SCIENCE (CHEMISTRY) SYLLABUS

Upper Secondary Normal (Academic) Course

Implementation starting with
2023 Secondary Three Cohort

Ministry of Education
SINGAPORE

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SECTION 1: INTRODUCTION

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* of science, *Practices of Science*, and *Values, Ethics and Attitudes* in science.

- 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;
  (b) Understanding the Nature of Scientific Knowledge; and
  (c) Relating Science, Technology, Society and Environment.

  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.

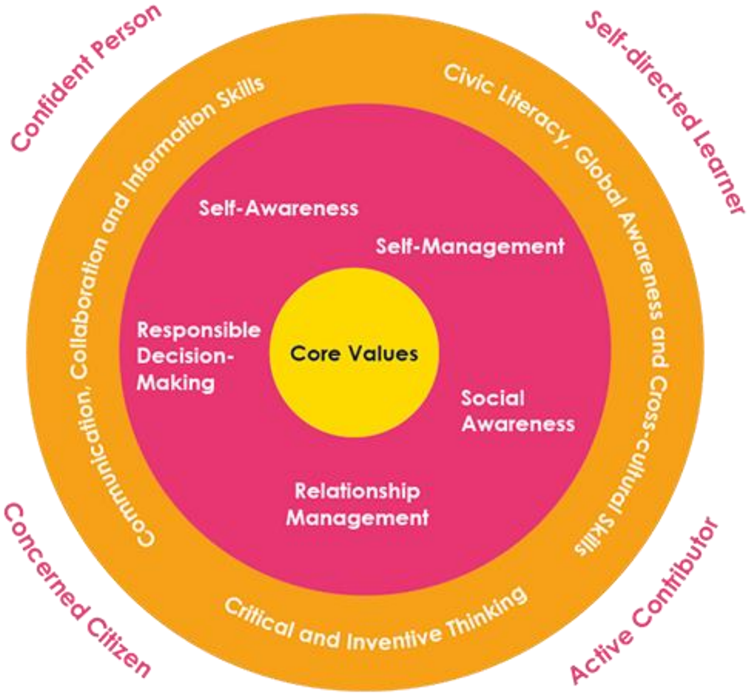

Figure 1.2: Framework for 21st Century Competencies and Student Outcomes

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 21st Century Competencies (21CC).

<u>Supporting the Development of 21CC through Science</u>

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 Chemistry Education

Chemistry, as the study of matter and its changes, influences every facet of our lives and shares many essential ties to other science disciplines. While chemistry seeks to understand the nature of matter by relating the study of energy and particles such as atoms and molecules in physical systems to chemical systems, it also provides a basis for studying and understanding molecules and processes in biological systems.

The Upper Secondary Chemistry syllabus is designed to lay a strong foundation in the discipline through developing conceptual understanding, skills and attitudes relevant to the study and practice of chemistry. The syllabus aims to enable students to connect chemical concepts between topics and to transfer learning from one context to another through disciplinary core ideas. The syllabus is conceptualised around overarching ideas of matter and their chemical reactions. Organised in this way, acquisition and mastery of chemical concepts are fostered through a way of thinking and doing involving the use and development of models to explain observable characteristics and changes of matter, and to represent particles and changes of matter through symbols. Chemical concepts learnt in this syllabus should be seen as tools to better understand the world one lives in and means to suggest solutions for global challenges such as those related to energy and the environment.

1.4 Aims

The Upper Secondary Chemistry 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 chemistry in the real world,
b) deepen their interest in chemistry for future learning and work,
c) become scientifically literate citizens who can innovate and seize opportunities in the 21st century, and
d) develop a way of thinking to approach, analyse and solve problems by explaining macroscopic characteristics and changes in chemical systems through the use of sub-microscopic and symbolic representations.

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

1.5 Disciplinary Ideas of Chemistry

The disciplinary ideas of chemistry described below represent the overarching ideas which can be applied to explain, analyse and solve a variety of problems that seek to address the broader questions of what matter is and how particles interact with one another. The purpose of equipping students with an understanding of these ideas is to develop in them a coherent view and conceptual framework of scientific knowledge to facilitate the application and transfer of learning. These ideas can be revisited throughout the syllabus, deepened at higher levels of learning and beyond the schooling years.

1. Matter is made up of a variety of chemical elements, each with characteristic properties, and the smallest particle that characterises a chemical element is an atom.

2. The structure of matter and its chemical and physical properties are determined by the arrangement of particles and electrostatic interactions between them.

3. Energy changes across and within systems usually occur during physical and chemical changes, when there is rearrangement of particles.

4. Energy plays a key role in influencing the rate and extent of physical and chemical changes.

5. Matter and energy are conserved in all physical and chemical changes.

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.

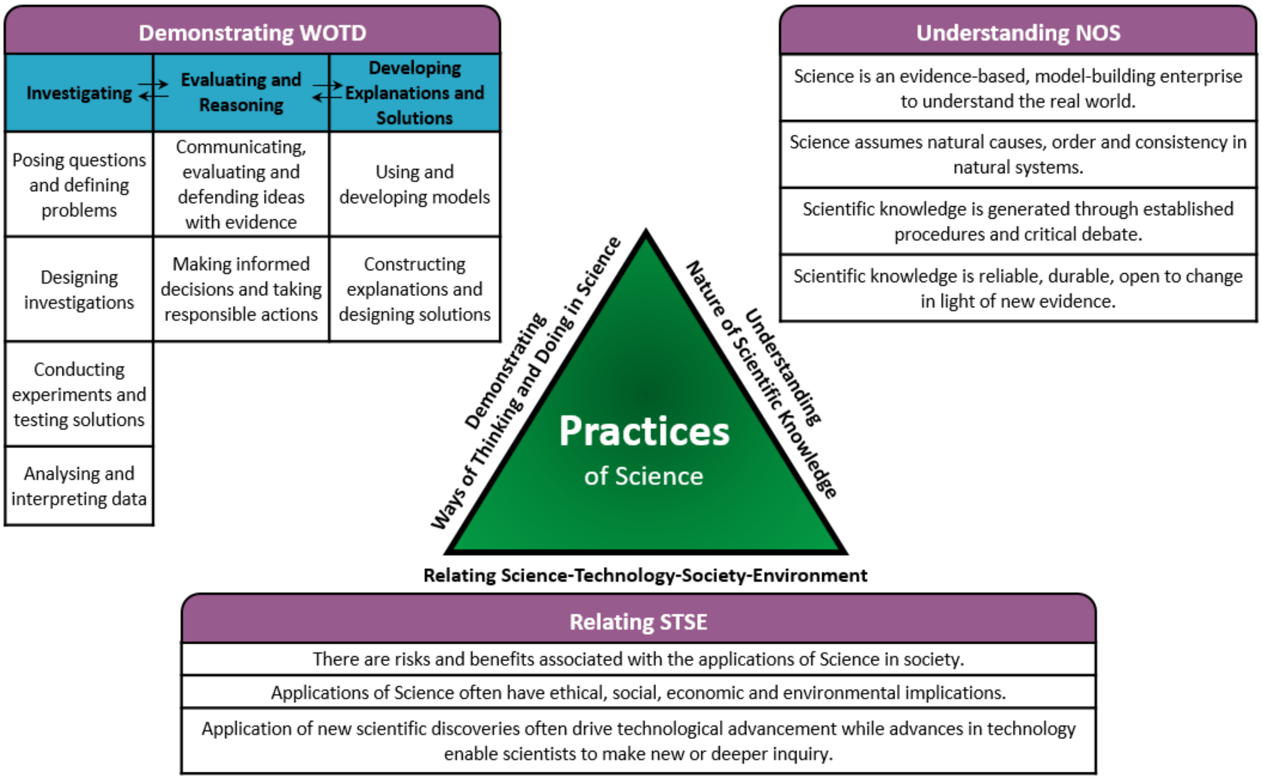

Figure 1.3: Practices of Science

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

Matter – Structures and Properties
Chemical Reactions
Chemistry in a Sustainable World

2. CONTENT

Content structure

Each of the three sections represents an important aspect of chemistry. In Section 2.1, students explore how the structures at the sub-microscopic level affects the properties exhibited at the macroscopic level. In Section 2.2, students are introduced to different types of chemical reaction and how these reactions can be quantified in terms of the mass-mole relationship. In the final Section 2.3, students learn how chemistry can be used to make the world a sustainable one.

Sections	Topics
Matter – Structures and Properties	1. Experimental Chemistry
	2. The Particulate Nature of Matter
	3. Chemical Bonding and Structure
Chemical Reactions	4. Chemical Calculations
	5. Acid-Base Chemistry
	6. Qualitative Analysis
	7. Patterns in the Periodic Table
Chemistry in a Sustainable World	8. Organic Chemistry
	9. Maintaining Air Quality

Guide to using this section

This is a brief description of the features in **Sections 2.1 - 2.3.**

Section overview

2.1 Matter – Structures and Properties

Overview

Chemistry is the science of matter and the changes it undergoes. To investigate matter, chemists conduct experiments and make measurements. The need for precision and accuracy in measurements, and for safe handling and disposal of chemicals are integral to experimental chemistry.

Pure substances are also important in industries, such as food and medicine. The purity of a substance can be determined by a fixed melting point and boiling point. Over time, chemists have invented different experimental techniques to separate mixtures into pure substances, a process called purification.

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. EXPERIMENTAL CHEMISTRY

- Experimental Design
- Methods of Purification and Analysis

Guiding Questions

- What are some considerations that chemists have when selecting the tools to use in their experiments?
- How does one decide on the method of purification?
- Why is it important for us to be able to get a pure substance?

Topic Description

In carrying out experiments, chemists assemble suitable apparatus (with laboratory safety in consideration) and decide on what to look for and measure using appropriate techniques and apparatus. Physical quantities commonly measured include mass, volume, time and temperature. The apparatus used depends on the quantity being measured, and on how accurate and precise the measurement needs to be.

When matter undergoes changes, mixture of substances can be formed. Methods of separation and purification depend on the type of mixtures and the difference in physical properties of the substances in the mixture. Purifying mixtures is important in manufacturing to ensure quality and to separate useful substances from mixtures and waste products. Pure substances are important especially in consumer products such as food and medicine. A pure substance is a single element or compound. To assess the purity of a substance, its melting point or boiling point is measured and matched to reference values. Chromatography is also a method to determine purity of a substance and to identify components in mixtures.

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
1.1 Experimental Design
(a) name appropriate apparatus for the measurement of time, temperature, mass and volume; including burettes, pipettes, measuring cylinders and gas syringes
(b) suggest suitable apparatus, given relevant information, for a variety of simple experiments, including collection of gases

2.1 Matter – Structures and Properties

Overview

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Matter is understood in terms of particles, the way they are arranged and the forces that hold them together. Evidence of the particulate nature of matter come from daily observable phenomena such as diffusion and crystal growth. The simplest particle is known as an atom, which consists of sub-atomic particles like proton(s), neutron(s) and electron(s). From atoms in the hundreds of elements, a myriad of molecules with different properties are formed. The physical properties of a substance are determined by how its particles are arranged (i.e. structure) and the strength of the electrostatic forces between them.

This section on the structures and properties of matter forms a basis for an in-depth understanding of matter and its interactions.

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Learning Outcomes
1.1 Experimental Design
(a) name appropriate apparatus for the measurement of time, temperature, mass and volume; including burettes, pipettes, measuring cylinders and gas syringes
(b) suggest suitable apparatus, given relevant information, for a variety of simple experiments, including collection of gases
1.2 Methods of Purification and Analysis
(a) describe methods of separation and purification for the components of mixtures, to include: (i) use of a suitable solvent, filtration and crystallisation or evaporation (ii) distillation and fractional distillation (see also **8.1**(b)) (iii) paper chromatography
(b) suggest suitable separation and purification methods, given information about the substances involved in the following types of mixtures: (i) solid-solid (ii) solid-liquid (iii) liquid-liquid (miscible)
(c) interpret paper chromatograms including comparison with 'known' samples (the use of R_f values is **not** required)
(d) deduce from given melting point and boiling point data the identities of substances and their purity

TOPIC 2. THE PARTICULATE NATURE OF MATTER

- Kinetic Particle Theory
- Atomic Structure

Guiding Questions

- What does the kinetic particle theory tell us about matter?
- Why is the physical state of a substance affected by temperature?
- What is the structure of an atom?
- What is the significance of having different number of sub-atomic particles?

Topic Description

Models help chemists link macroscopic properties to microscopic behaviour. The kinetic particle theory is a model that describes matter as consisting of particles in constant motion with spaces between them. Forces of attraction of varying strength result in different physical states of a substance. As temperature increases, particles gain energy and move faster. When the particles gain sufficient energy to overcome the attractive forces between them, the substance changes state.

As new evidence become available, models of atomic structure developed. From the simplest model by Dalton, current models describe an atom as a positively charged nucleus containing protons and neutrons, surrounded by negatively charged electrons in discrete energy levels. The number of protons identifies an element while the number of electrons determines how an atom reacts. Contrary to the early model by Dalton which stated that all atoms of an element are identical, mass spectrometry reveal the relative atomic mass of chlorine to be 35.5 although the relative mass of protons and neutrons is 1 respectively. This suggests the presence of isotopes which are atoms of the same element with same number of protons but different number of neutrons.

Learning Outcomes	
2.1 Kinetic Particle Theory	
(a)	describe the solid, liquid and gaseous states of matter and explain their interconversion in terms of the kinetic particle theory and of the energy changes involved
2.2 Atomic Structure	
(a)	state the relative charges and approximate relative masses of a proton, a neutron and an electron
(b)	describe, with the aid of diagrams, the structure of an atom as consisting of protons and neutrons (nucleons) in the nucleus and electrons arranged in shells (energy levels) (knowledge of s, p, d and f classification is **not** required; a copy of the Periodic Table will be available in the examination)
(c)	define *proton (atomic) number* and *nucleon (mass) number*
(d)	interpret and use nuclide notations such as $^{12}_{6}C$
(e)	define the term *isotopes*
(f)	deduce the numbers of protons, neutrons and electrons in atoms and ions given proton and nucleon numbers

TOPIC 3. CHEMICAL BONDING AND STRUCTURE

- Ionic Bonding
- Covalent Bonding
- Structure and Properties of Materials

Guiding Questions

- How does the transfer or sharing of electrons between atoms result in the atoms being attracted to each other?
- Why does the bonding in and structure of a substance affect its physical properties?

Topic Description

This topic builds on the Bohr atomic model. During chemical changes, atoms lose, gain or share electrons to achieve noble gas configuration. While this configuration is used to determine the number of electrons in forming bonds, there are exceptions to this rule like phosphorus pentachloride, boron trihydride and other molecules.

Attractive forces exist between opposite charges when different bond types are formed. The ionic bond is the electrostatic attraction between oppositely charged ions. A covalent bond is formed by the electrostatic attraction between a shared pair of electrons and the nuclei. To describe the bonding in substances, dot and cross diagrams are constructed but they have limitations like the lack of movement of electrons or ions.

The physical properties of a substance depend on the nature and strength of forces between the particles. The nature of the particles involved determine the bonding and structure of the substance.

Learning Outcomes
3.1 Ionic Bonding
(a) describe the formation of ions by electron loss/gain and that these ions usually have the electronic configuration of a noble gas
(b) describe, including the use of 'dot-and-cross' diagrams, the formation of ionic bonds between metals and non-metals, e.g. $NaCl$; $MgCl_2$
(c) relate the physical properties (including electrical property) of ionic compounds to their lattice structure
3.2 Covalent Bonding
(a) describe the formation of a covalent bond by the sharing of a pair of electrons and that the atoms in the molecules usually have the electronic configuration of a noble gas
(b) describe, using 'dot-and-cross' diagrams, the formation of covalent bonds between non-metallic elements, e.g. H_2; O_2; H_2O; CH_4; CO_2
(c) deduce the arrangement of electrons in other covalent molecules
(d) relate the physical properties (including electrical property) of covalent substances to their structure and bonding
3.3 Structure and Properties of Materials
(a) describe the differences between elements, compounds and mixtures
(b) describe the general physical properties of metals as solids having high melting and boiling points, malleable and good conductors of heat and electricity
(c) describe an alloy as a mixture of a metal with another element, e.g. brass; stainless steel
(d) identify representations of metals and alloys from diagrams of structures

2.2 Chemical Reactions

<u>Overview</u>

Most interactions of matter involve chemical reactions which are central to any discussion in chemistry. In this section, different types of chemical reactions are delved into. The different chemical reactions lay the foundation for understanding what happens to energy and rate during a chemical change.

To describe chemicals and their reactions, chemists use symbols, formulae and equations. A balanced chemical equation elucidates the study of molar ratios in which substances react and quantifies the amounts of reactants and products in a reaction through performing calculations.

Given the multitude of chemical reactions, it is useful to broadly classify them for understanding. A main class of reactions is those of acids and bases. The study of acid-base reactions reveals patterns in the chemical properties of substances, leading to the organisation of elements in the Periodic Table.

TOPIC 4. CHEMICAL CALCULATIONS

- Formulae and Equation Writing
- The Mole Concept

Guiding Questions

- What information can be derived from the chemical symbols, formulae and equations?
- Why must a chemical equation be balanced?
- How can one determine the amount of substance from its mass?

Topic Description

Chemical symbols are shorthand used by chemists to represent elements. Through the chemical formulae, one is able to tell the type and number of atoms of each element present in the smallest representative unit (e.g. molecule or formula unit) in a substance. Chemical equations can also be constructed using formulae to represent overall changes in reactions. As atoms rearrange to form new substances during reactions, the same atoms are present before and after a reaction. The total mass of reactants is thus equal to the total mass of products and a chemical equation must be balanced to show this conservation of mass.

This topic also introduces the use of moles to count the number of particles, allowing one to deduce the number of particles present in a substance from measurement of physical quantities such as mass.

Learning Outcomes
4.1 Formulae and Equation Writing
(a) state the symbols of the elements and formulae of the compounds mentioned in the syllabus
(b) deduce the formulae of simple compounds from the relative numbers of atoms present and vice versa
(c) deduce the formulae of ionic compounds from the charges on the ions present and vice versa
(d) interpret chemical equations with state symbols
(e) construct chemical equations, with state symbols, including ionic equations
4.2 The Mole Concept
(a) define relative atomic mass, A_r
(b) define relative molecular mass, M_r, and calculate relative molecular mass (and relative formula mass) as the sum of relative atomic masses
(c) perform calculations involving the relationship between the amount of substances in moles, mass and molar mass (calculations of stoichiometric reacting masses and volumes of gases are **not** required)

TOPIC 5. ACID-BASE CHEMISTRY

- Acids and Bases

Guiding Questions

- What are the key differences between an acidic solution, a neutral solution and an alkaline solution?

Topic Description

Acids and bases are important in our daily live. They play a role in everything from the digestion of the food we eat to the medicine we take and even the cleaning products we use. Svante Arrhenius, a Swedish chemist, proposed the theory that acids, alkali, and salts in water are composed of ions. Acids form hydrogen ions when they dissolve in water and solutions of alkalis contain hydroxide ions. Acids and bases have characteristic properties as in their reactions with metals, bases and carbonates.

Learning Outcomes
(a) describe the meanings of the terms acid and alkali in terms of the ions they produce in aqueous solution and their effects on Universal Indicator
(b) describe neutrality and relative acidity and alkalinity, in terms of (i) relative H^+ and OH^- ion concentrations, (ii) colour in Universal Indicator, and (iii) the pH scale (calculation of pH from hydrogen ion concentration is **not** required)
(c) describe the characteristic properties of acids as in reactions with metals, bases and carbonates to form salts (description of the preparation of pure salts is **not** required)
(d) describe the reaction between hydrogen ions and hydroxide ions to produce water, $H^+ + OH^- \rightarrow H_2O$, as neutralisation
(e) describe the importance of controlling the pH in soils and how excess acidity can be treated using calcium hydroxide
(f) describe the characteristic properties of bases in reactions with acids and with ammonium salts
(g) classify oxides as acidic, basic, amphoteric or neutral based on metallic/non-metallic character

TOPIC 6. QUALITATIVE ANALYSIS

Guiding Questions

- What constitutes a good chemical test?

Topic Description

A good chemical test should identify a substance exactly. Some tests identify a substance by eliminating certain substances when a negative result is obtained. In instances like these, additional tests should be carried out to identify a substance completely.

This topic illustrates how the properties of some gases are used to identify them. For example, moist litmus papers are used to test the nature of gases, whether they are acidic, neutral or alkaline. Further tests are then carried out to confirm their identity. Oxygen supports combustion so a glowing splint is used to test for oxygen. If the splint relights, the gas is oxygen. When carbon dioxide is bubbled into limewater, a white precipitate is formed. Carbon dioxide is an acidic oxide and reacts with limewater, a base, to form calcium carbonate which is insoluble in water and thus forms a white precipitate.

Learning Outcomes
(a) describe tests to identify the following gases: carbon dioxide (using limewater); hydrogen (using a burning splint); oxygen (using a glowing splint)

TOPIC 7. PATTERNS IN THE PERIODIC TABLE

- Periodic Trends
- Group Properties
- Reactivity Series

Guiding Questions

- What are the patterns or trends that can be found in the Periodic Table?
- How and why do chemical/physical properties change across the periods and down the groups?
- What is the usefulness of the reactivity series?

Topic Description

Mendeleev's organisation of elements was refined into the modern Periodic Table, which shows the recurring relationship in properties of elements with their atomic numbers. Properties of elements across a period change from metals to non-metals as number of valence electrons increases. Elements in a group have the same number of valence electrons and share similar chemical properties.

Trends in the Periodic Table allow predictions to be made such as the reactivity of metals from their group trends. Like a league table for football, the reactivity series shows metals in order of their reactivity from the most reactive at the top to the least reactive at the bottom. Besides group trends, the metals are put in order of their reactivity by their reactions with water and dilute acid.

Learning Outcomes
7.1 Periodic Trends
(a) describe the Periodic Table as an arrangement of the elements in the order of increasing proton (atomic) number
(b) describe how the position of an element in the Periodic Table is related to proton number and electronic configuration
(c) explain the similarities between the elements in the same group of the Periodic Table in terms of their electronic configuration
(d) describe the change from metallic to non-metallic character from left to right across a period of the Periodic Table
(e) describe the relationship between number of outer (valence) electrons and metallic/non-metallic character
(f) predict the properties of elements in Group 1 and Group 17 using the Periodic Table
7.2 Group Properties
(a) describe lithium, sodium and potassium in Group 1 (the alkali metals) as a collection of relatively soft, low density metals showing a trend in melting point and in their reaction with water
(b) describe chlorine, bromine and iodine in Group 17 (the halogens) as a collection of diatomic non-metals showing a trend in colour, state and their displacement reactions with solutions of other halide ions
(c) describe the lack of reactivity of the elements in Group 18 (the noble gases) in terms of their electronic configurations
7.3 Reactivity Series
(a) place in order of reactivity calcium, copper, (hydrogen), iron, lead, magnesium, potassium, silver, sodium and zinc by reference to the reactions, if any, of the metals with water, steam and dilute hydrochloric acid
(b) deduce the order of reactivity from a given set of experimental results
(c) describe the ease of obtaining metals from their ores by relating the elements to their positions in the reactivity series
(d) describe the essential conditions for the corrosion (rusting) of iron as the presence of oxygen and water; prevention of rusting can be achieved by placing a barrier around the metal, e.g. painting; greasing; plastic coating

2.3 Chemistry in a Sustainable World

Overview

Ubiquitous in modern life, organic compounds range from the fuels we burn, the materials we use such as plastics to the food we eat. Urbanisation, industrialisation, increasing population and economic development have created a huge demand for consumption of materials and energy. These activities affect environmental sustainability which aims to meet the resource needs of present and future generations while preserving the health of the ecosystems that provides them.

Although crude oil is one of the most important raw materials in the world, it is non-renewable and finite. Besides providing us with fuels to generate energy, crude oil is also an important chemical feedstock for the production of useful materials such as plastics. To conserve this important resource for sustainable development, innovations by chemistry include alternative fuels such as biofuels and recycling of plastics. In addition, the uses of crude oil and plastics have their resulting environmental side-effects on the quality of air. Solutions to maintain air quality can be developed through understanding the sources and effects of common air pollutants.

This section provides an avenue for students apply their learning from other topics within the syllabus to assess the impacts of the consumption of organic compounds like fuels and plastics, the environmental issues related to their uses and the solutions afforded by chemistry.

TOPIC 8. ORGANIC CHEMISTRY

- Fuels and Crude Oil
- Hydrocarbons
- Polymers

Guiding Questions

- Why are natural gas and crude oil important in our lives?
- How do chemists classify organic compounds into homologous series?
- Why is the systematic naming of organic compounds useful?
- How and why do organic compounds in different homologous series behave differently?
- How does chemistry contribute to sustainable development, particularly in the area of plastics recycling?

Topic Description

Natural gas and crude oil are important sources of energy and raw materials and consist of organic compounds. The creation of urea by Friedrich Wohler in 1828 dispelled the belief that organic compounds were from living organisms. His work led to the synthesis of a variety of organic compounds which are classified into homologous series such as alkanes, alkenes. Members in the same homologous series share characteristics like same functional group and general formula, and a gradual change in physical properties as one molecule differs from the next by a $-CH_2$ group. From these characteristics, predictions of physical and chemical properties of organic molecules in the same homologous series can be made.

Also known as plastics, addition polymers are large, useful organic molecules but they are non-biodegradable. Recycling plastic waste through physical and chemical means contribute to sustainability by turning it to chemical feedstock and fuel.

In describing reactions, students will be expected to quote the reagents, e.g. aqueous bromine, and the essential conditions, e.g. high temperature and pressure. Detailed conditions involving specific temperature and pressure values are **not** required.

Learning Outcomes
8.1 Fuels and Crude Oil
(a) name natural gas, mainly methane, and crude oil as non-renewable sources of energy
(b) describe crude oil as a mixture of hydrocarbons and its separation by fractional distillation to yield fractions which have competing uses as fuels and as a source of chemicals (see also **1.2**(a))
(c) describe biofuel (exemplified by bioethanol from sugarcane) as a renewable alternative to natural gas and crude oil
(d) describe how biofuel, when compared to fossil fuels, is more environmentally sustainable in terms of the offset in carbon dioxide emission during burning by that taken in during plant growth (see also **9**(e))
8.2 Hydrocarbons
(a) describe a homologous series as a group of compounds with a general formula, similar chemical properties and showing a gradation in physical properties as a result of increase in the size and mass of the molecules, e.g. melting and boiling points; viscosity
(b) describe the alkanes as a homologous series of saturated hydrocarbons with the general formula C_nH_{2n+2}
(c) draw the structures of unbranched alkanes, C_1 to C_3, and name the unbranched alkanes methane to propane
(d) describe alkanes (exemplified by methane) as being generally unreactive except in terms of combustion and substitution by chlorine
(e) describe the alkenes as a homologous series of unsaturated hydrocarbons with the general formula C_nH_{2n}
(f) draw the structures of unbranched alkenes, C_2 and C_3, and name the unbranched alkenes ethene and propene
(g) describe the manufacture of alkenes and hydrogen by cracking hydrocarbons and recognise that cracking is essential to match the demand for fractions containing smaller molecules from the refinery process
(h) describe the difference between saturated and unsaturated hydrocarbons from their molecular structures and by using aqueous bromine
(i) describe the reactions of alkenes (exemplified by ethene) in terms of combustion, polymerisation (see also **8.3**(b)) and the addition with bromine and hydrogen
(j) state the meaning of *polyunsaturated* when applied to food products
(k) describe the manufacture of margarine by the addition of hydrogen to unsaturated vegetable oils to form a solid product

Learning Outcomes
8.3 Polymers
(a) describe polymers as large molecules built up from small units (monomers), different polymers having different units
(b) describe the formation of poly(ethene) as an example of addition polymerisation of ethene as the monomer (see also **8.2**(i))
(c) state some uses of poly(ethene) as a typical plastic, e.g. plastic bags; clingfilm
(d) deduce the structure of the addition polymer product from a given monomer and vice versa
(e) describe the pollution problems caused by the disposal of non-biodegradable plastics
(f) describe two methods of recycling plastics as (i) physical method (exemplified by melting small pieces of poly(ethene) waste into pellets) (ii) chemical method (exemplified by cracking of plastic waste into fuel)
(g) discuss the social, economic and environmental issues of recycling plastics

TOPIC 9. MAINTAINING AIR QUALITY

Guiding Questions

- How does human activity impact the environment?
- What can we do to minimise the negative impacts of human activity on the environment?

Topic Description

A useful material, plastics are produced in large quantities generating a lot of waste and polluting the air when they are disposed of by burning. Atmospheric pollutants such as nitrogen oxides fall to Earth as acid rain and pollute land and water. Discarded waste when washed into rivers and seas pollutes them. Human activity at the individual and societal levels has impact on the environment.

The impact on the environment can be reduced by recycling some of the substances we use: recycling metals to conserve metal ores and recycling plastics to conserve the petroleum from which they are made. As a first and important step in managing effects on the climate, this topic identifies common air pollutants, understands where they come from and recognises their effects. This knowledge will help one identify key ways in which one can contribute to maintaining air quality.

Learning Outcomes
(a) describe the volume composition of gases present in dry air as being approximately 78% nitrogen, 21% oxygen and the remainder being noble gases (with argon as the main constituent) and carbon dioxide
(b) name some common atmospheric pollutants, e.g. carbon monoxide; methane; nitrogen oxides (NO and NO_2); ozone; sulfur dioxide; unburned hydrocarbons
(c) state the sources of these pollutants as (i) carbon monoxide from incomplete combustion of carbon-containing substances (ii) nitrogen oxides from lightning activity and internal combustion engines (iii) sulfur dioxide from volcanoes and combustion of fossil fuels
(d) discuss some of the effects of these pollutants on health and on the environment (i) the toxic nature of carbon monoxide (ii) the role of nitrogen dioxide and sulfur dioxide in the formation of 'acid rain' and its effects on respiration and buildings
(e) describe the carbon cycle in simple terms, to include (i) the processes of combustion, respiration and photosynthesis (ii) how the carbon cycle regulates the amount of carbon dioxide in the atmosphere (see also **8.1**(d))
(f) state that carbon dioxide and methane are greenhouse gases and may contribute to global warming; give the sources of these gases and describe the potential effects of increased levels of these greenhouse gases, including more extreme weather events and melting of polar ice

SECTION 3: PEDAGOGY

Teaching and Learning of Upper Secondary Chemistry
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 Chemistry

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, and are 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 to 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.

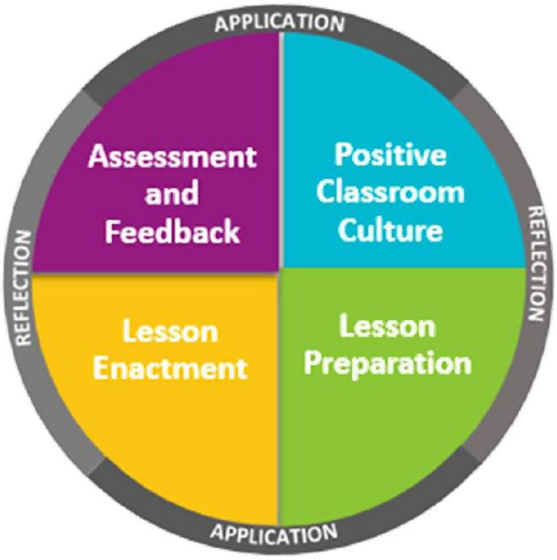


Figure 3.2: The four core *Teaching Processes* within the *Pedagogical Practices* in *STP*

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:

- Developing science inquiry skills
- Developing experimental techniques and practical manipulative skills
- Understanding of the nature of scientific knowledge
- Enhancing conceptual understanding
- Cultivating 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

<u>What is e-Pedagogy?</u>
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.

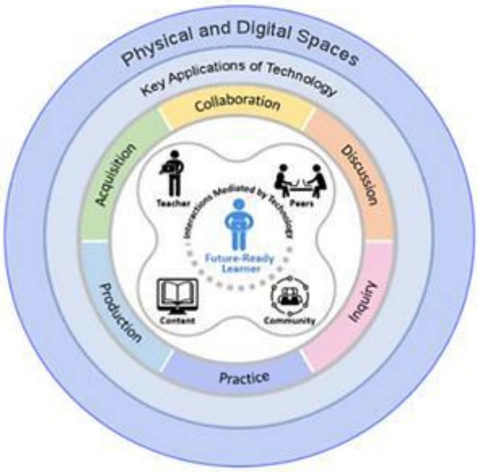


Figure 3.3: Overview of e-Pedagogy

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 Chemistry syllabus, students can be acquainted with the use of basic digital tools (e.g. data loggers, simulations etc). Apart from better preparing students for the technologically-driven world, using digital tools in the classroom supports the development of the practices of science. For instance, when students are given opportunities to collect experimental data using these tools, competencies such as understanding experimental design can be strengthened. Digital tools such as simulations or virtual molecular models allow student to explore and visualise abstract concepts better.

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**. It 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.

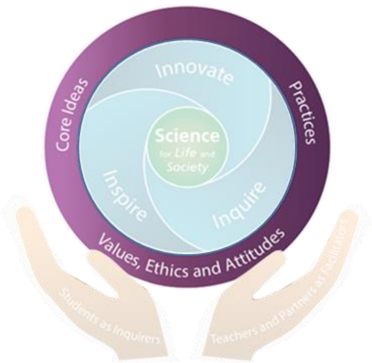
- Assessment provides feedback to **teachers**. It enables them to understand the strengths and weaknesses of their students. It provides information about students' attainment of learning outcomes (which includes 21CC development) as well as the effectiveness of their teaching.

- 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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