Topic 2: Molecular Biology

2.1 Molecules to metabolism

Nature of science:
Falsification of theories—the artificial synthesis of urea helped to falsify vitalism.

Understandings:

- Molecular biology explains living processes in terms of the chemical substances involved.
- Carbon atoms can form four covalent bonds allowing a diversity of stable compounds to exist.
- Life is based on carbon compounds including carbohydrates, lipids, proteins and nucleic acids.
- Metabolism is the web of all the enzyme-catalysed reactions in a cell or organism.
- Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.
- Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.

Applications and skills:

- Application: Urea as an example of a compound that is produced by living organisms but can also be artificially synthesized.
- Skill: Drawing molecular diagrams of glucose, ribose, a saturated fatty acid and a generalized amino acid.

Utilization:

Syllabus and cross-curricular links:

Chemistry

Topic 4 Chemical bonding and structure

Option B Biochemistry

Aims:

- **Aim 7:** ICT can be used for molecular visualization of carbohydrates, lipids and proteins in this sub-topic and in 2.3 and 2.4.
- **Aim 6:** Food tests such as the use of iodine to identify starch or Benedict's reagent to identify reducing sugars could be carried out.
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- Skill: Identification of biochemicals such as sugars, lipids or amino acids from molecular diagrams.

Guidance:

- Only the ring forms of D-ribose, alpha–D-glucose and beta-D-glucose are expected in drawings.
- Sugars include monosaccharides and disaccharides.
- Only one saturated fat is expected and its specific name is not necessary.
- The variable radical of amino acids can be shown as R. The structure of individual R-groups does not need to be memorized.
- Students should be able to recognize from molecular diagrams that triglycerides, phospholipids and steroids are lipids. Drawings of steroids are not expected.
- Proteins or parts of polypeptides should be recognized from molecular diagrams showing amino acids linked by peptide bonds.

2.2 Water

Nature of science:
Use theories to explain natural phenomena—the theory that hydrogen bonds form between water molecules explains the properties of water.

Understandings:

- Water molecules are polar and hydrogen bonds form between them.
- Hydrogen bonding and dipolarity explain the cohesive, adhesive, thermal and solvent properties of water.
- Substances can be hydrophilic or hydrophobic.

Applications and skills:

- Application: Comparison of the thermal properties of water with those of methane.
- Application: Use of water as a coolant in sweat.
- Application: Modes of transport of glucose, amino acids, cholesterol, fats, oxygen and sodium chloride in blood in relation to their solubility in water.

Guidance:

- Students should know at least one example of a benefit to living organisms of each property of water.
- Transparency of water and maximum density at 4°C do not need to be included.
- Comparison of the thermal properties of water and methane assists in the understanding of the

International-mindedness:

- There are challenges for the increasing human population in sharing water resources equitably for drinking and irrigation, electricity generation and a range of industrial and domestic processes.

Theory of knowledge:

- Claims about the “memory of water” have been categorized as pseudoscientific. What are the criteria that can be used to distinguish scientific claims from pseudoscientific claims?

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 4.3 Carbon cycling
Topic 4.4 Climate change
Physics
Topic 3.1 Thermal concepts

Aims:

- **Aim 6:** Probes can be used to determine the effect of different factors likely to influence cooling with water.

significance of hydrogen bonding in water.

2.3 Carbohydrates and lipids

Nature of science:
Evaluating claims—health claims made about lipids in diets need to be assessed. (5.2)

Understandings:

- Monosaccharide monomers are linked together by condensation reactions to form disaccharides and polysaccharide polymers.
- Fatty acids can be saturated, monounsaturated or polyunsaturated.
- Unsaturated fatty acids can be cis or trans isomers.
- Triglycerides are formed by condensation from three fatty acids and one glycerol.

Applications and skills:

- Application: Structure and function of cellulose and starch in plants and glycogen in humans.
- Application: Scientific evidence for health risks of trans fats and saturated fatty acids.
- Application: Lipids are more suitable for long-term energy storage in humans than carbohydrates.
- Application: Evaluation of evidence and the methods used to obtain the evidence for health claims made about lipids.
- Skill: Use of molecular visualization software to compare cellulose, starch and glycogen.
- Skill: Determination of body mass index by calculation or use of a nomogram.

Guidance:

- The structure of starch should include amylose and amylopectin.
- Named examples of fatty acids are not required.

International-mindedness:

- Variation in the prevalence of different health problems around the world could be discussed including obesity, dietary energy deficiency, kwashiorkor, anorexia nervosa and coronary heart disease.

Theory of knowledge:

- There are conflicting views as to the harms and benefits of fats in diets. How do we decide between competing views?

Utilization:

- Potatoes have been genetically modified to reduce the level of amylose to produce a more effective adhesive.

Syllabus and cross-curricular links:
Biology
Option B: Biotechnology and bioinformatics

Aims:

- **Aim 8:** There are social implications of obesity.
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- Sucrose, lactose and maltose should be included as examples of disaccharides produced by combining monosaccharides.

2.4 Proteins

Nature of science:
Looking for patterns, trends and discrepancies—most but not all organisms assemble proteins from the same amino acids.

Understandings:
- Amino acids are linked together by condensation to form polypeptides.
- There are 20 different amino acids in polypeptides synthesized on ribosomes.
- Amino acids can be linked together in any sequence giving a huge range of possible polypeptides.
- The amino acid sequence of polypeptides is coded for by genes.
- A protein may consist of a single polypeptide or more than one polypeptide linked together.
- The amino acid sequence determines the three-dimensional conformation of a protein.
- Living organisms synthesize many different proteins with a wide range of functions.
- Every individual has a unique proteome.

Applications and skills:
- Application: Rubisco, insulin, immunoglobulins, rhodopsin, collagen and spider silk as examples of the range of protein functions.
- Application: Denaturation of proteins by heat or by deviation of pH from the optimum.
- Skill: Drawing molecular diagrams to show the formation of a peptide bond.

Guidance:
- The detailed structure of the six proteins selected to illustrate the functions of proteins is not needed.
- Egg white or albumin solutions can be used in denaturation experiments.

- Students should know that most organisms use the same 20 amino acids in the same genetic code although there are some exceptions. Specific examples could be used for illustration.

Utilization:

- Proteomics and the production of proteins by cells cultured in fermenters offer many opportunities for the food, pharmaceutical and other industries.

Aims:

- **Aim 7:** ICT can be used for molecular visualization of the structure of proteins.
- **Aim 8:** Obtaining samples of human blood for immunological, pharmaceutical and anthropological studies is an international endeavour with many ethical issues.

2.5 Enzymes

Nature of science:
Experimental design—accurate, quantitative measurements in enzyme experiments require replicates to ensure reliability.

Understandings:

- Enzymes have an active site to which specific substrates bind.
- Enzyme catalysis involves molecular motion and the collision of substrates with the active site.
- Temperature, pH and substrate concentration affect the rate of activity of enzymes.
- Enzymes can be denatured.
- Immobilized enzymes are widely used in industry.

Applications and skills:

- Application: Methods of production of lactose-free milk and its advantages.
- Skill: Design of experiments to test the effect of temperature, pH and substrate concentration on the activity of enzymes.
- Skill: Experimental investigation of a factor affecting enzyme activity. (Practical 3)

Guidance:

- Lactase can be immobilized in alginate beads and experiments can then be carried out in which the lactose in milk is hydrolysed.
- Students should be able to sketch graphs to show the expected effects of temperature, pH and substrate concentration on the activity of enzymes. They should be able to explain the patterns or trends apparent in these graphs.

Theory of knowledge:

- Development of some techniques benefits particular human populations more than others. For example, the development of lactose-free milk available in Europe and North America would have greater benefit in Africa/Asia where lactose intolerance is more prevalent. The development of techniques requires financial investment. Should knowledge be shared when techniques developed in one part of the world are more applicable in another?

Utilization:

- Enzymes are extensively used in industry for the production of items from fruit juice to washing powder.

Syllabus and cross-curricular links:

- Biology
- Topic 8 AHL Metabolism, cell respiration and photosynthesis

2.6 Structure of DNA and RNA

Nature of science:
Using models as representation of the real world—Crick and Watson used model making to discover the structure of DNA.

Understandings:

- The nucleic acids DNA and RNA are polymers of nucleotides.
- DNA differs from RNA in the number of strands present, the base composition and the type of pentose.
- DNA is a double helix made of two antiparallel strands of nucleotides linked by hydrogen bonding between complementary base pairs.

Applications and skills:

- Application: Crick and Watson's elucidation of the structure of DNA using model making.
- Skill: Drawing simple diagrams of the structure of single nucleotides of DNA and RNA, using circles, pentagons and rectangles to represent phosphates, pentoses and bases.

Guidance:

- In diagrams of DNA structure, the helical shape does not need to be shown, but the two strands should be shown antiparallel. Adenine should be shown paired with thymine and guanine with cytosine, but the relative lengths of the purine and pyrimidine bases do not need to be recalled, nor the numbers of hydrogen bonds between the base pairs.

Theory of knowledge:

- The story of the elucidation of the structure of DNA illustrates that cooperation and collaboration among scientists exists alongside competition between research groups. To what extent is research in secret 'anti-scientific'? What is the relationship between shared and personal knowledge in the natural sciences?

Utilization:
Syllabus and cross-curricular links:
Biology
Topic 2.2 Water

Topic 3.5 Genetic modification and biotechnology
Topic 7 Nucleic acids

2.7 DNA replication, transcription and translation

Nature of science:
Obtaining evidence for scientific theories—Meselson and Stahl obtained evidence for the semi-conservative replication of DNA.

Understandings:

- The replication of DNA is semi-conservative and depends on complementary base pairing.
- Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.
- DNA polymerase links nucleotides together to form a new strand, using the pre-existing strand as a template.
- Transcription is the synthesis of mRNA copied from the DNA base sequences by RNA polymerase.
- Translation is the synthesis of polypeptides on ribosomes.
- The amino acid sequence of polypeptides is determined by mRNA according to the genetic code.
- Codons of three bases on mRNA correspond to one amino acid in a polypeptide.
- Translation depends on complementary base pairing between codons on mRNA and anticodons on tRNA.

Applications and skills:

- Application: Use of Taq DNA polymerase to produce multiple copies of DNA rapidly by the polymerase chain reaction (PCR).
- Application: Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.
- Skill: Use a table of the genetic code to deduce which codon(s) corresponds to which amino acid.
- Skill: Analysis of Meselson and Stahl's results to obtain support for the theory of semi-conservative replication of DNA.
- Skill: Use a table of mRNA codons and their corresponding amino acids to deduce the sequence of amino acids coded by a short mRNA strand of known base sequence.
- Skill: Deducing the DNA base sequence for the mRNA strand.

Guidance:

- The different types of DNA polymerase do not need to be distinguished.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 3.5 Genetic modification and biotechnology

Topic 7.2 Transcription and gene expression
Topic 7.3 Translation

Aims:

- **Aim 8:** There are ethical implications in altering the genome of an organism in order to produce proteins for medical use in humans.

2.8 Cell respiration

Nature of science:
Assessing the ethics of scientific research—the use of invertebrates in respirometer experiments has ethical implications.

Understandings:

- Cell respiration is the controlled release of energy from organic compounds to produce ATP.
- ATP from cell respiration is immediately available as a source of energy in the cell.
- Anaerobic cell respiration gives a small yield of ATP from glucose.
- Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose.

Applications and skills:

- Application: Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking.
- Application: Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions.
- Skill: Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer.

Guidance:

- Details of the metabolic pathways of cell respiration are not needed but the substrates and final waste products should be known.
- There are many simple respirometers which could be used. Students are expected to know that an alkali is used to absorb CO_2, so reductions in volume are due to oxygen

use. Temperature should be kept constant to avoid volume changes due to temperature fluctuations.

Aims:

- **Aim 8:** The ethics of the use of animals in experiments could be discussed in relation to respirometer experiments. Large-scale use of food plants for biofuels and the resulting impact on food prices has ethical implications.

2.9 Photosynthesis

Nature of science:
Experimental design—controlling relevant variables in photosynthesis experiments is essential.

Understandings:

- Photosynthesis is the production of carbon compounds in cells using light energy.
- Visible light has a range of wavelengths with violet the shortest wavelength and red the longest.
- Chlorophyll absorbs red and blue light most effectively and reflects green light more than other colours.
- Oxygen is produced in photosynthesis from the photolysis of water.
- Energy is needed to produce carbohydrates and other carbon compounds from carbon dioxide.
- Temperature, light intensity and carbon dioxide concentration are possible limiting factors on the rate of photosynthesis.

Applications and skills:

- Application: Changes to the Earth's atmosphere, oceans and rock deposition due to photosynthesis.
- Skill: Drawing an absorption spectrum for chlorophyll and an action spectrum for photosynthesis.
- Skill: Design of experiments to investigate the effect of limiting factors on photosynthesis.
- Skill: Separation of photosynthetic pigments by chromatograph. (Practical 4)

Guidance:

- Students should know that visible light has wavelengths between 400 and 700 nanometres, but they are not expected to recall the wavelengths of specific colours of light.
- Water free of dissolved carbon dioxide for photosynthesis experiments can be produced by boiling and cooling water.
- Paper chromatography can be used to separate photosynthetic pigments but thin layer chromatography gives better results.

Utilization:

Syllabus and cross-curricular links:
Biology
Topic 2.5 Enzymes