. generator (rotating coil or rotating magnet) and the use of slip rings (where needed)
(c) sketch a graph of voltage output against time for a simple a.c. generator
(d) describe the structure and principle of operation of a simple iron-cored transformer as used for voltage transformations
(e) recall and apply the equations $V_P / V_S = N_P / N_S$ and $V_P I_P = V_S I_S$ to new situations or to solve related problems (for an ideal transformer)
(f) describe the energy loss in cables and deduce the advantages of high voltage transmission

2.6 Radioactivity

Overview

As radiation cannot be easily seen, it is commonly feared and shunned. Coupled with news about the dangers of nuclear radiation and the potential detriments to health, the general public is apprehensive about the use and application of any form of radiation. This section aims to provide an objective evaluation of the risks and benefits of the use of radiation through the development of a good understanding of ***Radioactivity***.

The accidental discovery of radioactivity by Henri Becquerel inspired Marie and Pierre Curie to study this phenomenon further. In their search for signs of radioactivity in substances and minerals, they identified and extracted new elements. Radioactivity is the study to understand the nature of the radiation emitted by radioactive materials. It was later understood that there are three types of emissions – alpha particles (helium atoms with no electrons), beta particles (fast moving electrons) and gamma rays (electromagnetic radiation similar to X-rays). These emissions are the result of the decay or disintegration of an unstable atomic nucleus.

Radioactivity has many practical applications. For example, radiometric dating makes use of a radioactive element's half-life to help determine the age of rocks or carbon. Radioactive materials are used for medical diagnosis and treatments. However, excessive exposure to radioactivity can cause cancer if the dose is too high. Many early scientists working with radioactive materials died from the harmful effects of high levels of radiation before proper safety guidelines were drawn.

Large amounts of energy are also involved in radioactive emissions and physicists quickly recognized the power of this. In the 1930s and 1940s, many scientists were working on this in Europe. The development of World War II forced many of them to leave their home countries and flee to the United States. This led to a brain drain which benefited the United States and allowed them to develop the two atomic bombs that ended the war. This highlights the impact of science on society and human interactions.

In the years immediately after the war, research on nuclear energy continued, but with attention focused on peaceful uses like harnessing it in a controlled fashion for naval propulsion and generating electricity. Many nuclear power stations were also built to generate electricity in that era. However, since then, a number of nuclear disasters around the world have impacted the industry, with some countries deciding to phase out nuclear energy altogether. Nevertheless, with the rapidly increasing demand for electricity, many countries have turned to nuclear fuel as an alternative energy resource while simultaneously increasing the use of sustainable energy. It is important to develop reliable nuclear technologies that minimise the risks to health and safety of communities when using nuclear energy.

TOPIC 20. RADIOACTIVITY

- The composition of an atom
- Radioactive decay
- Dangers and uses of radioactivity

Guiding Questions

- What is radioactivity?
- What are the types and nature of radioactive decay?
- How can radioactive materials be used safely?

Topic Description

Radioactive emissions are happening around us all the time and we are constantly exposed to it. There are numerous applications of radioactive emissions, ranging from smoke detectors to life-saving medical procedures like radiation therapy. Yet, there is immense fear about the use of radioactive isotopes due to a lack of understanding of radioactive emissions and what constitutes the danger. Factors to consider when assessing the hazard of radioactive materials include their half-lives, types of emissions and the extent of exposure to these emissions.

This topic begins with an introduction to the **composition of an atom**. Students will then learn that **radioactive decay** involves unstable nuclei losing energy by emitting different types of radiation with a range of ionising effects and penetrating powers, in the process altering the composition of the nuclei. While radioactive decay is spontaneous and random in nature, students will learn that it could be expedited through nuclear fission and fusion, releasing immense amounts of energy in the process. Finally, depending on the nature of the radioactive emissions, students will learn that radioactive materials offer a multitude of **applications in the medical and industrial fields**, though precautions should be taken to address the potential **dangers** that they pose.

Learning Outcomes
(a) describe the composition of an atom in terms of a positively charged nucleus (with protons and neutrons) and negatively charged electrons
(b) use the terms proton (atomic) number Z, nucleon (mass) number A and isotope
(c) use and interpret the term nuclide and use the nuclide notation $^{A}_{Z}X$
(d) show an understanding that nuclear decay is a random and spontaneous process whereby an unstable nucleus loses energy by emitting radiation
(e) show an understanding of the nature of alpha (α), beta (β), and gamma (γ) radiation (including ionising effect and penetrating power) [β-particles are assumed to be β^- particles only]
(f) use equations involving nuclide notation to represent changes in the composition of the nucleus when radioactive emissions occur
(g) show an understanding of background radiation
(h) use the term half-life in simple calculations, which might involve information in tables or decay curves
(i) discuss the applications (e.g. medical and industrial uses) and hazards of radioactivity based on: (i) half-life of radioactive materials, (ii) penetrating abilities and ionising effects of radioactive emissions
(j) state the meaning of nuclear fusion and nuclear fission and relate these nuclear processes with the release of energy from nuclear fuels (recall of the energy-mass equivalence and details of technologies in nuclear power plants are not required)

SECTION 3: PEDAGOGY

Teaching and Learning of Upper Secondary Physics
Students as Inquirers
Blended Learning
Teachers as Facilitators
Practical Work
Use of ICT
Designing STEM Learning Experiences in Science

3. PEDAGOGY

3.1 Teaching and Learning of Upper Secondary Physics

We believe that all students are curious and want to explore and learn about things around them. The curriculum seeks to nurture students as inquirers by providing opportunities for them to explore and to appreciate the role of *Science for Life and Society*.

To nurture students as inquirers, teachers are key in facilitating a variety of learning experiences to support students in understanding *Core Ideas*, developing *Practices* and cultivating *Values*, *Ethics and Attitudes*.

These learning experiences can be situated in various authentic contexts, in both formal and informal settings, and should inspire students to inquire and innovate. In designing purposeful and engaging learning experiences, teachers should consider amongst others, profile of students, resources available and relevant pedagogical approaches. Students should also be provided with opportunities to reflect on their own learning progress and act on feedback as part of Assessment for Learning (AfL).

Learning of science will not be complete without the incorporation of practical work, which develops in students the ways of thinking and doing while supporting their development of scientific knowledge and knowledge about science.

3.2 Students as Inquirers

For students to be inquirers, their thinking skills and dispositions should be developed as part of their learning experiences. To engage students as inquirers, they can be provided with learning experiences centred on authentic contexts that allow them to pose questions, be involved in discussions on socio-scientific issues, or be engaged in problem solving. Through these learning experiences, students are likely to

- ask questions as they engage with an event, phenomenon, problem or issue. They learn to be objective, ask questions which they are curious about and identify key variables of their questions. The questions and variables can guide the design of investigations, from which they draw valid conclusions.

- gather evidence to respond to their questions. They gather evidence through observations and collect qualitative or quantitative data using simple instruments. In the process, they have to make appropriate decisions about measurements or observations, which should be made with appropriate degree of precision and good details respectively.

- formulate explanations based on the evidence gathered. They explain their findings with integrity, based on evidence gathered (e.g. qualitative descriptions of observations or quantitative data collected over a time interval), conclusion(s) from the interpretation of experimental data or observations and underlying principles. They practise healthy scepticism towards the evidence gathered and observations made, aware of the effect of significant sources of errors on the reliability and validity of the explanations and conclusions reached.

- connect their explanations to various contexts. They explain how the concepts are related or applied in various examples and contexts around them. This helps them to appreciate how science is relevant and universally applicable in everyday life and unfamiliar situations.

- communicate and justify their explanations. After data collection, they present and communicate the evidence in appropriate forms (e.g. tables, charts, graphs, with all quantitative data to an appropriate number of decimal places/significant figures) to facilitate the analysis of patterns and relationships. For example, they can use texts, drawings, charts, tables, graphs, equations or a combination of representations to support their explanations.

- reflect on their learning and progress. They can reflect on their learning (e.g. what they have learnt, how they would like to improve, what they are curious about) in different ways (e.g. ask questions, write journals). For laboratory-based learning experiences, students can propose how significant errors may be overcome or reduced, as appropriate, including how experimental procedures may be improved. These reflections help them take greater ownership of their own learning and develop deeper conceptual understanding.

3.3 Blended Learning

3.3.1 Why Blended Learning

Blended Learning in MOE's context transforms our students' educational experience by providing them with a more seamless blending of different modes of learning. The key intended student outcomes are to nurture (i) self-directed and independent learners; and (ii) passionate and intrinsically motivated learners.

An aspect of Blended Learning is the integration of home-based learning (HBL) as a regular feature of the schooling experience. HBL can be a valuable complement to in-person schooling. Regular HBL can equip students with stronger abilities, dispositions and habits for independent and lifelong learning, in line with MOE's Learn for Life movement.

Blended Learning presents an opportunity to re-think curriculum and assessment design and innovate pedagogies for a more effective and student-centric educational experience. It involves giving students more ownership and agency over how they learn, at a pace they are comfortable with. It also offers scope for teachers to tap the advantages of both in-person learning and distance learning to plan lessons best suited to each mode of learning opportunity.

3.3.2 What is Blended Learning

Blended Learning provides students with a broad range of learning experiences (see **Figure 3.1**).

Figure 3.1: Examples of Blended Learning experiences

Possible Blended Learning Experiences	What this means
Structured/Unstructured learning	A combination of structured time for students to learn within a given time frame and unstructured time for students to learn at their own pace and exercise self-management
Synchronous/Asynchronous learning	A combination of in-person schooling, live online lessons and online/offline learning where students learn remotely and at their own pace.
Within-curriculum/Out-of-curriculum learning	Opportunities for students to learn from and beyond the formal curriculum
Distance/In-person learning	Opportunities for students to learn during face-to-face lessons with teachers and peers in school, complemented by out-of-school learning activities
ICT-mediated/Non-ICT-mediated learning	Opportunities for students to learn through a combination of ICT-mediated and non-ICT-mediated learning experiences

Table 3.1: Elaboration of possible Blended Learning experiences

3.4 Teachers as Facilitators

In the teaching and learning process, teachers play an important role in stimulating students' curiosity, as well as encouraging students to see the value of science and its applications in their everyday lives.

To do these, teachers should ensure that the learning experiences provided for students go beyond learning facts and outcomes of scientific investigations. Teachers should play the role of facilitators to support students as inquirers.

As facilitators, teachers should:

- provide students with opportunities to ask questions about events/ phenomenon/problems/issues that are related to their daily lives, society and environment;
- support students in gathering and using evidence;
- encourage students to formulate and communicate explanations based on evidences gathered;
- encourage students to apply concepts learnt in understanding daily events/phenomenon, finding solutions to problems/issues and creating products; and
- provide students with opportunities to reflect on their own learning progress and act on feedback provided through formative assessment.

The *Pedagogical Practices* in the *STP*, as shown in **Figure 3.2**, comprise four core *Teaching Processes* which lie at the heart of good teaching. Teachers can refer to the Teaching Processes and relevant Teaching Areas under each process to guide them in the design and enactment of students' learning experiences. To design student-centred learning experiences, teachers will need to consider student profiles, readiness and needs as they transit from lower to upper secondary, as well as understand the interest and aspirations of these students as they progress to the next stage of studies and the future workplace.

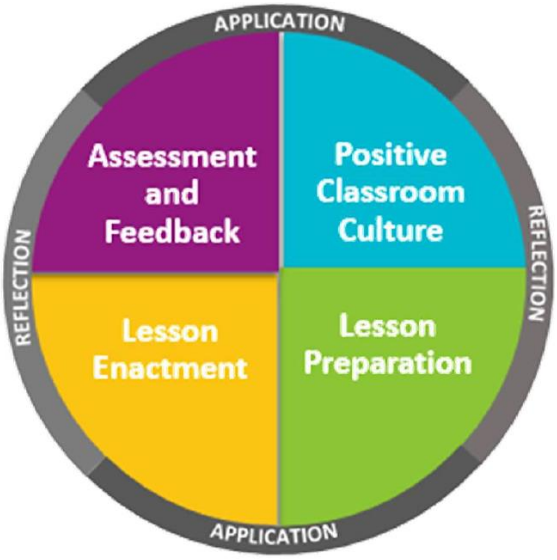

Figure 3.2: The four core *Teaching Processes* within the *Pedagogical Practices* in *STP*

3.5 Practical Work

Practical work is an essential component of science teaching and learning, both for the aim of developing students' scientific knowledge and that of developing students' knowledge about science.

Good quality science practical work supports the teaching and learning of science in the following ways:

- Develop science inquiry skills
- Develop experimental techniques and practical manipulative skills
- Understand of the nature of scientific knowledge
- Enhance conceptual understanding
- Cultivate interest in science and in learning science

3.6 Use of ICT

Integrating ICT can enhance teaching and learning practices in the science classroom.
Teachers are encouraged to harness:

- e-pedagogy principles for lesson design;
- technology for active learning; and
- technology for assessment and feedback.

3.6.1 e-Pedagogy Principles for Lesson Design

What is e-Pedagogy?
e-Pedagogy is the practice of teaching with technology for active learning that creates a participatory, connected, and reflective classroom to nurture the future-ready learner.

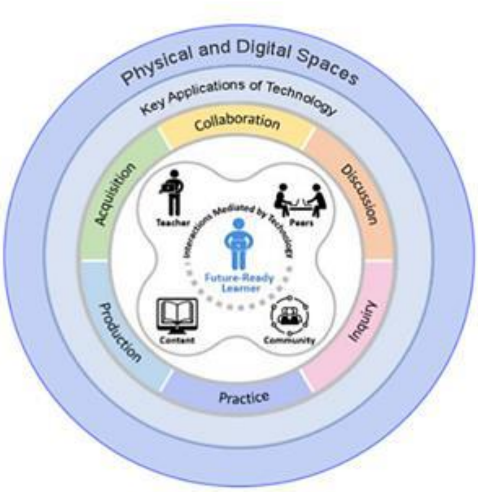

Figure 3.3: Overview of e-Pedagogy

Teachers can be guided by the Key Applications of Technology (see **Figure 3.3**) in designing different learning experience types to achieve the intended learning outcomes of the Science syllabus and the Science Curriculum Framework. The following are the LE types that teachers could design with technology: Acquisition, Collaboration, Discussion, Inquiry, Practice and Production. These learning experience types, occurring in the physical and/or digital spaces, capitalise on the role of technology in mediating learning interactions between the learner and the teacher, peers, content, and community.

3.6.2 Technology for Active Learning

Beyond the use of digital resources, there is a need to evaluate and select appropriate technological tools based on their pedagogical affordances and apply technologies to support active learning in science. For example, online collaboration tools can be used by teachers to facilitate students' co-construction of knowledge through scientific experimentation/investigations (inquiry-based learning) or discussion of science-related issues (socio-scientific issues-based learning).

In the Upper Secondary Physics syllabus, students will be acquainted with the use of basic digital instruments (e.g. data loggers, digital calipers, digital micrometer, digital multimeter and Geiger Muller counter). Apart from preparing students for the technologically driven world, using digital instruments in the classroom also supports the enactment of learning experiences that focus on developing critical and inventive thinking and problem-solving skills by reducing the cognitive load involved in reading of scales in analogue instruments and/ or calculating physical quantities that can otherwise be measured directly using digital instruments (e.g. resistance using a digital multimeter). When teachers guide students in using digital instruments to collect experimental data, competencies such as choosing an appropriate instrument for measurement and analysing data can be developed.

3.6.3 Technology for Assessment and Feedback

Meaningful integration of technology also supports teacher-student interactions. When students are given opportunities to demonstrate their understanding in multi-modal ways, supported by technology, rich learning data is available for assessment and feedback. In designing AfL items in Singapore Student Learning Space (SLS), teachers should invite a range of different response strategies in order to assess students' learning, and use the monitoring features to understand students' learning gaps, provide timely feedback and track their learning progress.

3.7 Designing STEM Learning Experiences in Science

STEM education seeks to strengthen the interest and capabilities of our students in STEM to prepare them for an increasingly complex and uncertain world. We want our students to be curious about the world around them, to think creatively and critically in solving problems, and be concerned citizens who make a difference in society. These are in line with the goals of Science Education.

When designing STEM learning experiences, consider two aspects: 1) level of integration and 2) level of application. These two aspects lie on a continuum as illustrated in **Figure 3.4**.

Level of integration	***Disciplinary*** • Learning is anchored within a discipline.	⟷	***Integrative*** • Learning involves integration of concepts/skills across two or more STEM disciplines.
Level of application	***Learning knowledge and skills through real-world examples*** • Use of real-world examples to illustrate concepts. • Involves application of knowledge/skills to solve simplified/routine problems set in real-world contexts.	⟷	***Creative application of knowledge and skills in real-world contexts*** • Creative application of knowledge and skills (e.g. in ideating and making) to address real-world issues. • Involves application of knowledge/skills to solve complex real-world problems.

Figure 3.4: Design considerations for STEM Learning

SECTION 4: ASSESSMENT

Purposes of Assessment
Scope of Assessment
Designing Assessment for Learning (AfL)
Designing Assessment of Learning (AoL)

4. ASSESSMENT

4.1 Purposes of Assessment

Assessment is the process of gathering and analysing evidence about student learning to make appropriate decisions and enhance learning. Assessment is integral to the teaching and learning process. In designing assessments, we need to have **clarity of purpose**. Assessment measures the extent to which desired knowledge, skills and attitudes are attained by students. It should produce both quantitative and qualitative descriptions of a learner's progress and development that can be analysed and used to provide feedback for improving future practices.

- Assessment provides feedback to **students**, allows them to understand their strengths and weaknesses. Through assessment, students can monitor their own performance and progress. It also points them in the direction they should go to improve further. The use of feedback in this way helps students work towards mastering their 21CC.

- Assessment provides feedback to **teachers**, enables them to understand the strengths and weaknesses of their students. It provides information about students' attainment of learning outcomes (which includes 21CC development) as well as the effectiveness of their teaching.

- Assessment provides feedback to **schools**. The information gathered facilitates the placement of students in the appropriate course, and the promotion of students from one level to the next. It can also help to inform the review of the instructional programmes in schools.

- Assessment provides feedback to **parents**. It allows them to monitor their children's learning attainment and progress through the information obtained.

4.2 Scope of Assessment

Besides knowing the reasons for assessment, it is important to be clear about what is being assessed. If the assessment objectives are not clear, then the information obtained from the assessment process will not help improve student learning; neither will the information be meaningful for making decisions about student progression.

The *Science Curriculum Framework* shares that students should be provided with strong grounding in the three fundamentals:

- Core Ideas of Science
- Practices of Science
- Values, Ethics and Attitudes (VEA) in Science

These broad goals are translated into more specific learning objectives under the Subject Content section.

While VEA are usually not assessed formally, informal assessment is encouraged.

4.3 Designing Assessment for Learning (AfL)

Assessment for Learning (AfL) is assessment conducted constantly during classroom instruction to support teaching and learning. The critical feature about AfL is that information gathered from the assessment is used to adjust and improve the teacher's teaching strategies, as well as surface students' learning progress and difficulties.

4.4 Designing Assessment of Learning (AoL)

Assessment of Learning (AoL) aims to summarise how much or how well students have achieved at the end of a course of study over an extended period of time. The Preliminary and O/N-Level examinations are examples of AoL. To ensure content validity, the assessment should be designed to cover a representative sample of the syllabus. The assessment content should reflect the scope of the syllabus and be pitched at the appropriate demand.

For more information on the scheme of assessment for the national examinations, please refer to the Singapore Examinations and Assessment Board.

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