STEM-ED Scotland

Building a New Educational Framework to Address the STEM Skills Gap

A fundamental review from a 21st century perspective

Annexes

A: Science storylines supporting entry to study in higher education

B: The teaching Units

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Annex A: Science storylines supporting entry to study in higher education

In approaching any new area of study or application, a good STEM practitioner will set out to understand, and form a mental model of, the topic on the basis of a conceptual picture established from previous studies of science. This conceptual picture is described here as a series of basic science storylines, presented at an appropriate depth as a basis for entry to study at higher education in Scotland, in any STEM subject.

The storylines are written descriptively. They form an appropriate mental starting point. The rigorous scientific investigation and analysis to follow require application of the appropriate levels of skills and methodologies described in Chapters 3 and 5 of the main part of this report on *Building a New Educational Framework to Address the STEM Skills Gap* (STEM-ED Scotland, 2010).

The storylines are listed under the discipline subject headings of Physics, Chemistry, Biosciences and Earth Systems Science. This can be a little misleading as the science disciplines do not represent separate water-tight areas of study, and conceptual strands bridge traditional subject boundaries. Several of the storylines described below could in principle have been set down under different subject headings. Nearly all of the storylines are relevant to the understanding of topics conventionally studied under more than one disciplinary banner.

Physics has a significantly longer list of distinct strands of storyline than other sciences viewed in this way: this reflects the fact that many of the ideas of other sciences are themselves couched on a basis of fundamental ideas derived from physics, as is the technology used in many experimental investigation techniques.

Physics

Mass and energy are two fundamental properties. Within classical physics these two quantities are conserved.

Matter carries mass and is built of a number of different types of atoms, each containing a small central nucleus orbited by a number of electrons (described more fully below under the Chemistry heading). The constituent protons and neutrons of atomic nuclei are themselves composed of yet more basic elementary particles.

Energy exists in various forms including kinetic, gravitational, electrostatic, electromagnetic and nuclear. Energy is carried by radiation; material substances carry chemical energy and internal energy; and energy is held by materials distorted under stress and by gases under pressure. Energy can be transferred from one form to another.

Energy involved in internal motions of molecules and atoms within substances is described as heat. In any body or ‘system’ of material left to itself (isolated from any possibility of energy transfer in or out) random collisions between constituent particles distribute the ‘heat’ energy in a way that results in ‘thermal equilibrium’, with a uniform settled temperature throughout the body or system. Temperature, for a given system, is related to the total amount of heat energy contained: at the absolute zero of temperature the very minimum possible energy would be present, and the greater the total quantity of heat energy present the higher the settled temperature would be. When bodies at different temperatures are brought into contact, heat energy will spontaneously flow from the warmer into the cooler body, till both settle at a uniform, intermediate temperature level.

A force acting on a body, unless balanced by an equal opposing force, will cause a motion of the body, through an acceleration inversely proportional to the body's mass. One universal force (on earth) is the body's own weight, due to gravitation.

Where a force on a body is (wholly or partially) resisted by an opposing force acting at a different point, the body may be distorted to some degree, producing stress forces opposing

each applied force at its point of application. Any body held at rest must have its weight force opposed by an equal and opposite force through its point(s) of support: these forces will result in local stress forces throughout the body. In fluids (at rest), stress forces at any point have to balance in all directions; such forces are described as pressure.

Where the two opposing forces are not co-linearly aligned they will exert a torque on the body which, if not countered by an equal opposing torque, will cause a rotational acceleration. Any body involved in uniform circular motion about a central point is experiencing a centripetal force towards the centre in order to cause the continuous acceleration required to keep it on its circular path rather than to move off tangentially.

The above insights can be used to analyse, track and predict the motion of bodies in terms of positions, velocities, accelerations and kinetic energy. All forces applied between bodies ('actions') are opposed by equal but opposite opposing forces ('reactions'): this results in conservation of total momentum.

Materials can exist in different physical states referred to as phases. Solids, liquids and gases differ in the extent to which cohesive forces constrain independent motions of constituent molecules. In a gas, molecules move essentially independently between random collisions: a gas will fill any container it is confined to, and molecular collisions on the container walls exert a uniform outward pressure. In a liquid, molecules are held closely together but are able to move relative to one another, exchanging partners: the total volume occupied changes marginally with pressure and temperature. In a solid, molecules are generally confined in constant positions relative to one another. The phase adopted by any substance depends on the strength of intermolecular cohesive forces relative to the heat energy invested in molecular motions. All substances will be solid at a low enough temperature, but will typically pass through phase changes into liquids and then to gases as the temperature is raised.

Many solids can be more complex in internal structure, embedding local dislocations or dopant species. There are also disordered solid-like phases such as glasses. Liquids can dissolve third-party substances, and different liquids may be freely miscible. Many gases closely approach the

model behaviour of an ‘ideal gas’, with a well-defined relationship between its temperature, pressure and volume.

A number of areas in physics can be explained in terms of wave motions. Waves can be longitudinal (as in sound waves that involve pressure fluctuations when passing through air) or transverse (as in waves on the surface of water, or electromagnetic radiation). Wave motions can occur in one dimension (as along a tautly held string), in two dimensions (as on the surface of water or a drum) or in three dimensions (as for sound and radiation). The speed of propagation of a simple regular wave pattern is equal to the product of its wavelength and frequency. Waves can be reflected at rigid boundaries or fixed points, and two- and three-dimensional waves can be diffracted when passing by fixed obstacles. Waves of different wavelengths, when travelling together, ‘superimpose’ to create more complex wave shapes. Waves of a single wavelength superimposing after reflection or diffraction can produce standing waves or interference patterns. Where a wave motion passes into a different medium (as when light passes from air into glass) it is refracted, resulting in a change of direction that varies with its frequency.

Sound involves longitudinal vibrations transmitted outwards from a vibrating source through surrounding matter, be it solid, liquid or gaseous. The speed of transmission is dependent on the substance passed through and its temperature and pressure, but it is the same for all wavelengths. Audible sounds of different frequencies link to different perceived pitch of the sound as detected through the ear. Musical notes are associated with a single frequency of sound, though usually as mixed ‘harmonics’ consisting of sound waves with frequencies that are whole-number multiples of the ‘fundamental’ frequency. The term ‘ultrasound’ refers to sound at higher frequencies than the human ear drum is sensitive to.

Some materials exhibit the property of magnetism. A magnet has a north and a south pole. Magnetic forces act between different magnets, with attraction between opposite poles and repulsion between like poles. Magnetic field lines can be traced around the vicinity of the magnet, and two interacting magnets free to rotate will tend to align themselves so that each aligns along the local field line from the other. Some atoms are magnetic, and the magnetism of a body results from the combined effect of these. Atomic magnets often point in random

directions, cancelling one another throughout the solid as a whole. When exposed to an external magnet, such materials can have their atomic magnets aligned, so that the material as a whole becomes magnetized. Motions in the earth's core mean that the earth as a whole acts as a magnet.

Electrons and nuclei carry opposite electrical charges, and hence objects of any scale may carry negative or positive charge through embodying a relative excess or deficiency of electrons. Separate charges attract or repel one another through an electrostatic force described by Coulomb's law.

Moving charges travelling through a medium constitute an electric current (this may result, for instance, from a stream of electrons flowing along a cable or a stream of ions flowing through a solution). An electrical voltage is required to sustain an electric current. The voltage provides a driving force to overcome the inherent resistance of the medium, transferring the energy required to sustain the current's flow. The voltage, current and resistance can be measured in standard units, and their values are related through Ohm's law. Materials of extremely high resistance are known as electrical insulators, whilst those of relatively low resistance are described as conductors. At very low temperatures there are a number of very specific materials, known as superconductors, that have zero resistance.

Modern electronics is based on transistors which are constructed using semiconductor materials. Semiconductors have relatively low electrical conductivity and are of two types, ‘n’ and ‘p’, with different mechanisms for conducting electricity. Transistors connect these in ways that produce devices that can switch or amplify electronic signals.

Electromagnetic induction: An electric current flowing along a wire generates a magnetic field circularly oriented around the wire, and there will thus be a force between the conductor and any nearby magnet. If the wire or the magnet is free to move, this force will cause, or induce, motion, transferring energy to this motion. When electric current is flowing along two neighbouring wires the magnetism produced in both results in a magnetic force between them, which can again act to transfer electrical energy into motion of one or both wires. These energy transfer processes can act in the reverse direction, so that when a magnet, or a wire carrying a

current, moves past another wire, energy can be transferred from the motion, ‘inducing’ an electric current in the other wire.

When a current circulates around a coil the overall magnetic field produced combines to act as a magnet positioned along the axis of the coil, referred to as an electromagnet. This arrangement can lead to much stronger forces between currents carried in two different circuits, or between one circuit and a magnet. This is exploited in the design of electric motors and transformers, and to generate electricity from fuels of diverse kinds. Electric motors and generators involve rotating coils and can naturally lead to the production of electricity in alternating current (AC) form, as is standard in commercially distributed electricity.

Electromagnetic radiation involves transverse oscillations of electric and magnetic fields that travel, in a vacuum, at a universally constant high speed, ‘the speed of light’. Radiation can occur at any wavelength over a huge range, referred to as the electromagnetic spectrum. Radiation carries energy which can be transferred to or from matter by absorption or emission.

Visible light is one form of electromagnetic radiation, covering a relatively narrow range of wavelengths, which happen to be able to be absorbed by molecules in the retina of human eyes, in a way that can generate an electrical signal that is transmitted to the brain. Different wavelengths within the visible range are perceived as different colours of light, whereas white light is a mixture of all wavelengths. Several other regions of the electromagnetic spectrum are classified, by their wavelengths, variously as radiowave, microwave, infrared (IR), ultraviolet (UV) and X-rays, and each of these regions is exploited in characteristically different technological ways. Refraction and reflection can be exploited, through the use of lenses and curved mirrors, to produce magnified images, as in microscopes and telescopes. Arrangements that will generate standing waves, or ‘resonances’, at particular wavelengths can be used to tune a receiving device to selectively detect signals at a particular frequency. Through prisms or diffraction gratings, radiation carrying a range of wavelengths can be dispersed, allowing single-wavelength beams to be selected. A special emission process can be designed, which produces intense radiation of a single wavelength in a highly directional single ‘laser’ beam, an important technology underlying many modern applications.

A number of properties mentioned above, including relative positions, velocities and forces, are characterized by both a magnitude and a direction in space. These can be described as vector quantities. Vectors can be treated by standard mathematics, which describes how they can be added and how they can be ‘resolved’ into components, and which gives useful ways to calculate how interactions involving vector quantities work out (as when a force acts to alter a velocity).

The planets, asteroids and comets of the solar system orbit the much larger sun, held by the centripetal force of its gravitational attraction. The solar system is one of billions held together in the Milky Way galaxy. This galaxy is one of billions composing the universe.

The universe is believed to have been formed in the ‘Big Bang’ many billion years ago and it continues to expand rapidly. Galaxies, stars and solar systems have developed in the intervening period, and continue to develop. The motions of stars within galaxies, and planets and moons within solar systems, are governed by gravity. Stars go through a life cycle dependent on their size, and collision events are significant in the history of planets. Much of the mass of the universe is believed to be vested in ‘dark matter’ which has not been directly observed. Much energy is similarly believed to exist in the form of unobserved ‘dark energy’.

The chemical elements are created by nuclear reactions, largely in stars. Energy from nuclear reactions fuels the emission of radiation across the electromagnetic spectrum, and also highly energetic cosmic rays. Observations of these, involving various designs of telescopes, form the basis of our understanding of the universe.

Space exploration, both manned and unmanned, provides for better telescopic observations from beyond the earth's atmosphere as well as allowing experiments under zero gravity conditions, and remote sensing of conditions on the earth and other nearby bodies. Probes can be used to land on other planetary bodies to directly analyse samples, and there has been much interest in exploring evidence of possible extra-terrestrial life. Space exploration presents severe challenges in engineering and equipment design.

Non-classical physics: The physics of the last hundred years has been hugely influenced by the discovery that many of the principles of classical physics do not hold when dealing with

phenomena of either very small or very large scale. Classical physics continues to dominate non-advanced education in the subject, partly because the classical picture continues to be valid to a very high level of accuracy within its traditional domain, and also because non-classical physics in general requires much more advanced mathematics. Nonetheless it is important, by SCQF level 6, to understand some of the non-classical storylines, at an elementary and quite general level.

Whilst the spectral range and propagation of radiation is well described by the classical wave model, radiation is created, and absorbed, as individual photons. A photon carries a packet, or ‘quantum’, of energy of magnitude proportional to the wave frequency, as given by Planck's law.

The classical laws of motion become inadequate at the molecular scale and below, where the motions of electrons within atoms and molecules, and the vibrations and rotations of molecules, follow laws of quantum mechanics. One consequence of this is that there are a limited number of ‘energy states’ for these motions, characterized by discrete values of energy. Atoms and molecules have distinct allowed energy levels. In spectroscopy, when a photon of radiation is emitted or absorbed, its frequency must be such that its energy precisely matches the energy lost or gained by an atom or molecule undergoing a transition from one allowed energy level to another.

Mass and energy can in fact be interconverted in extreme processes, and in particular this is significant in nuclear reactions. A small change of mass involves a very large change in energy, as given by Einstein's relationship $E = mc^2$. Energy-releasing (and therefore mass-consuming) nuclear reactions include radioactivity, fission of nuclei of heavy atoms, and fusion of light nuclei. Fusion involves the greatest proportional energy change, and is the dominant energy-producing process in stars during the main part of their life cycles.

For objects and observers moving at extreme speeds relative to one another, measurements of time and distance will differ. One consequence of this is the phenomenon of ‘time dilation’.

In regions subject to extremely high gravitational forces the conventional rules of geometry do not apply: space is described as ‘curved’.

Chemistry

All materials in the normal natural world are made of atoms, and different atom types characterize different chemical elements. The periodic table lists all elements in a systematic way, and position in this table correlates closely with the different properties of elements and their atoms.

Molecules are the characteristic building blocks of most materials, and each of the very many different possible molecules consists of atoms bonded together in a specific arrangement.

Atoms contain electrically charged nuclei and electrons, and the number and arrangement of the electrons provide a basis for understanding the significance of the periodic table and the structures and properties of atoms, molecules and of substances in general.

The electrons within atoms are accommodated within a shell structure; comparing atoms in a given row of the periodic table, the outer shell (valence shell) is held more tightly for elements nearer the right, leading to decreasing atomic radius and increasing electronegativity. Proceeding down a given column of the periodic table, atoms have similar outer shell electron arrangements; they gradually increase in radius and become more electropositive.

Chemical bonds result from the transfer or sharing of electrons (for ionic and covalent bonding, respectively). The number of outer shell electrons, and the number of vacancies that could potentially be filled in the outer shell, dictate the number of bonds that ordinarily can be formed. Only the most electronegative atoms can readily form negative ions (anions). On the other hand a large number of electropositive atoms (including all elements classed as metallic) can quite readily form positive ions (cations).

In most stable molecules, electrons are arranged in pairs. Most of chemistry involves the behaviour of covalently bound molecules: each covalent bond involves a pair of electrons, and unshared valence shell electrons generally occupy ‘lone pairs’ on their parent atoms. Where a covalent bond joins atoms which differ in electronegativity, the electrons will be shared unequally, resulting in polarity of the bond. Where a covalently bonded cluster of atoms includes

a strongly electronegative or a strongly electropositive atom it may achieve full electron pairing by transfer of an electron (to or from another molecule) to make a molecular ion.

The geometric shape of a multi-atom molecule can be largely understood as resulting from repulsions between different pairs of valence shell electrons.

Electrical polarity and molecular shape strongly influence the properties of substances, how the same or different molecules are arranged and held within substances, and how molecules react.

All forms of bonds involve energy: total energy is conserved, and energy in the form of heat will generally be produced or consumed in the course of reactions.

Heat energy within matter exists through internal motions of the components within molecules, and of the whole molecules themselves: the more heat energy a substance holds the higher its temperature.

The electrical charge of electrons and nuclei explains the origins of ions, and of the electrical polarity of many molecules.

Chemical reactions involve interchange and rearrangements of atoms and bonds, to form different molecules: all atoms are conserved in these processes, which result from collisions between reactant molecules.

Chemical reactions will proceed to the point of chemical equilibrium, at which point the rate at which new product molecules are being formed from collisions of reactants is balanced by the rate of the reverse reaction in which collisions of product molecules lead to the production of reactants. The equilibrium point, at any given temperature, can be quantified in terms of an equilibrium constant for the reaction. The yield of a chemical process may be significantly limited by reaching equilibrium, and also often by the occurrence of alternative, and competing, reactions.

Carbon is a unique element in the variety of molecules for which it can provide the backbone. Carbon generally forms four quite strong and stable bonds to a number of other elements. C—C

and C—H bonds are effectively non-polar. Bonds to more electronegative atoms (eg O, N, Cl) are polar covalent, and double or triple bonds between C-atoms are relatively open to reaction. The properties and reactivities of organic molecules can be rationalized and predicted in terms of functional groups present. A functional group is a characteristic local structural feature with a well-recognized susceptibility to a range of standard types of reaction. Organic compounds are often classified according to prominent functional groups (such as alkenes, alcohols, esters, amines).

It is useful to classify different types of reaction including:

(a) redox reactions (involved, for instance, in chemical cells)

(b) acid-base reactions (which, for instance, considerably influence biological processes)

(c) substitution, addition and elimination reactions

(d) polymerization reactions.

The quantities of reactant substances consumed, of product substances formed, and of energy generated or consumed can be directly related to the corresponding changes at individual molecule level: the 'mole' is the scaling factor that enables such calculations.

The strength of intermolecular attractions, relative to the heat energy present, determines whether a substance is in solid, liquid or gaseous form.

In solutions, dissolved substances are stabilized by attractions to molecules of the solvent, whilst motions allow different dissolved substances to collide and potentially react.

Radiation interacts with materials through individual molecules absorbing or emitting individual photons: there is a precise energy exchange in this process, characterizing transitions involving excited states of the molecule and dependent on the precise frequency of the radiation.

Biosciences

All living things obey the laws of chemistry and physics, such as those of conservation of energy and matter; the processes of life at root involve molecular reactions and interactions.

There is huge variety and diversity in the nature of living things. Similarities and differences between organisms allow them to be classified. Organisms can be assigned scientific names that aid in cataloguing biodiversity.

All living organisms are made of cells that contain and regulate assemblies of chemicals. Cells can be aggregated into tissues, tissues into organs, and organs into organ systems.

Plants capture energy from the sun in photosynthesis, a process that forms the basis of virtually all food webs. Certain bacteria, fungi and other organisms break down and recycle waste products and dead organisms.

Carbohydrates, fats, nucleic acids and proteins are large molecular chemicals essential for life.

DNA plays a central role in the structure and functioning of individual cells and whole organisms. Cell chemistry involves a complex interplay of molecular reactions and interactions, and requires input of nutrients and export of waste material. DNA defines the genes of an organism, which determine its characteristics.

The role of DNA is central in the key processes of cell division and in the reproduction of organisms. It defines the inherited characteristics of offspring. In sexual reproduction the interplay of the genes of the two parents affects the detailed individual characteristics of the offspring.

An understanding of human anatomy, physiology and biochemistry is essential for healthy living, for exercise science and for diseases to be combated medically. Various physiological systems within humans, animals and plants act to achieve homoeostasis and control, to mediate growth and development, and to defend against infection and disease.

The nervous systems in animals allow them to derive information of their surroundings through sensory organs, and to direct and control their behaviour.

Human and animal behaviour is in general adaptive. Organisms co-exist in ecosystems and depend on one another for such things as energy, nutrients, pollination and habitats.

The range of life we see today can be understood as having evolved through natural selection.

Humans have considerably altered habitats and biodiversity, and are increasingly responsible for pollution, climate change and species extinctions.

The application of knowledge gained in the biosciences can be applied in numerous ways to advance developments in agriculture, industry and medicine. Such developments require regulation to ensure that an acceptable balance is achieved of risks relative to benefits, and that any ethical issues are properly considered.

Earth systems science

The earth formed 4.5 billion years ago during the early development of the solar system. It was pulled together by gravitation with considerable release of energy. The earth cooled from its surface, where the mean temperature over recent millennia fluctuated to a small (but highly significant) degree across an effectively steady range. The earth loses energy to space by radiation, receiving broadly balancing radiated energy from the sun and a geothermal energy flow from the interior. The latter energy store is largely replenished by natural radioactivity.

Below ground the earth consists of a surface crust, composed of igneous, sedimentary and metamorphic rocks of various mineral compositions. Below this two main layers are recognized, the mantle and core, each with a distinctive composition. Temperature and pressure increase steadily with increasing depth. Circulatory motions of material in the inner earth drive volcanic action, where material from the mantle breaks through the core, and earthquakes, where extreme forces cause local fracture and movement in the crust. Large-scale volcanic action and disturbance of the crust have been caused from time to time by collisions of comets or asteroids with the earth.

The earth's surface consists of a number of tectonic plates which move slowly relative to one another, driven by new material pushed through the crust at various mid-oceanic ridges and, where plates are pushed together, by the material of one plate being driven downwards under the other plate. Pressures from the latter process are responsible for mountain building. Most volcanic and earthquake activity is in the vicinity of plate boundaries. Earthquakes result in shockwaves that travel throughout the solid earth, and observations of these have provided the principal evidence through which the internal structure of the earth has been understood.

The composition of the earth's atmosphere has evolved over the earth's history, with oxygen becoming a significant component only after the evolution of abundant photosynthetic plant life. The pressure of the atmosphere is a consequence of the weight of gas above any given level, so the pressure drops at higher levels. Owing to heat loss from ground level, the atmosphere cools with height in the lower troposphere region, allowing mixing of the air in this part of the

atmosphere, which mostly influences weather. Higher up, from the boundary with the stratosphere, the atmosphere becomes warmer at greater altitudes due to the absorption of lower-wavelength ultraviolet radiation from the sun.

Weather is driven by differences in energy gained from solar radiation in different regions of the earth's surface, which lead to convective flows in the atmosphere that are much disturbed by differential forces due to the earth's rotation, leading to the circulatory low- and high-pressure systems. Circulation of water vapour plays a large part, as it is evaporated from oceans and land (with local energy absorption) and condensed in clouds (with energy release to the local atmosphere).

Water also considerably influences climate, through ice covering colder regions reflecting much incoming solar radiation, and through major ocean currents carrying large amounts of energy between different regions.

Natural processes of the earth, including those in its biosphere, circulate materials. Natural and human-influenced cycles of the elements carbon and nitrogen are particularly vital for life on the planet.

Human activity has depended on exploiting natural resources, through mining and processing important mineral and fuel resources, and considerably changing the biosphere through, for example, felling forests, water management schemes and agriculture. These activities steadily deplete valued natural resources, and generate waste streams that have further impacts on the environment and the biosystem it supports.

The earth's environment involves extremely complex and diverse interacting processes. Modelling these and accurately predicting future trends is scientifically very demanding. Observations and conclusions from such studies must drive and inform technologies to achieve sustainability of life and civilization, and efficient use and recycling of materials.

Annex B : The teaching Units

A New Educational Framework for Progression in Science and Engineering, SCQF Level 5/6

Introduction to the STEM-ED Scotland programme

The STEM-ED Scotland programme is a skills-led framework for developing individuals' capabilities in science, technology, engineering and mathematics. It has been designed to engage students of mixed ability and diverse interests in active participation in their learning. It takes lecturers and students beyond the standard curriculum and allows them scope to select from a content menu that develops the different discipline strands in harmony and with mutual reinforcement. It emphasizes skills development and a broad understanding of the key concepts that are required by employers and universities alike. These key conceptual strands represent the 'big ideas of science' — a fundamental framework of ideas which we have described fully in Chapters 4 and 5 of the main report, *Building a New Educational Framework to Address the STEM Skills Gap* (STEM-ED Scotland, 2010, hereafter referred to as the main STEM-ED report). A shorter version of these ideas and methodologies is given in Section 2 below. In the introductory notes for each Unit, information is provided on its storylines and also the skills it develops.

In Chapters 1 to 5 of the main STEM-ED report (mentioned above) we describe this new model of approach to STEM education at sub-degree levels, consistent with modern perspectives, and in Chapter 6 of the main STEM-ED report we give details of our implementation model. In this annex we give the detailed Unit descriptors for our exemplar course.

The design is guided by the framework approach previously outlined in Chapter 1 of the main STEM-ED report to:

(a) engage interest and commitment
(b) progressively and systematically strengthen skills
(c) deepen understanding of the main explanatory concepts, models and storylines of the sciences
(d) develop and apply the techniques and methodologies listed in Chapter 5
(e) select and schedule a sequence of specific applications to be studied.

The Unit titles are shown in Table 1 below, and the Unit content is given in the Unit descriptors later in this Annex.

Table 1 Unit titles

Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Numeracy	Energy sustainability	Calculus	Statistics	Information systems
Atoms and molecules	Reactivity	Eukaryotic cells	Materials	The universe
Forces, motion, energy	Electricity	Radiation	Prosthetics	Nanotechnology
Earth processes	Equations and graphs	The human organism	Industrial chemical processes	Genetics
Ecosystems	Study of a domestic appliance	Investigation of a large infrastructure project	Commercial case studies	Analysis of a commercial application

1 Structure of the Units

The programme presented here consists of 25 Units: 5 at SCQF level 5 and 20 at SCQF level 6. Each Unit has a core driver — maths, computing, sciences or engineering. The Units are numbered according to the learning cycle to which they belong, with Units in cycle 1 being at SCQF level 5 and Units in cycles 2–5 representing increasing complexity within SCQF level 6 (see Table 1, which gives an overview of the programme).

In the introductory notes for each Unit, information is provided on its storylines and also the skills it develops. Every Unit is subdivided into a number of topic areas, and Unit notes provide an outline of content, teaching notes and resources for each of these. Within each Unit, lecturers and students may choose to concentrate on particular areas of interest. In most Units it is envisaged that individual students will undertake different tasks and report back to the rest of the class, so that no student will be expected to tackle directly all of the content in a Unit. The content of the *Numeracy* Unit in cycle 1, however, is so basic and important for many other Units that failure to cover all aspects may put students at a disadvantage.

The national SCQF specifications, intended to apply across all areas of education, give general statements describing the different types of context in which a given skill is demonstrated, typically referring to ‘simple tasks’ at level 5, ‘more complex situations’ at level 6 and ‘contexts requiring pre-planning’ at level 7. In Chapter 3 of the main STEM-ED report we have developed our own statements to demonstrate a similar progression. Our emphasis on the matrix of skills relevant for STEM practice means that we should naturally aim to reach a higher level in the application of these skills by the end of a course at level SCQF 6, especially skills in numeracy and analytical analysis. Our course Units are designed in the light of what we believe to be achievable for students who enter appropriately qualified at the preceding level and, although Units have been classified at level 6 overall, we indicate that the hope is that in the fifth cycle of Units students have achieved a higher level of skills development than would have been the case in a more conventional type of course.

2 Key storylines and methodologies developed in Units

The following seven lists summarize the codes and brief descriptions for the key storylines and methodologies used in the Units.

PHYSICS

P1 Applications in electricity and electronics

P2 Study involving radiation (including lasers)

P3 Study of a wide range of materials properties

P4 Studies of forces, motion and energy

P5 Study involving spontaneous processes

P6 Study involving non-classical physics

CHEMISTRY

C1 The periodic table as a key explainer

C2 Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts

C3 Reactions, including mechanisms and yields

C4 Solution processes, including electrochemistry and reaction equilibrium

C5 Processes involving light absorption/emission

BIOSCIENCES

B1 Organization and operation of the cell, and the nature, roles and management of the key chemicals of life

B2 Organization and systems operation of an organism; homeostasis & control; healthy living & combating disease

B3 Cell division, reproduction, heredity

B4 Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability

B5 Adaptation and evolution

EARTH SYSTEMS SCIENCE

G1 Study involving (human influenced) element cycle and environmental modelling

G2 Study implicating major seismic processes

G3 Study involving evolution of the earth, the solar system and the universe

G4 Study involving weather, climate and interplay with the biosphere

MATHEMATICS METHODOLOGIES

M1 Exponentials and logarithms (including exp and ln)

M2 Trigonometry, coordinate geometry

M3 Vectors in two and three dimensions, components, products

M4 Basic introductory calculus

M5 Basic statistics, variability, risk assessment

M6 Key tools from numeracy, algebra, proportion and graphs

ENGINEERING METHODOLOGIES

E1 Project planning and management

E2 Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact

E3 Materials selection to meet required needs and to minimize costs

E4 Process control methodologies

E5 Quality methodologies, and sustainability issues

COMPUTING & INFORMATION SCIENCES METHODOLOGIES

CI1 Roots of computer science in numeracy: using symbols for quantities

CI2 The concept of information: classes of information

CI3 Solution specification for a general problem — algorithms

CI4 Basic introduction to programming (using a simple high-level language)

CI5 General ideas of how digital computers store, input, transform and output information

CI6 Analysing design issues in a range of applications (from in-built control devices in appliances to large scientific and technological information processing systems)

3 Mapping skills and concept development, and connections

Within the Unit notes, clear guidance is provided on which other Units provide useful prior knowledge and which will provide application, consolidation or extension. These links illustrate the real links between subjects that have historically been regarded as discrete and taught accordingly, and so allow the student to understand STEM education as a coherent whole as well as providing new routes to develop generic problem-solving skills. To facilitate such links, each Unit has three tables:

1 to give the key concepts and storylines associated with the Unit
2 to give links from the Unit to other parts of the programme
3 to show skills development within the Unit.

The level of skills is developed progressively (see below) throughout the different cycles. Table 2 shows how the skills are developed progressively throughout the Units (from SCQF level 5 to level 7) and Table 3 shows the storylines covered in the different Units. The column headings (1a etc) of Tables 2 and 3 link to the Unit titles (Table 1), with the number relating to the cycle (1 first cycle, 2 second cycle, etc) and the letter relating to the rows of Table 1 (a is the first row, b the second row, etc). For example, 1a is the *Numeracy* Unit and 5d is the *Genetics* Unit. The row headings of Table 2 (S1—S9) refer to the skills described in Chapter 3 of the main STEM-ED report (also given in the skills development table for each teaching Unit in this Annex). The row headings of Table 3 (P1—P6, C1—C5, etc) refer to the storylines and methodologies mentioned in Chapters 4 and 5 of the main STEM-ED report (also listed above in Section 2 of this Annex).

Enquiry-based learning develops important transferable skills and enables students to gain experience in facing the types of problems encountered by practising engineers and scientists. Independent learning is an important skill for any student to develop and is recommended for a significant part of most Units. Useful resources for this purpose, including websites, are given where appropriate. Wikipedia and similar generic web-based resources are helpful but students

should be cautioned about content that has not been subjected to any kind of review process before publication.

The assessment criteria are given for each Unit. The final Unit, *Analysis of a commercial application*, brings together a lot of the work done in previous Units, and its assessment will play an important role in the overall grade attained for the course.

4 The Units at SCQF levels 5 and 6

A brief summary of the content of each Unit has already been given in Chapter 6 of the main report, *Building a New Educational Framework to Address the STEM Skills Gap* (STEM-ED Scotland, 2010), and the detailed Units are given in this Annex. The Units have been given in five cycles; each cycle builds on the skills and knowledge gained in the previous cycle. The order or way in which Units are tackled in a given cycle is immaterial: they can be run simultaneously or in any other suitable way. At the end of each cycle there will be time allocated to review progress, to reflect on what has been learned, to look at how skills are being developed and to set future targets.

The content of the Units is not meant to be too prescriptive, and much of the work is project based. The descriptors do not say how Units should be delivered but they contain ideas and examples of possible projects. It will be up to the lecturer to decide on the most appropriate approach for a particular class.

5 Engineering as a discipline

In Chapter 5 of the main STEM-ED report, entitled ‘Important tools, methodologies and practices in STEM subjects’, under the heading ‘Engineering technology’ we broached the subject of

student awareness of engineering as a discipline. A brief outline and some useful resources for communicating what an engineer is and does were given; this has been repeated below so that it can be read in conjunction with relevant Units.

What is engineering?

The following description is quoted from the website 'What is Engineering?' at **http://cnx.org/content/m13680/latest/**

> Engineering is the practical application of science and mathematics to solve problems, and it is everywhere in the world around you. From the start to the end of each day, engineering technologies improve the ways that we communicate, work, travel, stay healthy and entertain ourselves.
>
> Engineers influence every aspect of modern life and it's likely that today you will have already relied on the expertise of one or more engineers. Perhaps you woke to a DAB clock radio, or used a train or a bus? Maybe you have listened to an iPod? Or watched television? Did you wash your hair today? Do you have a mobile phone in your pocket or trainers on your feet? These have all been designed, developed and manufactured by engineers.
>
> Engineers are problem-solvers who want to make things work more efficiently and quickly, and less expensively. From computer chips and satellites to medical devices and renewable energy technologies, engineering makes our modern life possible.

The above website gives further information and also discusses the difference between science and engineering.

There are different engineering disciplines, and engineers can work in many different environments. For more information about this, see **http://www.enginuity.org.uk/what_is_engineering.cfm**

A useful video clip entitled 'Is engineering right for me?' from the University of Buffalo in the USA can be found at **http://www.youtube.com/watch?v=vj-H_Mbfvu4**

It may also be helpful to know that there are three nationally (and internationally) recognized professional levels that can be worked towards: Engineering Technician (Eng Tech), Incorporated Engineer (IEng) and Chartered Engineer (CEng). Each of these levels can be achieved by various routes of study — going to university to study an engineering course is just one of the many options available. To find out more, see the 'Enginuity' website at:
http://www.enginuity.org.uk/routes_into_engineering/your_options.cfm

Table 2 Skills development throughout the Units (from SCQF level 5 to level 7)

	1a	1b	1c	1d	1e	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	4a	4b	4c	4d	4e	5a	5b	5c	5d	5e
S1	5	5	5	5	5	6	5	5	6	5	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7
S2	5	5	5	5	5	6		5	6	5	6	6	6	6	6	6	6	6	6	7	6	7	7	7	7
S3	6	6	5	5	5	6		5	6	5	6	6	6		6	6	6	6	6		6	7	6		7
S4		5		5		6			6		6	6	6		6	6	7		6	7	7		7	7	7
S5	5	5	5	5		6			6	5	6	6	6		6	6	6	6	6	6	7		6	6	7
S6	5	5	5	5	5						6		6			6	6						7	7	7
S7		5	5	5		6				5	7	6	6			6	6	6	6		7	7	7		7
S8		5		5		6	5				6	6	6	6	6	6	6		6		7		7		7
S9							5	5		5							6	6		7			7		7

The column headings (1a etc) in Tables 2 and 3 link to the Unit titles (Table 1), with the number relating to the cycle (1 first cycle, 2 second cycle, etc) and the letter relating to the rows of Table 1 (a is the first row, b the second row, etc). For example, 1a is the *Numeracy* Unit and 5d is the *Genetics* Unit.

The row headings of Table 2 (S1—S9) refer to the skills described in Chapter 3 of the main STEM-ED report (also listed in the individual skills development tables for the teaching Units in this Annex).

The row headings of Table 3 (P1—P6, C1—C5, etc) refer to the storylines and methodologies mentioned in Chapters 4 and 5 of the main STEM-ED report (also listed above in Section 2 of this Annex). Unit 5e, *Analysis of a commercial application*, does not directly relate to any of the key concepts/storylines. As this is the final Unit in the programme it will draw on the concepts and storylines relevant to the area chosen for study.

Table 3 Storylines covered in the Units

Unit: Code:	1a	1b	1c	1d	1e	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	4a	4b	4c	4d	4e	5a	5b	5c	5d	5e
P1				X		X		X		X	X		X		X		X	X	X				X		
P2			X	X		X					X		X												
P3				X		X						X	X		X	X	X	X		X			X		
P4				X		X			X		X	X		X	X					X					
P5			X			X										X		X							
P6						X											X						X		
C1		X		X		X	X										X		X						
C2		X		X			X					X	X				X	X	X				X	X	
C3						X	X		X		X					X	X		X						
C4		X				X		X		X									X				X		
C5				X									X				X						X		
B1				X								X		X										X	
B2													X	X		X							X	X	
B3												X		X										X	
B4				X	X				X		X				X					X				X	
B5					X																			X	
G1				X		X																			
G2																X						X			
G3																						X			
G4			X		X										X	X						X			
M1	X								X		X		X						X						
M2	X								X				X		X										
M3			X												X										
M4			X		X						X				X										
M5															X	X				X			X		
M6	X	X		X		X			X				X					X	X				X		
E1											X				X					X	X				
E2			X												X	X		X	X	X	X				
E3															X			X		X					
E4															X				X	X	X				
E5															X	X				X					
CI1	X																								
CI2																									
CI3																					X				
CI4																					X				
CI5																					X				
CI6																		X			X				

Numeracy

Introduction to the Unit

The primary purpose of this Unit is to develop an understanding of, and provide practical experience of, handling numerical information. It is important that this Unit is approached through the practical application of number rather than just learning how to manipulate numbers as an arithmetical or algebraic discipline. The examples chosen should be selected in such a way as to allow linkages to be made with as many other Units as possible. This Unit, by using real scientific problems, allows a brief introduction to many aspects of science and engineering which will be covered in greater detail in subsequent parts of the programme. The suggested content is included as a guideline only. However, this is such a basic Unit that failure to cover all aspects may put students at a disadvantage in later parts of the programme. The overall approach should be one of using practical examples from elsewhere in the programme.

This website is a useful general resource for the Unit:

http://www.teachingideas.co.uk/maths/contents02problems.htm

On completion of this Unit students should be able to:

- manipulate and use numerical data in a number of scientific and engineering contexts
- understand and use indices, exponents, scientific notation and logarithms
- rearrange equations
- plot and interpret graphs (including slope and area underneath)
- understand the concepts of significant figures and relate to measured value
- present data in various formats appropriate to end use
- use elementary geometry, trigonometry and algebra

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Numeracy*

Code	Key concepts and storylines developed	Developed by the student being required to:
CI1	Roots of computer science in numeracy: using symbols for quantities	Use elementary algebra and rearrange equations
M1	Exponents and logarithms (including exp and ln)	Understand and use indices, exponents, scientific notation and logarithms
M2	Trigonometry, coordinate geometry	Plot and interpret graphs, carry out elementary surveying tasks and use trigonometry to process the data collected
M6	Key tools from numeracy, algebra, proportion and graphs	Manipulate and use numerical data in a number of scientific and engineering contexts. Understand and use indices, exponents, scientific notation and logarithms. Rearrange equations. Plot and interpret graphs. Understand the concepts of significant figures and relate to precision of measurement. Present data in various formats appropriate to end use. Use elementary geometry, trigonometry and algebra

Links from *Numeracy* to other parts of the programme

This a fundamental Unit with links forward to almost every other Unit. If the Unit is delivered as envisaged, lecturers will select examples from later Units to illustrate the necessity for students to become competent in manipulating numerical data.

Skills development in *Numeracy*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Carry out at least two enquiry-based exercises
S2. Interpersonal communication and team working	✓			• Carry out at least two enquiry-based exercises
S3. Numeracy: assessing and manipulating data and quantity		✓		• Complete the Unit satisfactorily
S4. Critical and logical thinking				
S5. Basic IT skills	✓			• Use symbols to represent quantities
S6. Handling uncertainty and variability	✓			• Calculate experimental errors and estimate the uncertainty of measured values
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis				
S9. Entrepreneurial awareness				

Numeracy: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
SI units	• length • mass • volume • conversions • prefixes • scale and magnitude	This provides an opportunity to introduce the ideas of scale and magnitude by using unit prefixes. Use areas such as electromagnetic radiation, the atom and the solar system. A useful website: **http://physics.nist.gov/cuu/Units/units.html**
Numbers	• decimal places • fractions • ratios • precision, accuracy and significant figures • direct and indirect proportions • percentages and percentage change • interconversion of percentages, fractions and decimal numbers	A recommended approach to this topic would be through the practical use and manipulation of number in various scientific and engineering applications such as using a calculator to determine X^n (bits in a binary integer of length n) $1/X$ (parallel resistors) $\sqrt{X}$ (pendulum) e^X (population growth) $\log_{10}X$ (pH and decibels) $\log_e X$ (bacterial counts vs time) percentage yield (mainly organic synthesis) ratio predictions in Mendelian inheritance This could be supported by practical work in the lab if time permits. There are two enquiry-based exercises which should be used if at all possible to stimulate interest and to encourage the development of team working and organization. These are the sports league fixture programme and the stadium design.

Topic	Suggested content	Teaching notes and materials
	• percentage concentrations (w/w and v/v) • area and volume (calculations, units and notations) • calculator — standard function buttons and use • order of precedence of arithmetic operations	Some useful websites: **http://www.purplemath.com/modules/percents.htm** **http://www.slideshare.net/RyanWatt/math-presentation-3007769** For BODMAS see: **http://mathcentral.uregina.ca/QQ/database/QQ.09.07/h/brit1.html.**
Indices, exponents, scientific notation and logarithms	• definitions • positive and negative interconversion • addition, subtraction, multiplication, division in all forms	This important area is often neglected or not fully explained in the traditional approach through pure mathematics. The meaning and use of these concepts should be more fully understood if introduced by solving problems relating to, for example, dilutions, pH, Avogadro's number, or population growth. Some useful websites: **http://www.purplemath.com/modules/exponent.htm** **http://www.purplemath.com/modules/logs3.htm** **http://www.purplemath.com/modules/exponent3.htm**
Formulae and equations	• simple linear equations • quadratic equations	Real examples should be used with particular emphasis on the practice of using symbols to represent real numbers and the use of equations to represent relationships between quantities. The relationships used could be relatively simple mathematically, such as the gas laws, the equations of motion, $V = IR$, $E = mc^2$. It may also be worth discussing the fact that the relationships represented by equations do not necessarily

Topic	Suggested content	Teaching notes and materials
	• rearranging equations • =, <, >, ≤, ≥	hold under all conditions (eg ideal gases) as this would serve as introduction to the concept of uncertainty, which will be covered at a later stage in the programme. A useful website: **http://plus.maths.org/issue29/features/quadratic/index-gifd.html**
Plotting and interpretation of graphs	• scaling • gradient, intercept and area under graph • linear and non-linear interpretation • rate of change • general shapes of $y = mx$ and $y = x^2$	The practical approaches used here could come from the following areas: Boyle's law Charles's law Ideal gas law $V = IR$ °C to °F conversion mph to km/h conversion rate of reaction activation energy bacterial growth equations of motion (eg V vs $T \rightarrow$ distance) Students should be able plot data suggestive of a linear fit and be able to use the 'x, y' system of Cartesian coordinates. There should be some exercises in calculating and using gradients and areas under graphs to determine related quantities in preparation for later work on calculus. If time permits, practical work could allow students to collect some of their own data. If time is short then experimental data could be supplied to students. A useful website: **http://www.fsmq.org/data//files/amwusareasi-9656.pdf**

Topic	Suggested content	Teaching notes and materials
Presentation of data	• tables • graphs • bar charts • histograms • pie charts • scattergrams	Sets of experimental data should be given to students for presentation using one or more methods. This will provide an opportunity to introduce students to the display options available with Microsoft Excel. Some useful websites: **http://www.qaproject.org/methods/resstattools.html** **http://www.qaproject.org/methods/reshistorgram.html** **http://gsociology.icaap.org/methods/presenting.htm**
Data handling	• mean • meaning of significant figures	The important concept here is the understanding that there may not necessarily be a 'right' answer for a measurement. This can be demonstrated by using data produced by practical work as a class, to illustrate the variations in measured values and then showing that, as more values are added to obtain a mean, the result approaches an ideal value. Measurements could be made as follows: simple titration, height and weight measurements of students, measurement of respiration rates; enzyme activity reaction rates could also be used. Some useful websites: **http://www.bbc.co.uk/schools/gcsebitesize/maths/data/** **http://www.bbc.co.uk/skillswise/numbers/handlingdata/**
Errors and precision	• precision of data collected relating to type of equipment used to collect data and its suitability for purpose (calculations should reflect data reliability)	Students often quote results to many decimal places as a result of calculator use. It should be shown that the number of significant figures is related to the precision of the measuring instrument using simple comparisons between, for example, measurement using a ruler and a micrometer or a measuring cylinder and a burette. This offers a useful opportunity for practical work. A simple approach for calculating errors: eg error = $+/-\sqrt{(a^2 + b^2 + c^2)}$, could be introduced to determine the error in a simple titration.

Topic	Suggested content	Teaching notes and materials
	• errors (random, systematic, relative, absolute) • use of ± to represent absolute error • use of estimation as a guide to accuracy • effect of rounding off in the middle of a calculation	Some useful websites: **http://mtsu32.mtsu.edu:11009/Graphing_Guides/Excel_Guide_Std_Error.htm** **www.radford.edu/~biol-web/stats/standerr_explanation.doc** **http://www.fordhamprep.org/gcurran/sho/sho/lessons/lesson28.htm**
Geometry	• angles and shapes	Use of angles to define basic shapes, eg triangle, square, hexagon, tetrahedron. The importance of angles and shapes within the overall programme should be emphasized with a mention of VSEPR (valence shell electron pair repulsion theory) and molecular shape, isomers, lock and key approach to drug design, and the helical shape of DNA. Some useful websites: **http://www.chemistry-drills.com/VSEPR.php** **http://www2.chemistry.msu.edu/~reusch/VirtTxtJml/intro3.htm** **http://www.bbc.co.uk/schools/ks2bitesize/maths/shape_space/shapes/read1.shtml**
Trigonometric ratios	• sine • cosine • tangent • Pythagoras	The functions sin, tan and cos should be related to the sides of a right-angled triangle and Cartesian coordinates, and be introduced through practical work relating to surveying problems (eg calculating the height of a tree). Mention should be made of the use of trigonometric units to describe periodic functions.

Topic	Suggested content	Teaching notes and materials
		Some useful websites: **http://www.slideshare.net/RyanWatt/math-presentation-3007769** **http://www.gcse.com/maths/trigonometry.htm**
Algebra	• solving for unknowns • equations (simultaneous, linear and quadratic) • factorization • manipulation of fractional expressions and equations	The use of algebra in solving practical scientific problems should be used as the basic approach, with links to other parts of the programme. A particular weakness with the traditional approach is the inability of many students to cross-multiply and rearrange equations. There are a substantial number of equations within the programme which could be introduced here and used as examples with which to work. Simultaneous equations could, for instance, use examples from the method of calculating equilibrium constants from concentrations. Some useful websites: **https://www.bbc.co.uk/schools/ks3bitesize/maths/algebra/** **http://www.gcse.com/maths/algebra.htm** **http://www.gcse.com/maths/factorising.htm** **https://camtools.cam.ac.uk/access/content/group/6041b37a-7fa4-4a47-808b-b20db3a36122/Module%203/Textbook%20pdf_s/3A3printableversion.pdf** **https://camtools.cam.ac.uk/access/content/group/6041b37a-7fa4-4a47-808b-b20db3a36122/Module%203/Textbook%20pdf_s/3A3printableversion.pdf**

Atoms and molecules

Introduction to the Unit

The primary purpose of this Unit is to develop an understanding of atomic and electronic structure and relate this to the properties of the elements and their position in the periodic table, chemical bonding and reactions in solution.

Students should be encouraged to research material for themselves and also to work in groups. A modified problem-based learning approach could be used for most of this Unit.

On completion of this Unit students should be able to:

- relate atomic and electronic structure to the properties of elements
- relate the shapes, bonding and properties of chemical compounds to electronic structure
- understand the factors involved in chemical reactions
- understand the nature of reactions in solution

Approaches to assessment

Assessment could mainly be by satisfactory completion of worksheets, production of laboratory reports and written reports on aspects of bonding, the periodic table and solution chemistry. Worksheets could involve mainly calculations on energy levels in atoms, equations, yields and molarity, the mole, Avogadro's number and pH.

Key concepts/storylines in *Atoms and molecules*

Code	Key concepts and storylines developed	Developed by the student being required to:
C1	The periodic table as a key explainer	Relate chemical properties of elements to their atomic and electronic structure
C2	Understanding bonding and 3D structures of molecules, notably in organic/biological and materials contexts	Relate bonding type and molecular shape to electronic structure and deduce the properties of compounds by bond type
C4	Solution processes, including electrochemistry and reaction equilibrium	Investigate acid-base, redox and other chemical reactions
M6	Key tools from numeracy, algebra, proportion and graphs	Manipulate equations and perform numerical and algebraic tasks

Links from *Atoms and molecules* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Atomic structure: powers of 10 and numerical calculations in energy level calculations Chemical reactions: calculations involving yields, amounts, the mole and Avogadro's number Reactions in solution: calculations on concentration of solutions and pH
Links forward to *Reactivity*	Chemical compounds: work in this Unit is further progressed in *Reactivity*, where bonding theories are advanced, organic reactions discussed and different types of polymers dealt with
Links forward to *Materials*	The introduction to chemical compounds in this Unit is advanced in *Materials* to include alloys, smart materials and further types of polymers
Links forward to *Eukaryotic cells*	Significance of hydrogen bonding in nature and the importance of pH in enzyme activity, chemical structure of lipids, etc
Links forward to *Equations and graphs*	pH plots and bond angles
Links forward to *Radiation*	Interaction of radiation with matter: functional groups in organic chemistry
Links forward to *Statistics*	Laboratory quantitative measurements
Links forward to *Industrial chemical processes*	Enthalpy changes: writing chemical equations Chemical equilibrium: writing acid-base and redox equations
Links forward to *Nanotechnology*	Properties of nanomaterials: Carbon allotropes and hybridization of carbon

Skills development in *Atoms and molecules*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Plan an experiment and carry through all steps successfully
S2. Interpersonal communication and team working	✓			• Work as part of a team on lab and search projects
S3. Numeracy: assessing and manipulating data and quantity		✓		• Collect and process lab data • Calculate energy levels, concentrations of solutions and pH, perform calculations involving equations
S4. Critical and logical thinking	✓			• Design an experiment and analyse results • Draw conclusions from a project
S5. Basic IT skills	✓			• Produce lab reports, search the web for information
S6. Handling uncertainty and variability	✓			• Begin to look at experimental errors and uncertainty of results
S7. Experimentation and prototype construction: design and execution	✓			• Design and perform a lab experiment
S8. Scientific analysis	✓			• Analyse experimental results
S9. Entrepreneurial awareness				

Atoms and molecules: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Atomic and electronic structure	• elements in the periodic table • atomic structure, atomic number, atomic mass and chemical symbols • the periodic table and trends in properties • electronic structure, electron shells and sub shells (n, l and m); Aufbau principle and Hund's rule • basic trends in the periodic table related to electronic structure • use of the periodic table in understanding some physical and chemical properties of the elements, including ionization energy • introduction to energy states and absorption/emission of radiation; flame tests and simple spectra of elements • calculations relating to energy levels and line spectra	A modified problem-based learning approach could be used, with students working alone or in groups. This topic could be approached with **practical work**: flame tests of common elements using appropriate salts such as sodium, potassium, calcium, barium, strontium, copper, etc. Flames could then be looked at using a spectroscope to identify lines. (Examples of spectra could also be obtained from the web.) These experiments could then be used to reason out the electronic structure of the atom, and perhaps the energy levels could be calculated from the spectral lines — although this may be left until a later Unit. The Rainbow Fire in Science Buddies website **http://www.sciencebuddies.org/science-fair-projects/project_ideas/Phys_p058.shtml?fave=no&isb=cmlkOjQwMjY4MTYsc2lkOjEscDoxLGlhOkNoZW0&from=TSW** gives the experiment in project form and asks students to do research to understand a list of terms and concepts. Using Google, various interactive periodic tables can be obtained with a wealth of information. These can be used to discuss trends and properties, with students finding out the information required. Trends in the periodic table are also given in the creative chemistry website **http://creativechemistry.org.uk**

Topic	Suggested content	Teaching notes and materials
		Some useful websites: Interactive periodic table at: **http://chemistry.about.com/library/blperiodictable.htm** **http://cas.sdss.org/DR6/en/proj/advanced/spectraltypes/energylevels.asp** **http://www.colorado.edu/physics/2000/quantumzone/lines2.html**
Chemical compounds: bonding, shape and properties	• bonding (metallic, ionic, covalent including multiple, polar and coordinate bonds) • shapes of molecules (VSEPR) • the periodic table position of constituent elements of simple compounds in relation to the type of bonding (ionic, covalent or metallic) encountered • introduction to hybridization using boron and beryllium compounds, methane, carbon dioxide, ammonia and water • properties and structures of compounds and their dependence on the types of bonding involved • diverse range of structures, their properties and function (ionic crystals, water, solvated ions, metals, macromolecules, polymers, rings & cages, bio-molecules)	A modified problem-based learning approach could be used, with students working alone or in groups. In **practical work**, students could look at various materials such as salt (sodium chloride), a metal, a liquid (bromine), a gas (hydrogen and nitrogen, methane), a simple polymer (polythene), examine their properties and then look at the different types of bonding. They can be asked to reason out the shapes of molecules and relate this to properties. Students can begin to look at polymers and macromolecules, at single and double bonds and the concept of oxidation states. An introduction to VSEPR (valence shell electron pair repulsion theory) should be given and the shapes of some simple molecules deduced. Some useful websites: **http://www.s-cool.co.uk/alevel/chemistry/atomic-structure/the-structure-of-the-atom.html** **http://www.chem4kids.com/files/atom_intro.html**

Topic	Suggested content	Teaching notes and materials
	• names and formulae of the ions and associated compounds • the concept and derivation of oxidation states of the elements when in their common compounds	Problems on formulae can be found at **http://chemistry.about.com/library/weekly/bl041303a.htm** Help in naming compounds can be found at **http://chemistry.about.com/od/nomenclature/a/nomenclature-ionic-compounds.htm**
Chemical reactions	• chemical reactions (balanced equations, conservation of matter, yield of product and scaling up reactions) • the mole, Avogadro's number • types of reaction (precipitation, acid-base and redox)	A modified problem-based learning approach could be used, with students working alone or in groups. **Simple precipitation reactions can be demonstrated** and equations drawn up, as can those of displacement reactions. There are a lot of balancing equations on the web, and there is a good web detective game called 'Monkey Business', which gives clues when equations are correctly balanced, at **http://legacyweb.chemistry.ohio-state.edu/betha/chembal/shihome.html** Another web-based project is the Avogadro's number project, which can be used to develop an idea of scale as well as an appreciation of the mole concept. This is found at **http://www.sciencecases.org/avogadro/avogadro.asp**.
Reactions in solution	• water as a solvent, its polarity, and its ability to solvate molecules and ions • hydrogen bonding and its significance in nature • concepts of electrolytes, acid and bases, hydrogen ion concentration, pH and its measurement	Look at acids and bases **by experiment** — making pH paper using red cabbage, using it to measure pH of different solutions and performing a titration, at **http://chemistry.about.com/od/acidsbase1/a/red-cabbage-ph-indicator.htm** This can be treated as a project, with students finding out about certain key concepts such as acids, bases, logs and pH. Redox reactions could be studied by investigating how a breathalyzer works and then carrying out a titration using potassium dichromate. **An experiment can be set up** for demonstration as shown at:

Topic	Suggested content	Teaching notes and materials
	• acid-base reactions and neutralization • precipitation reactions • redox reactions • concentration of solutions — solubility and molarity • volumetric analysis involving an acid-base titration and a redox reaction	**http://electronics.howstuffworks.com/gadgets/automotive/breathalyzer3.htm** and more details are given at **http://www.practicalchemistry.org/experiments/advanced/redox-reactions/the-breathalyser-reaction,234,EX.html**

Forces, motion, energy

Introduction to the Unit

The primary purpose of this Unit is to develop an understanding of classical Newtonian physics and its extension to motion and energy. The number of links from this Unit to others emphasizes the importance of understanding this central theme. The equations of motion will be used as a means of introducing the basic ideas of calculus and the calculation and measurement of 'change with respect to'. The introduction of the various types of energy will be based on practical applications, such as hill walking, and the relationship between energy and diet (energy balance) will also be discussed. Finally the concepts of energy in living systems and in the biosphere will be introduced in preparation for fuller coverage in subsequent Units.

The suggested content of the Unit is included as a guideline only. Lecturers may choose to concentrate on particular areas of interest to themselves or their students. An enquiry-based learning approach to much of this Unit is recommended, with students investigating in groups of 2-4 and reporting back to the rest of the class. No student is expected to tackle all of the suggested content. It is important that students work on real science or engineering problems that are sufficiently complex to address the Unit's learning outcomes. This Unit provides important understanding of concepts that underpin the work of many other Units.

On completion of this Unit students should be able to:

- understand the significance of Newton's laws and carry out calculations using the equations of motion
- understand the concept of gravity and carry out simple calculations
- carry out calculations relating to potential and kinetic energy and to energy balances
- appreciate the reasons for some bridge failures and how these failures could have been avoided
- resolve vectors
- understand how energy is transferred in living and non-living systems
- understand the physical causes of some weather phenomena

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Forces, motion, energy*

Code	Key concepts and storylines developed	Developed by the student being required to:
E2	Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact	Study the causes of bridge failures
G4	Study involving weather, climate and interplay with the biosphere	Understand the causes of weather phenomena
M3	Vectors in two and three dimensions, components, products	Resolve vectors in two dimensions
M4	Basic introductory calculus	Determine the slope and area under a graph
P2	Study involving radiation (including lasers)	Understand the ways in which energy can be transferred
P5	Study involving spontaneous processes	Carry out calculations involving Newton's laws, the equations of motion and gravity

Links from *Forces, motion, energy* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Equations of motion and calculus (introduction); using graphs to derive the differentials; velocity and acceleration and the integral; displacement
Links forward to *Energy sustainability*	Kinetic energy (KE) and potential energy (PE) to introduce the concept of energy balances. Calculation of the energy required by living organisms
Links forward to *Equations and graphs*	Calculation of vectors
Links forward to *Study of a domestic appliance*	Calculation of the forces involved in rotating the drum of a domestic washing machine
Links forward to *Eukaryotic cells*	Energy conservation and conversion
Links forward to *The universe*	Circular motion, Newtonian mechanics
Links forward to *Calculus*	Calculation of slopes and areas under graphs and derivation of distance, velocity and acceleration. Distance time optimization
Links forward to *Radiation*	Methods of energy transfer
Links forward to *The human organism*	Energy generation and use in living organisms, and from KE and PE to calculate the energy used in the hill walking enquiry-based problem
Links forward to *Investigation of a large infrastructure project* (depending on project selection)	Calculation involving power, acceleration and energy. Possible link to causes of bridge failure
Links forward to *Equations and graphs*	Use of graphical methods to resolve vectors
Links forward to *Earth processes*	Discussion of the physical causes of various weather phenomena
Links forward to *The universe*	Discussion of the physical causes of various weather phenomena

Skills development in *Forces, motion, energy*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Carry out enquiry-based exercises into bridge design and failure
S2. Interpersonal communication and team working	✓			• Carry out enquiry-based exercises into bridge design and failure
S3. Numeracy: assessing and manipulating data and quantity	✓			• Perform calculations involving Newton's laws, the equations of motion and gravity. Resolve vectors. Calculate energy balances
S4. Critical and logical thinking				
S5. Basic IT skills	✓			• Produce reports
S6. Handling uncertainty and variability	✓			• Study bridge disasters
S7. Experimentation and prototype construction: design and execution	✓			• Design bridges
S8. Scientific analysis				
S9. Entrepreneurial awareness				

Forces, motion, energy: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Newton's laws	• inertia • $F = ma = m(dv/dt)$ • action—reaction	As far as possible, students should discover these relationships for themselves through practical work (eg Fletcher's trolley) or simulations. This also gives an opportunity to introduce the basic concept of calculus by showing that: velocity is the rate of change of distance with time acceleration is the rate of change of velocity with time If the practical work includes the production of graphs of say displacement versus time and velocity versus time then the gradients can be calculated and compared with the measured values of velocity and acceleration. The relationships between forces and motion could also be extended to cover, for example, the launching of satellites (escape velocity) and to introduce the calculation of the forces involved in circular motion (required in *Study of a domestic appliance*). Some useful websites: **http://csep10.phys.utk.edu/astr161/lect/history/newton3laws.html** **http://csep10.phys.utk.edu/astr161/lect/history/newton3laws.html** **http://www.physicsclassroom.com/mmedia/kinema/acceln.cfm** **http://www.grc.nasa.gov/WWW/K-12/airplane/newton.html**

Topic	Suggested content	Teaching notes and materials
		http://www.ajdesigner.com/phpnewtonssecondlaw/newtons_second_law_motion_equation_net_force.php
Gravity	• gravitational attraction • $F = G(m_1m_2/r^2)$	This provides an opportunity to discuss magnitude and scale. Also the difference between mass and weight (= mg). Some useful websites: **http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/space/gravityforceandweightrev1.shtml** **http://www.howstuffworks.com/question232.htm** **http://csep10.phys.utk.edu/astr161/lect/history/newtongrav.html**
Equations of motion	• $v = u + at$ • $s = ut + ½at^2$ • $v^2 = u^2 + 2as$ • $a = (v - u)/t$ • $\omega = \omega_0 + at$ • $x(t) = A \cos(2\pi ft + \Phi)$ • Calculus (introduction)	Students should construct graphs from real data and thereafter measure gradient and area. Practical work could consist of series of data-gathering exercises to produce graphs to determine measured values of eg speed, velocity and acceleration. Connect to Newton's laws exercises by reminding students that s vs t: gradient = v v vs t: gradient = a, area = s Some useful websites: **http://www.physicsclassroom.com/mmedia/circmot/ucm.cfm** **http://www.physicsclassroom.com/class/1dkin/u1l4a.cfm** **http://www.physicsclassroom.com/class/1dkin/u1l4a.cfm**

Topic	Suggested content	Teaching notes and materials
		http://www.physicsclassroom.com/class/1dkin/U1L4e.cfm **http://serc.carleton.edu/sp/compadre/interactive/examples/19352.html** **http://www.gcse.com/fm/motion.htm**
KE and PE	• KE = $\frac{1}{2}mv^2$ • $PE_{grav} = mgh$	These equations are probably best explained using hill walking as an example, and the concept of energy balances. A link can be made to the later topic of energy in living systems and to an enquiry-based learning exercise in *The human organism*. Some useful websites: **http://www.physicsclassroom.com/class/energy/u5l1c.cfm** **http://www.physicsclassroom.com/Class/energy/u5l1b.cfm** **http://hyperphysics.phy-astr.gsu.edu/hbase/ke.html** **http://www.gcsescience.com/pen28-kinetic-energy.htm**
Forces in bridges	• tension • compression • shear • torsion • bending • elasticity • Hooke's law • Euler—Bernoulli beam equation • buckling • arch and keystone	This topic provides an opportunity to introduce some engineering concepts and to demonstrate the use of physics in engineering. The approach could be via problem-based learning leading to study of real bridges and bridge disasters, and their causes and solutions. Possible subjects for such work are: Tacoma bridge (resonance) Forth/Tay rail bridges (response to a disaster) Kingston bridge (importance of support stability) Millennium foot bridge (resonance)

Topic	Suggested content	Teaching notes and materials
	• resonance • designing to withstand the forces of wind, tides, ice	Confederation bridge (PEI) (design in a hostile environment) Port Eglinton viaduct (construction while maintaining other services) Practical work could include designing and building bridges using a variety of materials, eg cardboard or balsa wood. Some useful websites: **http://www.garrettsbridges.com/** **http://www.garrettsbridges.com/design/theforces** **http://www.childs-ceng.demon.co.uk/** **http://www.pbs.org/teachers/connect/resources/6431/preview/** **http://www.eng.cam.ac.uk/outreach/CUEDresources/BridgeDesign/index.htm** **http://en.wikipedia.org/wiki/List_of_bridge_failures** **http://www.open2.net/sciencetechnologynature/worldaroundus/forensic_menu.html** **http://taybridgedisaster.co.uk/index/theories** **http://www.time.com/time/photogallery/0,29307,1649646_1421688,00.html** **http://www.youtube.com/watch?v=3mclp9QmCGs** **http://www.youtube.com/watch#!v=17tqXgvCN0E&feature=related** **http://www.youtube.com/watch#!v=Grvr_0K1p4M&feature=related** **http://www.youtube.com/watch#!v=j-zczJXSxnw&feature=related** **http://www.encyclomedia.com/video-tacoma_suspension_bridge_disaster.html**

Topic	Suggested content	Teaching notes and materials
		http://www.forthbridges.org.uk/railbridgemain.htm **http://www.confederationbridge.com/en/design_construction.php**
Vectors and scalars (introduction)	• addition • resolution	This topic may be done graphically at this stage and could be linked to practical work to determine values. Some useful websites: **http://www.physicsclassroom.com/Class/vectors/** **http://www.grc.nasa.gov/WWW/K-12/airplane/vectors.html** **http://www.s-cool.co.uk/alevel/physics/vectors-and-scalars-and-linear-motion/vectors-and-scalars--whats-the-difference-and-vector-addition.html** **http://www.college-cram.com/study/physics/vectors-and-scalars/introduction-to-vectors-and-scalars/** **http://www.physchem.co.za/Vectors/Introduction.htm** **http://www.netcomuk.co.uk/~jenolive/homevec.html**
Energy transfer	• conduction • convection • radiation • electromagnetic spectrum • Stefan's law	This topic serves as an introduction to some of the concepts used in *The universe*. Once the basic ideas of conduction, convection and radiation are understood, it should be relatively straightforward to extend these ideas to include their application to the concept of energy transfer introduced here or under KE and PE in order to serve as a basis for the ideas discussed in *The human organism* and *Industrial chemical processes*.

Topic	Suggested content	Teaching notes and materials
		Some useful websites: **http://www.uwsp.edu/cnr/wcee/keep/Mod1/Rules/EnTransfer.htm** **http://www.powermasters.com/heat_energy.html** **http://www.physics4kids.com/files/thermo_transfer.html** **http://www.bbc.co.uk/schools/gcsebitesize/science/aqa/energy/heatrev1.shtml** **http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html** **http://www.darvill.clara.net/emag/index.htm**
Energy in living organisms	• photosynthesis • respiration • metabolism • energy and nutrition	There are obvious links to *Earth processes and Energy sustainability*, where these topics are covered in greater detail. By discussing them briefly in this Unit it should be possible to make links between energy calculations in engineering and physics and energy calculations in living systems (and exercise, diet and weight gain and loss). Some useful websites: **http://www.ftexploring.com/me/me2.html** **http://en.wikipedia.org/wiki/Adenosine_triphosphate** **http://www.bbc.co.uk/scotland/learning/bitesize/standard/biology/investigating_cells/enzymes_and_aerobic_respiration_rev1.shtml** **http://ds9a.nl/metabolism/** **http://www.weightlossforall.com/nutrition.htm** **http://en.wikipedia.org/wiki/Photosynthesis**

Topic	Suggested content	Teaching notes and materials
Energy and climate	• introduction to causes of wind, rain, hail, snow, lightning, tornado, hurricane	The forces involved in forming and maintaining various meteorological phenomena in the biosphere can be discussed in preparation for more detailed coverage in *Earth processes* and *The universe*. Some useful websites: **http://maths.ucd.ie/~rca/climt/** **http://en.wikipedia.org/wiki/Tornado** **http://www.windows2universe.org/earth/Atmosphere/tornado/formation.html** **http://www.windows2universe.org/earth/Atmosphere/tornado/formation.html&edu=high** **http://www.meteo.physik.uni-muenchen.de/~roger/Publications/PWJUNE06smith.pdf** **http://regentsprep.org/regents/physics/phys03/alightnin/**
Work and power	• definitions and units	These ideas are an extension of those discussed earlier in the Unit and could be introduced in a variety of ways, for example: • the energy to lift a jumbo jet or launch a satellite or • the production of hydroelectricity (linking with *Energy sustainability* and possibly *Investigation of a large infrastructure project*). Possible practical work could be to design, build and test a miniature hydroelectric system. Some useful websites: **http://www.physlink.com/Education/AskExperts/ae158.cfm?CFID=28449843&CFTOKEN=13f2b24db2447d6c-6CF43677-15C5-EE01-B9F57782D4FD495E**

Topic	Suggested content	Teaching notes and materials
		http://www.mathsrevision.net/alevel/pages.php?page=93 http://www.physicsforums.com/showthread.php?t=159679 http://answers.yahoo.com/question/index?qid=20090305131241AAfrsUk http://library.thinkquest.org/17658/hydro/hydphysicsht.html http://www.vuw.ac.nz/scps-demos/demos/Circuits_and_Electromagnetism/HydroelectricGenerator/Hydroelectric.htm
Simple machines	• lever • fulcrum • pulley • gear • wheel and axle	The ideas of a fulcrum, moments, etc can be introduced in the context of artificial limbs, in preparation for *Prosthetics*. Some useful websites: http://www.brianmac.co.uk/levers.htm http://www.tooter4kids.com/Simple_Machines/wheel_and_axle.htm http://www.fi.edu/time/Journey/Time/Escapements/gearint.html
Momentum and impulse	• momentum • impulse	Some useful websites: http://www.physicsclassroom.com/mmedia/momentum/ast.cfm http://www.mathsrevision.net/alevel/pages.php?page=81 http://www.physicsclassroom.com/class/momentum/u4l1b.cfm http://www.lboro.ac.uk/faculty/eng/engtlsc/Eng_Mech/tutorials/tut15_1.htm

Earth processes

Introduction to the Unit

The primary purpose of this Unit is to develop an understanding of the processes and cycles affecting the earth's biosphere.

In this Unit, the sun, fossil fuels and biofuels are reviewed as energy sources, and their impact on the environment is investigated. Human food and energy use is reviewed and calculated. Technological developments in agriculture are reviewed and the sustainability of such methods investigated.

The syllabus is non-prescriptive, and lecturers/students may choose to concentrate on particular areas of interest for each topic. Students should work in groups of 2-4 investigating different topics and then report back to the rest of the class. The Unit offers students the important opportunity to gain experience in thinking about real scientific or engineering problems, which should be complex enough to address most of the learning outcomes by the end of the Unit. It is not expected that students will undertake all of the suggested content. Through this Unit it is expected that students will gain and improve their skills in gathering, assimilating and logically presenting information.

On completion of this Unit students should be able to:

- understand the human impact on the biosphere
- understand how both direct and indirect energy from the sun are used
- appreciate material and energy flows in an ecosystem
- relate human food and energy use in a quantitative manner
- understand the impact of agricultural practices on the environment, in support of the human population
- understand the impact of fossil fuels and biofuels on the environment

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Earth processes*

Code	Key concepts and storylines developed	Developed by the student being required to:
B1	Organization and operation of the cell, and the nature, roles and management of the key chemicals of life	Investigate the conversion of food into chemical energy
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Begin to investigate ecosystems, biodiversity, interdependence and sustainability
C1	The periodic table as a key explainer	Investigate fertilizers and pesticides and the properties of acid rain
C2	Understanding bonding and 3D structures of molecules, notably in organic and biological and materials contexts	Investigate the role of organic and biological molecules in metabolism
C5	Processes involving light absorption/ emission	Investigate the properties of photovoltaic cells
G1	Study involving (human influenced) element cycle and environmental modelling	Investigate element cycles
P1	Applications in electricity and electronics	Begin to investigate n and p type semiconductors
P2	Study involving radiation (including lasers)	Investigate energy from the sun
P3	Study of a wide range of materials properties	Investigate semiconductor materials
P4	Studies of forces, motion and energy	Calculate the energy values of different foods
M6	Key tools from numeracy, algebra, proportion and graphs	Manipulate equations and perform numerical and algebraic tasks

Links from *Earth processes* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Review of human food and energy use: numerical calculations of energy values
Links forward to *Industrial chemical processes*	Use of knowledge of chemistry to investigate the manufacture and properties of fertilizers and some pesticides
Links forward to *Materials* and *Energy sustainability*	Energy from the sun: n and p semiconductors
Links forward to *Eukaryotic cells*	The biosphere and human impact: photosynthesis and respiration
Links forward to *Calculus*	Agriculture in support of the human population: introduction to the idea of calculus when looking at population growth
Links forward to *Industrial chemical processes*	Agriculture in support of the human population: links into aspects of industrial manufacture in the later Unit
Links forward to *Ecosystems*	Flora and fauna and their relationship with different ecosystems and the abiotic factors affecting growth and sustainability
Links forward to *The universe*	The source of the earth's natural phenomena

Skills development in *Earth processes*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Plan an experiment and carry through all steps successfully
S2. Interpersonal communication and team working	✓			• Work as part of a team on lab and search projects
S3. Numeracy: assessing and manipulating data and quantity	✓			• Collect and process lab data • Carry out calculations involving energy changes
S4. Critical and logical thinking	✓			• Design an experiment and analyse results • Draw conclusions from a project
S5. Basic IT skills	✓			• Produce lab reports, searching the web for information
S6. Handling uncertainty and variability	✓			• Look at the uncertainty of population and climate models
S7. Experimentation and prototype construction: design and execution	✓			• Design and perform a lab experiment
S8. Scientific analysis	✓			• Analyse experimental results
S9. Entrepreneurial awareness				

Earth processes: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
The biosphere and human impact	• biosphere (all of life and where it lives) • biogeochemical cycles (chemical cycling in ecosystems) • the carbon cycle, cycling of carbon via photosynthesis and respiration • balance in nature being disrupted due to forest clearing of wood and burning of fossil fuels • global warming • the nitrogen cycle (nitrogen in atmosphere and fixation by bacteria into nitrates which can be assimilated by plants) • human impact (leguminous crops increase nitrogen fixation; nitric oxide from exhaust gases and acid rain) • the water cycle	Using **http://en.wikipedia.org/wiki/Biogeochemical_cycle**, the student can obtain a useful introduction to the different cycles, such as the carbon, nitrogen, water, oxygen and phosphorus cycles, and can draw and annotate the cycles. Man's impact on the cycles should be investigated. **http://chooseclimate.org/jcm/jcm4/** is a good interactive website showing global temperature rise with increase in CO_2 levels. **http://www.atm.ch.cam.ac.uk/tour/** gives information on the hole in the ozone layer.
Energy from the sun	• direct use (brief introduction to solar energy, photovoltaic cells and n and p conductors) • indirect use (photosynthesis and biological energy storage and use) • basics of photosynthesis (role of chloroplasts and chlorophyll)	A number of websites give information on photosynthesis for students: **http://www.ftexploring.com/me/photosyn1.html** (photosynthesis) **http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookPS.html** (good information and diagrams on photosynthesis)

Topic	Suggested content	Teaching notes and materials
	• conversion of carbon dioxide to glucose, and solar energy to chemical energy • moderation of global warming by photosynthesis	**http://www.sp.uconn.edu/~terry/Common/respiration.html** (anaerobic and aerobic respiration including animated diagrams)
Material and energy flows in an ecosystem	• different ecosystems • energy flow in ecosystems (energy pyramids from primary producers to tertiary consumers and decomposers) • food webs • ecosystem energetics and human nutrition	Students should investigate two different types of ecosystem, looking at the energy flow and different consumers and decomposers. A website that provides good charts on energy flow in different ecosystems: **http://www.google.co.uk/images?hl=en&q=energy+flow+in+ecosystems&um=1&ie=UTF-8&source=univ&ei=dmtyTK-GEIP_4AaeytzeCA&sa=X&oi=image_result_group&ct=title&resnum=5&ved=0CDgQsAQwBA&biw=1259&bih=823** A good website with interactive ecology labs, a population simulator and food web challenge: **http://www.learner.org/courses/envsci/unit/text.php?unit=4&secNum=0** Find photosynthesis, respiration and food chains at **http://www.ftexploring.com/me/me2.html** and more on food chains at **http://www.uwsp.edu/cnr/wcee/keep/Mod1/Flow/Introduction.htm** **http://www.ftexploring.com/me/pyramid.html**

Topic	Suggested content	Teaching notes and materials
Quantitative review of human food and energy use	• units of energy for food (kjoule and the calorie) • energy-giving foods (carbohydrates, fats, proteins and alcohol) • energy usage in body and energy used in various activities; what happens to excess energy intake • efficiency of conversion from food energy to chemical energy • ATP and cellular work; structure of ATP, phosphate transfer and the ATP cycle • metabolic pathways of aerobic and anaerobic cellular respiration (brief overview of glycolysis, the citric acid cycle and electron transport, anaerobic pathway to lactic acid)	The structure of the different classes of foods should be examined and typical properties investigated **by experiment**. Food energy can be measured by calorimeter in practical work in the laboratory, and typical values can be found from tables for different products. Notes on food tests can be found at **http://www.biologymad.com/resources/BiochemRevision.pdf.**
Agriculture in support of the human population	• human population growth; factors that cause an increase in growth and factors that inhibit growth • technological developments in agriculture in the last 50 years • fossil energy required in food production • energy cost of food • manufacture of fertilizers and their use • alternatives to use of fossil fuels for manufacture of fertilizers	A useful resource is Chapter 13 'The Energy Cost of Food' in *Sustainable Energy — Without the Hot Air* by David J.C. MacKay (UIT, 2008), available free on the web at **http://www.withouthotair.com/Contents.html** Students should engage in a case study on the use of a pesticide, eg DDT, and its effect on the environment. Find out about insecticides and pesticides at **http://biologymad.com/** Find out about the structure of some pesticides and their

Topic	Suggested content	Teaching notes and materials
	• structure of some pesticides and their effects on the environment • sustainability of intensive farming methods • organic farming as an alternative method (pros and cons)	effect on the environment, bioaccumulation and biomagnifications, and look at the effect of DDT, at **http://www.chemgapedia.de/vsengine/topics/en/vlu/index.html** Students can investigate different aspects of organic farming and debate its advantages and disadvantages.
Fossil fuels and biofuels, impact on element cycles and climate	• fossil fuels (coal, petroleum and natural gas); origin and known reserves; peak oil • use of fuel for producing electricity; carbon dioxide production, greenhouse gases and global warming; trends in carbon dioxide levels; effect on the carbon cycle • methods of reducing emissions using 'clean' coal technology and carbon capture • biofuels (wood, wastes and alcohol); wood burning and CO_2 emissions • production of bioethanol and biodiesel from crops • energy used in production compared to energy in the fuel; conflict in land use for fuel vs food supply • use of biochar as a fuel, for soil enhancement and as a carbon sink	The concept of peak oil is explained at **http://science.howstuffworks.com/peak-oil.htm** 'The Tightening Conflict: Population, Energy Use, and the Ecology of Agriculture' by M. Giampetro and D. Pimentel, can be found at **http://dieoff.org/page69.htm** 'The Post-petroleum Paradigm and Population', by W. Youngquist, is at **http://dieoff.org/page171.htm** 'The Peak of World Oil Production to the Olduvai Gorge', by R. Duncan, is at **http://dieoff.org/page224.htm** Find out about world temperature change, global warming and carbon storage at **http://www.seed.slb.com/content.aspx?id=2314** Students should investigate methods of reducing emissions using 'clean' coal technology and carbon capture. Examples of carbon capture could be the Heimdel field in Norway where natural gas is pumped up and (as the CO_2 tax in Norway is high) CO_2 is pumped down into a deep saline aquifer above the oil layer. In Canada, the Weyburn oilfield uses the waste gas (mainly CO_2) from the production of methane from coal to aid the flow of oil to the surface.

Topic	Suggested content	Teaching notes and materials
		Information on coal gasification can be found at **http://www.fossil.energy.gov/programs/powersystems/gasification/index.html** There is a useful starter article in *Catalyst*, Vol. 20, No. 4, April 2010: 'Carbon Capture' by Sarah Mackintosh. The properties and preparation of biodiesel from rapeseed can be found on the RSC websites given below, where comparison between diesel, biodiesel and petrol burning can be carried out. **http://www.rsc.org/education/teachers/learnnet/green/docs/biodiesel.pdf** **http://www.rsc.org/education/teachers/learnnet/green/index2.htm** **http://science.howstuffworks.com/question638.htm** is a good website which presents a project on price comparisons between solar energy from photovoltaic panels and biomass per acre of ground (units will need to be changed as this is a US site). This site shows how difficult it is to get a real comparison and illustrates the many factors that need to be taken into consideration. Practical work could include an experiment to make biodiesel.

Ecosystems

The primary purpose of this Unit is to develop an understanding of ecosystems and to introduce the ideas of evolution and the interdependence of species.

Introduction to the Unit

The practical approach to this Unit will ensure that all the topics covered will be revisited to a greater depth and level of understanding in later Units.

Discussion of controversial issues (eg creationism versus evolution) should be encouraged and it may be advisable to divide the class into groups to research evidence either favourable or unfavourable to a particular viewpoint. There are other ethical and moral issues which might be included, such as those concerned with biofuels, GM (genetically modified) crops, deforestation, eutrophication and air pollution.

A useful general reference book for this Unit is *Dynamics of Biological Invasions* by R. Hengeveld (Chapman and Hall, 1989).

On completion of this Unit students should be able to:

- distinguish between the different types of soils and list their properties
- describe the different types of flora and fauna (including aquatic)
- understand the different ecosystems, their interdependence and their contributions to biodiversity
- describe the principles of evolutionary theory
- describe the principles of the population growth and use the various models to predict the spread of populations
- understand the spread and control of infections
- carry out a number of practical procedures related to local ecology

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Ecosystems*

Code	Key concepts and storylines developed	Developed by the student being required to:
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Understand the different ecosystems and the flora and fauna they can support, the interdependence of species and the abiotic factors affecting population growth and sustainability. Study the effects of overcropping, eutrophication, pollutant waste management and the sustainability of ecosystems
B5	Adaptation and evolution	Study the work of Mendel, Darwin and Wallace and the relationship between population size and adaptation
G4	Study involving weather, climate and interplay with the biosphere	Relate biodiversity to climate
M4	Basic introductory calculus	Use models for population growth and the spread of infectious diseases

Links from *Ecosystems* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Use of population models and practical ecology exercises
Links back to *Earth processes*	Flora and fauna, their relationship with the different ecosystems and the abiotic factors affecting growth and sustainability
Links forward to *Calculus*	Use of population and infection spread models
Links forward to *Equations and graphs*	Use of population predator/prey and infection spread models
Links forward to *The human organism*	Study of the spread and control of infections
Links forward to *Genetics*	Diversity and variation in populations, evolution and adaptation
Links forward to *The universe*	Meteorology

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Skills development in *Ecosystems*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Carry out at least one enquiry-based exercise
S2. Interpersonal communication and team working	✓			• Carry out at least one enquiry-based exercise
S3. Numeracy: assessing and manipulating data and quantity	✓			• Use population growth and infection spread models and perform practical ecology exercises
S4. Critical and logical thinking				
S5. Basic IT skills				
S6. Handling uncertainty and variability	✓			• Perform practical ecology exercises
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis				
S9. Entrepreneurial awareness				

Ecosystems: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Soil	• soil types • nature and properties of soil types	Types of soils might include loams, clays, silts, sands and organic soils. Properties of soils might include formation, structure, water-holding capacity, pH, chemistry, fertility, crop rotation, role and dangers of fertilizers. Some useful websites: **http://www.ace.mmu.ac.uk/eae/acid_rain/older/Soils.html** **http://soils.tfrec.wsu.edu/mg/physical.htm** **http://greennature.com/article21.html**
Vegetation	• trees • grasses • berries • plant physiology • growth • uses of vegetation • composting • food sources • dispersal of seeds etc • biofuels • GM crops • deforestation • ethics • commerce and the environment	Plant physiology could include photosynthesis, respiration and water uptake. This topic allows for the introduction of a number of ethical and moral issues including deforestation and climate change, GM crops versus the food supply, and use of food as a biofuel. Some useful websites: **http://www.botgard.ucla.edu/html/botanytextbooks/worldvegetation/index.html** **http://en.wikipedia.org/wiki/Vegetation** **http://en.wikipedia.org/wiki/Plant_physiology** **http://en.wikipedia.org/wiki/Decomposer** **http://compost.css.cornell.edu/invertebrates.html** **http://www.educypedia.be/education/plantbiology.htm** **http://www.foe.co.uk/resource/briefings/gm_crops_food.pdf** **http://www.guardian.co.uk/commentisfree/cif-green/2010/apr/21/gm-crops-benefit-farmers**

Topic	Suggested content	Teaching notes and materials
		http://www.biofuels.co.uk/ http://en.wikipedia.org/wiki/Biofuel http://environment.nationalgeographic.com/environment/global-warming/deforestation-overview.html http://www.independent.co.uk/environment/climate-change/deforestation-the-hidden-cause-of-global-warming-448734.html
Animals and aquatic fauna	• diversity and variation in population • competition for resources • food webs • pests and diseases; chemical and biological control	The relationship between fauna diversity and ecosystems could be discussed. The interdependence of fauna (and flora), particularly in terms of nutrition, should also be considered. Some useful websites: http://www.vtaide.com/png/foodchains.htm http://www.sciencebob.com/questions/q-food_chain_web.php# http://animaldiversity.ummz.umich.edu/site/index.html http://www.marietta.edu/~biol/introlab/animaldiv1.pdf http://en.wikipedia.org/wiki/Aquatic_animal http://en.wikipedia.org/wiki/Marine_biology http://www.gardenorganic.org.uk/pdfs/international_programme/PestDisease.pdf http://www.appropedia.org/Pests_and_disease_control http://arjournals.annualreviews.org/doi/pdf/10.1146/annurev.py.31.090193.002155
Ecosystems	• ecosystems • biomes	Types of ecosystems might include temperate and tropical forests, grasslands, desert, tundra and marine ecosystems.

Topic	Suggested content	Teaching notes and materials
	• types of ecosystems • biodiversity • balance by natural phenomena such as fire, disease and the number of predators • effects of species transfer • unique biome of Australia and New Zealand • biosecurity • human impact on carbon, nitrogen, water cycles and food chain • overcropping • overfishing; eutrophication • pollution and waste management; human population • sustainability of the ecosystems	Interdependence of systems could include distribution of seeds by animals and birds, and the use of animal waste as a fertilizer. Biodiversity might include a discussion of abiotic factors present in an ecosystem (eg temperature, light, wind and water availability, soil, altitude, aspect and inclination) and the effect on organisms. Some useful websites: **http://library.thinkquest.org/11353/ecosystems.htm** **http://www.teachingonline.org/march07pdfs/Biosecurity.pdf** **http://www.coursework.info/AS_and_A_Level/Biology/Energy__Respiration___the_Environment/How_Abiotic_Factors_Present_In_an_Ecosys_L5801.html#ixzz0Z0CL9bA9** **http://www.unfpa.org/6billion/populationissues/development.htm** **http://www.water-pollution.org.uk/eutrophication.html** **http://www.eoearth.org/article/Eutrophication** **http://www.isse.ucar.edu/esp/espweb4.html** **http://www.docstoc.com/docs/22961572/The-Sustainability-of-Ecosystems**
Evolution	• Darwin • Wallace • Mendel • voyage of *The Beagle*	The gradual development of Darwin's theory of evolution from his early observations in the Galapagos to the publishing of *The Origin of Species* some 30 years later should be described. The reasons for Darwin's reluctance to publish until forced to do so by Wallace's independent observations and conclusions would provide a basis for a class debate. The role of accurate, detailed

Topic	Suggested content	Teaching notes and materials
	• Galapagos finches • natural selection (large populations) • genetic drift (small populations); adaptability • DNA mutation • effects of continental drift • *Homo sapiens* and *Homo Neanderthalensis* • placental and marsupial mammals • use of DNA analysis • migration of humans and spread of ideas and technology • evolutionary fitness • effects of climate change • effects of natural disasters (volcanoes, large meteorites)	observation in the development of scientific theories by Mendel, Darwin and Wallace should be emphasized. Draw attention to the fact that none of them knew about DNA mutations and so had no scientific mechanism for the changes that occurred. Some useful websites: **http://en.wikipedia.org/wiki/Evolution** **http://en.wikipedia.org/wiki/Creation%E2%80%93evolution_controversy** **http://www.allaboutcreation.org/creation-vs-evolution-n.htm** **http://www.youtube.com/watch?v=uz7U4k522Pg** **http://www.youtube.com/watch?v=6OPJnO9W_rQ** **http://www.slideshare.net/AutoSurfRestarter/the-descent-of-man-penguin-classics-by-charles-darwin** **http://www.slideshare.net/AutoSurfRestarter/the-voyage-of-the-beagle-charles-darwins-journal-of-researches-penguin-classics-by-charles-darwin** **http://en.wikipedia.org/wiki/Evolution** **http://www.cardiff.ac.uk/insrv/libraries/scolar/digital/insrv-scolar-darwin.html** **http://www.archaeologyinfo.com/homoneaderthalensis.htm** **http://humanorigins.si.edu/evidence/human-fossils/species/homo-neanderthalensis** **http://www.life.umd.edu/classroom/bsci338m/Lectures/Dichotomy.html** **http://txtwriter.com/Backgrounders/Evolution/EVpage14.html** **http://www.allaboutcreation.org/dna-evidence-for-evolution-faq.htm** **http://news.bbc.co.uk/1/hi/8550504.stm**

Topic	Suggested content	Teaching notes and materials
Classification of organisms	• need for classification • relationships between organisms • impact of man	Students need to understand the way in which organisms are classified and the need for classification. This leads on to the relationship between, and interdependence of, organisms in a specific environment and to further consideration of the impact of man on his environment. The links below provide a wealth of resources for an enquiry-based exercise covering these topics. Some useful websites: **http://www.slideshare.net/tregreer/organisms-to-ecosystems-assignment-1901046** **http://www.slideshare.net/tregreer/organisms-to-ecosystems-scheme-of-work**
Population growth	• introduction and spread of red deer and thar (New Zealand) • human spread • modelling population growth • exponential growth	The introduction of new species can quite easily affect the existing balance between hunter and hunted. There are plenty of examples of this, eg the introduction of sheep to Australia or the elimination of rats from Ailsa Craig. The use of models provides an opportunity to illustrate the application of calculus in a practical situation (effect and calculation of constant or variable growth rates). Some useful websites: **http://www.zoo.cam.ac.uk/zoostaff/larg/pages/RumPapers/Hone&Clutton-Brock%2007%20JAE.pdf** **http://www.biodiversity.govt.nz/land/nzbs/pests/thar.html** **http://en.wikipedia.org/wiki/Population_growth** **http://members.optusnet.com.au/exponentialist/Growth_Models.htm**

Topic	Suggested content	Teaching notes and materials
Infections	• cholera (London) • measles (Iceland) • increasing risk with travel and larger cities • role of Center for Disease Control (CDC) • flu epidemics • mathematical modelling of the spread of an infectious disease • population control and overcrowding	Use practical examples (not necessarily those listed, eg something topical such as Swine flu) to discuss the spread and control of infections. The US-based CDC plays a worldwide role in the latter respect, and a study of their operations may provide a 'key' to motivate students. Some useful websites: **http://www.victorianweb.org/science/health/health10.html** **http://bmb.oxfordjournals.org/cgi/reprint/69/1/87** **http://en.wikipedia.org/wiki/Mathematical_modelling_of_infectious_disease** **http://staffweb.cms.gre.ac.uk/~st40/Books/MathematicalModelling** **http://www.mtholyoke.edu/courses/jmorrow/math_models.html** **http://arjournals.annualreviews.org/doi/pdf/10.1146/annurev.publhealth.25.102802.124353** **http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1574284/**
Practical work on ecosystems	• analysis of soil samples • population surveys; variation and growth • air analysis, eg CO_2, CH_4, ICE exhausts • water analysis along the course of a river, eg heavy metals, fertilizers, microbial • rural versus urban results	Students can be given the opportunity to undertake some practical work, which might include a field trip. A range of problems may be chosen for enquiry-based exercises to reflect the interests of students and tutors. Students should carry out at least one enquiry-based exercise to improve their interpersonal and presentation skills.

Topic	Suggested content	Teaching notes and materials
		Some useful websites: **http://hse.niordc.ir/uploads%5C86_106_Binder1.pdf** **http://webcache.googleusercontent.com/search?q=cache:6x5tXI65Z6AJ:plantphys.info/plant_biology/labdoc/fall.field.trip.doc+ecol.ogy+field+trips&cd=1&hl=en&ct=clnk&gl=uk** **http://www.airquality.co.uk/what_causes.php** **http://www.waterencyclopedia.com/Ce-Cr/Chemical-Analysis-of-Water.html** **http://www.ehow.com/about_6521266_river-water-analysis.html**

Energy sustainability

In this Unit students investigate trends in global energy use and ways in which future demand can be met in addition to looking at ways to help reduce demand.

Energy use in the home, in transport and in industry is investigated, as are methods of energy production. An investigation of an ethical issue related to energy generation and use is also undertaken.

Introduction to the Unit

It is envisaged that the bulk of the work of this Unit will be enquiry-based and that students will work individually and in groups on projects related to the different topics. Students will investigate trends in global energy use and ways in which future demand can be met, in addition to looking at ways to help reduce demand. Energy use in the home, in transport and in industry can be investigated as well as methods of energy production. An investigation of an ethical issue related to energy generation and use is also proposed.

A very useful and readable resource is a book entitled *Sustainable Energy — Without the Hot Air* by David J.C. MacKay (UIT, 2008), available free on the web at **http://www.withouthotair.com/Contents.html**. This book gives a good review of energy resources and uses, and puts numbers to the facts.

A good website is the PEEP (Physics and Ethics Education Project) site at **http://www.peep.ac.uk/content/1113.0.html**. This site deals with ethical issues and also gives a useful introduction to the whole Unit. It addresses climate change, transport and energy resources, giving general details but limited technical information, which can be found elsewhere.

On completion of this Unit students should be able to:

- investigate global energy use and trends
- review energy use in the home
- review methods of energy production
- investigate energy use in transport
- investigate an application of energy use in industry
- investigate an ethical issue related to energy use or energy production

Approaches to assessment

Assessment of this Unit will be by completion of reports and by a presentation on an ethical issue. Worksheets involving calculations can also contribute to assessment for this Unit.

Key concepts/storylines in *Energy sustainability*

Code	Key concepts and storylines developed	Developed by the student being required to:
C1	The periodic table as a key explainer	Relate the properties of compounds to the elements they contain
C3	Reactions, including mechanisms and yields	Relate bond energy of a compound to the amount of energy produced
C4	Solution processes, including electrochemistry and reaction equilibrium	Research the manufacture of aluminium by an electrolytic process
G1	Study involving (human influenced) element cycle and environmental modelling	Relate global warming to carbon dioxide emissions
M6	Key tools from numeracy, algebra, proportion and graphs	Collect and process lab data, calculate bond energies from combustion data and perform nuclear energy calculations
P1	Applications in electricity and electronics	Develop an understanding of semiconductors
P2	Study involving radiation (including lasers)	Study the effect of solar power
P3	Study of a wide range of materials properties	Study the composition of solar cells, lithium batteries and catalysts
P4	Studies of forces, motion and energy	Calculate the power generated in fission and fusion and the energy produced on combustion
P5	Study involving spontaneous processes	Study fission and fusion
P6	Study involving non-classical physics	Study fission and fusion

Links from *Energy sustainability* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Calculations involving latent heat Calculations involving Hess's law, bond energies Calculations of binding energy and energy released on fission and fusion, calculation of power of wind turbine Constructing and reading graphical information and using spreadsheets
Links back to *Earth processes*	Global warming and energy conservation
Links back to *Forces, motion, energy*	KE and PE to introduce the concept of energy balance. Calculation of energy required by living organisms
Links forward to *Electricity*	Units of energy and power, and calculation of efficiency of different electrical appliances Electrochemical energy from batteries
Links forward to *Materials*	Work on semiconductors will be further progressed in *Materials*
Links forward to *Calculus*	Radioactivity and fission: rate of decay
Links forward to *Radiation*	The electromagnetic spectrum: nature and properties of gamma radiation
Links forward to *Industrial chemical processes*	Enthalpy changes and Hess's law
Links forward to *Investigation of a large infrastructure project*	Methods of energy production, including hydroelectric
Links forward to *Study of a domestic appliance*	Calculation of energy usage
Links forward to *The human organism*	Exercise, diet, energy balance calculations

Skills development in *Energy sustainability*

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Plan an experiment and carry through all steps successfully
S2. Interpersonal communication and team working		✓		• Work as part of a team on lab and search projects
S3. Numeracy: assessing and manipulating data and quantity		✓		• Collect and process lab data, calculate bond energies, combustion data and nuclear energy calculations
S4. Critical and logical thinking		✓		• Prepare and argue a case on an ethical issue
S5. Basic IT skills		✓		• Produce lab reports, search the web for information
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution		✓		• Design and perform a lab experiment
S8. Scientific analysis		✓		• Analyse experimental results
S9. Entrepreneurial awareness				

Energy sustainability: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Global energy use and trends	• current energy use (UK and globally) • reliance on fossil fuels • brief survey of energy use for heating/cooling, transport, powering devices and for industry • future demand and the need for energy balance • the need for other energy sources to meet demand and to reduce carbon dioxide levels • energy conservation to help reduce demand	This topic acts as an introduction to the Unit, and students should work in groups interpreting graphs and charts on current and future energy use. PEEP (Physics and Ethics Education Project) has a good activity called 'Energy use across the world' at **http://www.peep.ac.uk/content/960.0.html** Students could also find the UK facts from other sources. Students can investigate what is meant by 'peak oil' and the need for alternative energy resources and energy conservation. There is relevant information on the PEEP website and also in *Sustainable Energy — Without the Hot Air* by David J.C. MacKay (UIT, 2008), available free on the web at **http://www.withouthotair.com/Contents.html.** A good chart on global annual energy use is available at **http://environment.newscientist.com/data/images/archive/2515/25151501.jpg** There is an energy calculator at **http://2050-calculator-tool.decc.gov.uk/** which enables future demand and emissions to be predicted; this could form the basis of a project on trends.

Topic	Suggested content	Teaching notes and materials
Energy in the home	• units of energy and power (revision) • what we use energy for (heating/cooling, lighting and gadgets) • average consumption per household • heating systems (coal, gas, oil, electricity) • energy efficiency in the home	A very useful resource for this topic *is Sustainable Energy — Without the Hot Air* by David J.C. MacKay (UIT, 2008), available free on the web at **http://www.withouthotair.com/Contents.html** Students should work in small groups to investigate some simple household items. For example, students could start with practical work by determining by experiment the efficiency of a kettle, and perform the necessary calculations to compare the efficiency of different types of light bulbs: conventional, compact fluorescent (CFL) and light-emitting diode (LED). Some calculations are given at **http://www.techmind.org/energy/calcs.html**. Other possibilities include a comparison of the use of a microwave or electric oven to cook; the cost effectiveness of taking a bath compared with taking a shower; calculating the energy saved by switching off the computer and not having the TV on standby. The class could collectively identify where power is consumed in the home and estimate an average consumption per household, looking at heating, cooking, lighting, freezers, gadgets, etc to arrive at the average power consumption per household. A group could look at which type of heating system is most efficient, eg compare the price of coal, gas and oil. Others could calculate heat losses through walls, windows and roof of a typical house. They could then calculate the impact of double glazing, loft insulation and cavity wall insulation on fuel bills.

Topic	Suggested content	Teaching notes and materials
		Another group could investigate how a refrigerator or freezer works, and look at possible coolants. An interactive teaching unit for schools is available and also a Chemcases guide on refrigerants at **http://www.chemcases.com/**
Methods of energy production	• non-renewable energy sources (oil, gas and coal; origin, known reserves and how long they will last; process of combustion, heats of reaction and heats of combustion of different fuels; bond energies and Hess's law; how a coal-fired power station works, including reactor, heat transfer to turbines, transformers and the grid; how coal-fired stations can reduce emissions — carbon capture and storage, coal gasification to generate hydrogen) • nuclear energy (fission process, mass defect, binding energy, critical mass and energy generated; fusion and energy generated from it; problems with fusion reaction; Magnox or AGRs (advanced gas-cooled reactors) compared with PWRs (pressurized water reactors); radioactive waste; generating costs per unit from coal, gas and nuclear reactors; advantages and disadvantages of nuclear reactors)	Students should investigate non-renewable methods of power generation and then select two methods from renewable sources which they can study in more depth. Students should look at different sets of combustion data, to identify those which will give most energy, and then look at bond energies and Hess's law, doing calculations using bond energies, and enthalpies of formation and combustion. Students could draw a flow diagram of a fossil power plant and explain how each part operates. A possible web reference is **http://en.wikipedia.org/wiki/Fossil_fuel_power_plant**. Examples of ways of reducing emissions should be discovered, including efficiency of process and if possible an estimate of cost. A starter website is **http://news.bbc.co.uk/1/hi/sci/tech/4468076.stm**. There is a student project on nuclear fission and PWR reactors at **http://library.thinkquest.org/17940/texts/fission/fission.html**. Nuclear waste is also discussed on this site. Some other useful websites: **http://www.tva.gov/power/pdf/nuclear.pdf** (PWR) **http://science.howstuffworks.com/nuclear-power.htm** (nuclear power) **http://science.howstuffworks.com/framed.htm?parent=nuclear-power.htm&url=http://www.ida.liu.se/%7Eher/npp/demo.html** (nuclear plant simulation game)

Topic	Suggested content	Teaching notes and materials
	• renewable sources of energy (use of solar power to heat buildings or water directly, photovoltaic generation, CSP (concentrated solar power) using parabolic mirror and receiving device, heat conversion to electricity and its transmission, energy storage using liquids or molten salts; latent heats of fusion and their calculations, use of power for desalination by reverse osmosis, hydrogen production, photovoltaics, p—n conductors, silicon lattice, doping, the photovoltaic effect, band gaps and efficiency; solar cell arrays, series and parallel; design of a wind turbine; dependence of power generated on blade diameter and wind velocity; shape and optimum number of blades and pitch; the efficiency factor; control in strong winds; siting of wind turbines; energy and costs)	A good introduction to renewable energy is at **http://www.berr.gov.uk/files/file23329.pdf** and **http://en.wikipedia.org/wiki/Desertec**. Through practical work students can learn about solar power by experiment using the Science Enhancement Programme (SEP) material at the website given below and also identify suitable sites for solar panels. There are several examples for a project-based approach at **http://www.berr.gov.uk/files/file23349.pdf** The Desertec project in the Sahara is interesting. Some useful websites for this are: **http://www.desertec.org/en/concept/faq/** (mirrors in the Sahara) **http://www.greenpeace.org/raw/content/international/press/reports/concentrating-solar-power-2009.pdf** (solar power) **http://en.wikipedia.org/wiki/Desertec** (solar energy plant in Sahara desert) **http://en.wikipedia.org/wiki/File:Solar_land_area.png** (sun's energy distribution in the world) **http://www.scolar.org.uk/html/pdf/stu-pdf/advanced.pdf** (how solar power works, with examples) The booklet *Solar Power: Energy from the Sun* can be obtained from the SEP website at **http://www.sep.org.uk/** and has experiments and spreadsheets for data on solar radiation variation with latitude and time of day. The website has a lot of information and experiments on wind turbines. It also has a spreadsheet which enables turbine costs to be calculated. (You may need to join as an associate member, which is free, before you can access this material.)

Topic	Suggested content	Teaching notes and materials
		Wind power can be investigated by looking at the best location for a wind farm, calculating power that can be generated, and construction and running costs. Material is available on the SEP website at **http://www.sep.org.uk/** **http://www.berr.gov.uk/windspeed-database/page27326.html** maps the wind speed for different locations in the UK. There is information on Whitelee wind farm at **http://whiteleewindfarm.co.uk/about/wind_power/statistics** and **http://www.whiteleewindfarm.co.uk/** For calculations on power generated using wind, look at **http://www.reuk.co.uk/Calculation-of-Wind-Power.htm** **http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/explained/wind/windsp_databas/windsp_databas.aspx** gives a wind speed database for the UK **http://www.vu.union.edu/~sustain/resources/lectures/wind.ppt** gives a PowerPoint presentation on wind power generation
Energy use in transport	• CO_2 emission and how this can be reduced in cars • dual-fuel cars (Honda and Toyota) (revision of how batteries work) • rechargeable batteries, the lithium ion battery • use of lanthanides in batteries and cars, problems of sourcing	Students should research two alternative methods of car propulsion apart from petrol/diesel fuel, such as electrical from batteries and the use of hydrogen. They should compare these to conventional methods. Some useful websites: **http://auto.howstuffworks.com/fuel-efficiency/hybrid-technology/history-of-hybrid-cars.htm** (hybrid cars)

Topic	Suggested content	Teaching notes and materials
	• hydrogen cars (hydrogen fuel cell, polymer exchange membrane (PEM), catalyst and platinum nanoparticles) • energy produced in reaction and compared with other fuels • source of hydrogen, either electrolysis of water or from natural gas (does this defeat the purpose?); storage and distribution of hydrogen • emissions from planes in comparison to car emissions (per person per km)	**http://www.molycorp.com/pdf/RARE%20EARTHS%20IN%20SELECTED%20U%20S%20%20DEFENSE%20APPLICATIONS.pdf** (use of rare earths as catalysts) **http://www.molycorp.com/other_applications.asp** (uses of rare earths) **http://www.molycorp.com/hybrid_ev.asp** (hybrid electric vehicles) **http://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/fuel-cell.htm** (fuel cells) Typical emission figures for two types of aircraft should be found and compared with car emissions.
Energy use in industry	• power requirements in the manufacturing process and how these can be reduced, eg extracting aluminium from its ores • the electrolysis process and amount of electricity required to produce aluminium • use of hydroelectric and other power in smelting • siting of aluminium factory	Aluminium has been chosen as an example as it uses a large amount of power to produce, but other manufactured products or materials can be selected.
Ethical issues	Preparing a case with others and taking part in a debate on, eg:	There are many ethical issues in this Unit and only one needs to be selected.

Topic	Suggested content	Teaching notes and materials
	• fossil fuels and global warming • siting of wind turbines, nuclear power stations etc. • use of nuclear power and production of radioactive waste • clean coal technology, will it work and what is the cost?	A suitable issue should be chosen and groups should gather facts and figures and produce a presentation to peers. The class should debate the issue and come to a conclusion. The PEEP (Physics and Ethics Education Project) site at **http://www.peep.ac.uk/content/1113.0.html** deals with ethical issues and gives information on climate change, transport and energy resources.

Reactivity

The primary purpose of this Unit is to develop the student's understanding of the role of molecular interaction as the driving force for chemical reactions to occur.

Introduction to the Unit

The concept of interatomic forces arising particularly from electronegativity differences (and periodic table location) is developed, along with electron—electron repulsion theory, to account for active areas in a molecule and for molecular shape. These ideas lead on to isomerism and hybridization and to further discussion of the properties of individual homologous series.

IUPAC (International Union of Pure and Applied Chemistry) nomenclature should not be taught as a formal discipline (although an introductory short outline of the underlying principles may be necessary) but it can be introduced naturally as and when required. If lecturers feel uneasy with this approach then students may be issued with naming exercises to complete in their own time. The later part of the Unit applies the skills and understanding developed earlier to a study of molecules of biological importance. Finally students are asked to carry out a case study of drug design and development.

The suggested content is included as a guideline only. Lecturers may choose to concentrate on particular areas of interest to themselves or their students. Students should work in groups of 2-4 investigating different topics and reporting back to the rest of the class. Students should gain experience in scientific or engineering enquiry relating to real problems, which need not be those suggested. It is envisaged that individual students will undertake different tasks and that no student is expected to tackle all the topics in the suggested content.

Project-based teaching and learning gives excellent results in terms of transferable skills and allows students to gain experience in facing the problems encountered by practising engineers

and scientists. The general approach should be to aim to trigger students' interest and thereby increase their motivation. The notes for each topic indicate some tasks that students may undertake to assist them in their research.

The following websites have material that is generally useful for this Unit:

http://findarticles.com/p/articles/mi_hb3325/is_1_6/ai_n28914605/?tag=content;col1
http://www.btinternet.com/~chemistry.diagrams/index.htm
http://www.springerlink.com/content/xp5111051046tx30/fulltext.pdf
http://pubs.acs.org/doi/pdfplus/10.1021/ed081p1083
http://www2.ups.edu/faculty/hanson/chemwebsites/organicwebsites.htm
http://docbrown.info

On completion of this Unit students should be able to:

- use the periodic table to predict molecular shapes and to predict the forces between atoms and thus forecast the reactivity of different molecules
- describe multiple bonding from a valence bond (VB) and a molecular orbital (MO) viewpoint
- describe simple reaction mechanisms
- use the IUPAC naming system
- understand the principles and processes of drug design

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Reactivity*

Code	Key concepts and storylines developed	Developed by the student being required to:
C1	The periodic table as a key explainer	Relate the strength of phenomena to the position of atoms in the periodic table. Use the principles of VSEPR (valence shell electron pair repulsion) theory. Use IUPAC rules
C2	Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts	Use the principles of VSEPR theory. Understand the theory of multiple bonding from a VB (valence bond) and MO (molecular orbital) viewpoint. Appreciate the 'lock and key' approach to drug design, and the importance of the link between shape and function in biological molecules
C3	Reactions, including mechanisms and yields	Develop an understanding of the driving force behind reactions and of the SN1, SN2, E1 and E2 mechanisms

Links from *Reactivity* to other parts of the programme

Links to other Units	Topics involved
Links back to *Atoms and molecules*	Bonding theories, organic reactions and their mechanisms, polymers
Links forward to *Materials*	Condensation and addition polymerization
Links forward to *Industrial chemical processes*	Reaction mechanisms, polymerization
Links forward to *Genetics*	The biological molecules carbohydrates, lipids (eg triglyceride), proteins, nucleic acids, amino acids, DNA, RNA, mRNA, tRNA

Skills development in *Reactivity*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Carry out an enquiry-based exercise into drug design
S2. Interpersonal communication and team working				
S3. Numeracy: assessing and manipulating data and quantity				
S4. Critical and logical thinking				
S5. Basic IT skills				
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis	✓			• Carry out an enquiry-based exercise into drug design
S9. Entrepreneurial awareness	✓			• Carry out an enquiry-based exercise into drug design

Reactivity: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Structure and bonding	• VSEPR (carbon) • tetrahedral shape • sp^3 hybridization • multiple bonds: shape, sp^2, sp. σ,π bonds • molecular orbitals • electrometric effects, reactive sites • nucleophiles • electrophiles • addition • elimination • substitution • bond breaking, C^+ and C^-, use in synthesis • organometallics • simple mechanisms • IUPAC names (as necessary) • relate to properties and reactions, functional groups • H bonding	The physical cause of the electronic effects should be linked to their relative magnitude according to the position of atoms in the periodic table. It is recommended that the homologous series are not approached in the traditional functional group by functional group method, but that particular functional groups are discussed as the need arises. This may have the effect that not all groups are covered formally but if students understand the reasons for the variations in group properties then they will have acquired the skills to work out the properties of any new group that they encounter. This part of the Unit could be delivered using practical work in the laboratory to discover properties, followed by group research to ascertain the reasons for the results obtained. Examples throughout could be limited to the reactions of alkyl halides, alkenes, alkanals, alkanones, aromatics, together with the necessary IUPAC names, which should be introduced as the need arises. Simple mechanisms should go no further than nucleophilic (SN1, 2) and elimination (E1, 2), and the use of the many websites illustrating these in graphical format is recommended. This will lead to polymerization (addition and condensation). Some useful websites: **http://www.chem.purdue.edu/gchelp/vsepr/** **http://www.meta-synthesis.com/webbook/45_vsepr/VSEPR.html** **http://chemlabs.uoregon.edu/GeneralResources/models/vsepr.html** **http://ibchem.com/IB/ibnotes/full/bon_htm/14.2.htm**

Topic	Suggested content	Teaching notes and materials
		http://answers.yahoo.com/question/index?qid=20100127094726AAGrbFz http://www.everyscience.com/Chemistry/Organic/Electronic_and_Steric_Effects/a.1162.php http://www.everyscience.com/Chemistry/Organic/Electronic_and_Steric_Effects/b.1163.php http://www.youtube.com/watch?v=bH6k1-nihGo http://www.youtube.com/watch#!v=zx-GNRpH8gU&feature=related http://www.goiit.com/posts/show/813828/fundamentals-of-organic-chemistry--inductive-effect-804381.htm http://www.chemicalforums.com/index.php?topic=36705.0 http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Questions/problems/indexam.htm http://evans.harvard.edu/cgi-bin/problems/search2b_advancedSearch.cgi http://www.organicchemistryreview.com/ALKENENOTECARDS.html http://chemistry.boisestate.edu/people/richardbanks/organic/organicchem.html http://www.ch.ic.ac.uk/local/organic/tutorial/ http://chemistry.about.com/library/weekly/bl052503a.htm http://www.youtube.com/watch#!v=4ucNtWtWu8M&feature=related http://www.chemguide.co.uk/mechanisms/eladdmenu.html http://www.elmhurst.edu/~chm/vchembook/161Ahydrogenbond.html http://www.chemguide.co.uk/atoms/bonding/hbond.html

Topic	Suggested content	Teaching notes and materials
Isomerism	• structural isomers • chain isomers • positional isomers • geometric isomers • optical isomers • conformational analysis and energy	Use models to build up and also derive the IUPAC names of all the possibilities (*cis* and *trans*, E and Z, and R and S). Optical isomerism should include a discussion of the chiral carbon and its importance in naturally occurring molecules. Cite the thalidomide disaster as an example of the serious impact of confusing isomers. Conformational analysis should include a discussion of the energies and conformations of straight-chain (eg halogen substituted) and cyclic (eg cyclohexane) compounds. Some useful websites: **http://www.chemguide.co.uk/basicorg/isomerism/structural.html** **http://www.creative-chemistry.org.uk/molecules/isomers.htm** **http://www.avogadro.co.uk/organic/isomer.htm** **http://www.chm.bris.ac.uk/motm/thalidomide/optical2iso.html**
Molecules of biological importance	• polymerization • structure and properties of important molecules • functional groups in monomer units • polymeric nature of biological macromolecules • multiple polymeric structures from a limited number of monomers • 3D structures	Using models, the students should build these biological molecules, identify the functional groups and their functions. Shape and folding should also be considered. Molecules discussed should include carbohydrates, lipids (eg triglyceride), proteins, nucleic acids, DNA, RNA, mRNA, tRNA. Some useful websites: **http://en.wikipedia.org/wiki/Polymer_chemistry** **http://www.gcsescience.com/o56.htm** **http://www.s-cool.co.uk/gcse/chemistry/products-from-crude-oil/polymerisation.html**

Topic	Suggested content	Teaching notes and materials
		http://docbrown.info/page04/OilProducts11.htm **http://cr4.globalspec.com/blogentry/6684/The-Chemistry-of-DNA?from_rss=1** **http://www.dnaftb.org/?gclid=CIqW9IbXyqICFQxBIAodzxLsyQ**
Drug design	• active sites • 'lock and key' approach to design • ligand and structure based drug design • steps in drug design	Active sites should include hydrophobic atom, H-bond donor, H-bond acceptor, polar atom. Steps in drug design should include at least some of the following: novel active compounds (sources: plants etc), screening, combinatorial chemistry, optimization, clinical trials, licensing. Give different groups a drug utilizing one of the four types of drug action. Use a case study approach to have each group investigate the design and development steps for 'their' drug and report back to the class. Examples of drugs that could be used are: Cimetidine (H_2 -receptor antagonist) Dorzolamide (a carbonic anhydrase inhibitor) Enfuvirtide (a peptide HIV entry inhibitor) Zanamivir (an antiviral drug) Some useful websites: **http://en.wikipedia.org/wiki/Drug_discovery** **http://www.alzforum.org/drg/tut/tutorial.asp** **http://www.actelion.com/en/scientists/r-and-d-approach/drug-discovery-process/index.page**

Electricity

The primary purpose of this Unit is to develop an understanding of the basic units and principles used to describe electric circuits.

Introduction to the Unit

An understanding of cells is developed naturally from a discussion of chemical redox reactions and the electrochemical series. It is emphasized that, as far as possible, students should learn through the practical experience of handling numerical information. It is important that this Unit is approached through the practical application of number rather than just learning how to manipulate numbers as an arithmetical or algebraic discipline.

The suggested content of the Unit is included as a guideline only. Lecturers may choose to concentrate on particular areas of interest to themselves or their students. A project-based learning approach to much of this Unit is recommended, with students investigating in groups of 2-4 and reporting back to the rest of the class. No student is expected to tackle all of the suggested content. It is important that students work on real science or engineering problems that are sufficiently complex to address the Unit's learning outcomes.

The following websites will provide a useful general introduction to this Unit:

http://www.gcse.com/electricity.htm
http://sydney.edu.au/science/uniserve_science/school/curric/stage6/phys/eenergy.html
http://www.physics.usyd.edu.au/teach_res/mteach/mt83/w83.htm
http://www.open2.net/roughscience/

On completion of this Unit students should be able to:

- use and understand the fundamental relationships in electricity
- explain and describe the phenomena associated with static electricity
- describe the effects arising from electromagnetism and also describe their uses
- explain the theory of transducers and measurement devices
- describe the practical applications of transducers and measurement devices
- understand the dangers of electricity to the human organisms and be aware of the necessary precautions
- explain the theory and applications of electrochemistry

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Electricity*

Code	Key concepts and storylines developed	Developed by the student being required to:
C4	Solution processes, including electrochemistry and reaction equilibrium	Explain the theory and applications of electrochemistry
P1	Applications in electricity and electronics	Study the practical applications of electricity, electromagnetism, transducers, measurement devices and electrochemistry

Links from *Electricity* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Calculations involving Ohm's law, power, resistors and capacitors in series and parallel
Links back to *Energy sustainability*	Units of energy and power. Calculations of electrical energy use and efficiency in the home
Links forward to *Study of a domestic appliance*	Function and design of electrical components. Control circuits. Calculation of energy usage
Links forward to *Calculus*	Rate of change of power
Links forward to *Industrial chemical processes*	Electrode processes: electron transfer. Electrolysis
Links forward to *Prosthetics*	Design and test control systems
Links forward to *Investigation of a large Infrastructure project*	Simple circuits, power transmission

Skills development in *Electricity*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Carry out an enquiry-based exercise
S2. Interpersonal communication and team working	✓			• Carry out an enquiry-based exercise
S3. Numeracy: assessing and manipulating data and quantity	✓			• Carry out relevant calculations
S4. Critical and logical thinking				
S5. Basic IT skills				
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis				
S9. Entrepreneurial awareness	✓			• Study the practical uses of electrical phenomena

Electricity: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Fundamental relationships in electricity	• terminology and units • Faraday's laws • electrical relationships • capacitors • electrical properties of materials • practical applications of electricity • electric circuits	Terminology and units might include current (ampere), potential difference (volt), electrical charge (coulomb), resistance (ohm), conductance (siemen). Definition of current in terms of rate of flow of mobile charge carriers. Definition of EMF (electromotive force) as measure of ratio of energy supplied per unit charge, conductance and resistance in relation to density of mobile charge carriers. Electrical relationships might include energy supplied ($W = VIt$), use of Ohm's law ($V = IR$), power ($P = IV$, $P = I^2R$, $Q = It$) and its rate of change, conductance ($G = 1/R$), resistivity ($R = \rho l/A$). Capacitors might include charge stored by capacitors ($Q = CV$) in operation as a reservoir, use of capacitors as a filter in AC circuits, units of capacitance (Farad and sub-units), charging and discharging, calculations of capacitances for parallel and serial capacitors. Electrical properties of materials might include conductivity and resistivity, insulators and conductors, Ohmic and non-Ohmic conductors, use of semiconductors. Applications could include induction motors, electrical generators, transformers DC current; transport (trams, railways), lifting gear, electrolysis; AC current induction furnace, operation and structure of a thermocouple; piezoelectric devices and fundamental principles; understanding the need for signal amplification in some of these devices.

Topic	Suggested content	Teaching notes and materials
		Students could carry out simple calculations on electricity use in the home, eg cost of heating a kettle, cost of baths versus showers, cost of running a washing machine. There should be as much practical work as time permits. For example, students might perform experiments to determine resistance using appropriate measuring instruments; relate the resistance, length and cross-sectional area of a wire; perform experiments to measure current and voltage in different circuit combinations. Electric circuits could include: circuit characteristics; correct assembly of series and parallel resistive circuits using up to three resistors in series, parallel and series — parallel combination; calculation of resistance and conductance in series and parallel. Students might also be presented with some of the practical electrical problems from BBC2's *Rough Science* programmes. Some useful websites: **http://www.slideshare.net/chalkie28/ohms-law-1438583** **http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/electricityintheory/** **http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/electricityintheory/** **http://www.s-cool.co.uk/gcse/physics/static-and-current-electricity/electricity-at-home.html** **http://en.wikipedia.org/wiki/Faraday's_law_of_induction** **http://www.kpsec.freeuk.com/components/capac.htm**

Topic	Suggested content	Teaching notes and materials
		http://www.livephysics.com/simulations/electricity-and-magnetism/faradays-law-moving-magnet.html http://hobby_elec.piclist.com/e_capa.htm http://www.andythelwell.com/blobz/ http://www.allaboutcircuits.com/vol_1/chpt_2/1.html http://www.physics.uoguelph.ca/tutorials/ohm/Q.ohm.intro.html http://www.electronics-tutorials.ws/dccircuits/dcp_2.html
Electric charge	• static electricity • electric current • laws of electrostatics • gold leaf electroscope • Van de Graaff generator • electrostatic induction	Students should see/produce static electricity phenomena and then discuss explanations of these. Some useful websites: http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/electricityintheory/ http://www.school-for-champions.com/science/static.htm http://science.howstuffworks.com/vdg1.htm http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/electricity/staticelectrev1.shtml http://www.regentsprep.org/Regents/physics/phys03/aeleclab/induct.htm
Electromagnetism	• permanent magnets • use of field lines to describe magnetic fields • concept of a neutral point • magnetic flux density (B-field) • magnitude of B defined by $F = BIl$	A computer model could be used to plot lines of force. Practical work could include investigation of magnetic field in a solenoid and near a straight wire using a pre-calibrated Hall probe, or investigation of EMF induced in a circuit by change of flux.

Topic	Suggested content	Teaching notes and materials
	• direction of *B* given by left-hand rule • vector nature of *B* • experimental study of the force on a current-carrying conductor in a magnetic field • magnetic field in a solenoid and near a straight wire with pre-calibrated Hall probe • electromagnetic induction • electricity generation • change of flux induces EMF in a circuit • data logging (*V* against *t* as a magnet falls through coil)	Some useful websites: **http://www.gcse.com/energy/electromagnetism.htm** **http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html** **http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html** **http://www.open2.net/sciencetechnologynature/worldaroundus/generate_your_own_electricity.html** **http://www.daviddarling.info/encyclopedia/M/magnetic_flux_density.html** **http://www.youtube.com/watch#!v=VPxdl1zpcC8&feature=related** **http://www.howstuffworks.com/motor.htm** **http://www.explainthatstuff.com/electricmotors.html** **http://en.wikipedia.org/wiki/Electricity_generation**
Transducers and measurement devices	• passive transducers • definition as devices which change the electrical characteristics within a circuit by the influence of external physical sources (sensors), eg light dependent resistors (LDRs), and their practical uses • measurement devices • biosensors • optical • electrochemical • piezoelectric	Practical uses could include lightmeters, automatic cameras, alarm systems, thermistors, reed switch, strain gauge, Wheatstone bridge arrangement and potential divider circuits. Measurement devices could include uses of oscilloscopes for voltage measurement and AC/DC display; multimeters and range of measurements; data logging devices as those which sense and store information from physical sources for use with visual/audio display and processing, eg pH meters, temperature sensors, moisture sensors, light sensors. Students should build simple devices. There should be as much practical work as time permits. Some useful websites: **http://www.tdx.cbuc.es/TESIS_URV/AVAILABLE/TDX-0831106-092350//PART3.pdf**

Topic	Suggested content	Teaching notes and materials
	• active transducers • production of EMF by conversion of energy from external physical source	**http://media.wiley.com/product_data/excerpt/43/04718991/0471899143.pdf** **http://realtimebiosensor.com/index.php?target=6** **http://www.wisegeek.com/what-are-transducers.htm** **http://en.wikipedia.org/wiki/Transducer**
Health and safety	• mains electricity • domestic ring main circuit • nature of AC voltage • human physiology and electricity	AC voltage could include changing polarity with instantaneous values varying sinusoidally, eg mains frequency, root mean square (RMS), peak and peak-to-peak voltages, earthing, fuses, significance of double insulation, residual current and earth leakage circuit breakers (RCCB and ELCB). Human physiology could include typical resistance values for current pathways in the body; skin resistance and changes of environment, eg moisture levels of the skin, contact with the ground; heart responses to electric shock; safe levels of DC voltage. Some useful websites: **http://factoidz.com/the-home-handy-persons-guide-to-electrical-safety-electricity-can-kill-you/** **http://www.slideshare.net/fullcircle/basic-electrical-safety** **http://www.slideshare.net/kgoff/electrical-safety-332311**
Electrochemistry	• oxidation and reduction • balancing redox equations (acidic, basic and neutral media) • electrochemical cells • standard potentials • spontaneity of redox reactions • cell EMF and concentration	Batteries could include dry, mercury, lead acid/lithium (rechargeable). Electrolysis could include molten NaCl, aqueous solutions (eg NaCl). Some useful websites: **http://www.open2.net/recharge_battery.html** **http://www.mpcfaculty.net/mark_bishop/Redox_balancing.htm**

Topic	Suggested content	Teaching notes and materials
	• Nernst • concentration cells • batteries • fuel cells • corrosion of Fe and common metals • electrochemical series • prevention of corrosion, coating, sacrificial anodes • electrolysis and electroplating • plating • applications of Faraday's laws	**http://hyperphysics.phy-astr.gsu.edu/hbase/chemical/electrochem.html** **http://library.kcc.hawaii.edu/external/chemistry/everyday_electro.html** **http://www.science.uwaterloo.ca/~cchieh/cact/c123/nernsteq.html** **http://corrosion-doctors.org/Corrosion-Thermodynamics/Nernst-equation.htm** **http://auto.howstuffworks.com/fuel-efficiency/alternative-fuels/fuel-cell.htm** **http://en.wikipedia.org/wiki/Fuel_cell** **http://corrosion-doctors.org/Corrosion-History/Kinds.htm** **http://www.britannica.com/EBchecked/topic/138721/corrosion** **http://www.britannica.com/EBchecked/topic/657347/zinc-processing/82107/Corrosion-protection?anchor=ref623327** **http://www.daviddarling.info/encyclopedia/S/AE_sacrificial_anode.html** **http://corrosion-doctors.org/CP/Sacrificial.htm** **http://corrosion-doctors.org/MatSelect/corriron.htm** **http://www.finishing.com/faqs/howworks.html** **http://en.wikipedia.org/wiki/Electroplating** **http://www.ausetute.com.au/faradayl.html**
Problem-based learning exercise	• Desert Island Rescue Problem (or other)	The following scenario is provided for students. 'You are the crew of a cargo plane carrying goods for PB plc, a large industrial wholesale company. Whilst travelling through a storm your plane is forced to make a crash landing on a small,

Topic	Suggested content	Teaching notes and materials
		remote island. Most of the equipment on the plane has been damaged by the landing, and only a few rudimentary components remain useable. Air traffic control knows you are missing but does not know where you are. You therefore need to build some kind of rescue beacon.' Students are provided with a list of equipment salvaged from the plane. The list includes two rescue beacons but no power sources. See: **http://www.heacademy.ac.uk/assets/ps/documents/practice_guides/ps0080_possibilities_problem_based_learning_in_physics_and_astronomy_mar_2005.pdf** (page 8)

Equations and graphs

Introduction to the Unit

In this Unit students will learn how to draw and use graphical information, acquire the ability to use vectors to solve 2D problems, learn how to manipulate trigonometric equations and to apply trigonometric techniques to real-life situations. Students will also learn how to apply a wide range of algebraic techniques involving factorization, solving quadratic equations and handling logarithms and exponentials. Students will also be given an introduction to mathematical modelling techniques.

The lecturer is free to select the method most suitable for the particular class. It may be that in some circumstances formal teaching of the mathematics first, followed by the introduction of the chosen examples will be the best approach. An alternative method would be to look at a particular application and see how the results can be calculated. The aim of this Unit is to demonstrate the use and application of mathematical techniques in a variety of situations.

http://nrich.maths.org/stemnrich is a good website for this Unit as it consists of a set of mathematical-science problems devoted to exploring the richness of the vital mathematical ideas underlying science, technology and engineering in thoroughly physical, relevant and engaging contexts. There are four applications nodes and two mathematical nodes. Together, these explore the mathematics which forms the foundation of any scientist's toolkit.

On completion of this Unit students should be able to:

- use graphical techniques
- use vectors in calculations
- use and apply algebraic techniques
- understand how to manipulate trigonometric expressions and apply trigonometric techniques
- use mathematical modelling techniques to solve a real-world problem

Approaches to assessment

Assessment will mainly be by satisfactory completion of worksheets and production of laboratory reports. The worksheets should contain problems that involve all of the Unit's topics and the application of mathematical techniques to the solution of problems of a scientific and/or engineering nature.

Key concepts/storylines in *Equations and graphs*

Code	Key concepts and storylines developed	Developed by the student being required to:
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Solve problems related to population growth
C3	Reactions, including mechanisms and yields	Calculate reaction order in chemical reactions
M1	Exponentials and logarithms (including log and ln)	Perform calculations using exponentials and logarithms in a science context
M2	Trigonometry, coordinate geometry	Use trigonometry to solve problems in optics and other areas
M6	Key tools from numeracy, algebra, proportion and graphs	Manipulate equations and perform numerical and algebraic tasks
P4	Studies of forces, motion and energy	Calculate forces and acceleration and velocity of objects both graphically and using equations

Links from *Equations and graphs* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Graphs and equations
Links back to *Ecosystems*	Mathematical modelling using ecological examples
Links back to *Atoms and molecules*	pH plots and bond angles
Links back to *Forces, motion, energy*	Use of vectors in calculations
Links forward to *Study of a domestic appliance*	Use of mathematical modelling in design
Links forward to *Calculus*	Exponential growth and decay
Links forward to *Industrial chemical processes*	Calculations involving acids/bases, buffers, equilibrium constants
Links forward to *The human organism*	Mathematical modelling techniques as applied to medical matters
Links forward to *Radiation*	Properties of radiation: the use of trigonometry and geometry in light calculations

Skills development in *Equations and graphs*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Plan what material is required, where to find it and how to use it in the mathematical modelling topic
S2. Interpersonal communication and team working		✓		• Team working in the mathematical modelling topic
S3. Numeracy: assessing and manipulating data and quantity		✓		• Assess and manipulate graphical data and equations. • Perform calculations involving vectors, logs and indices, and trigonometric functions
S4. Critical and logical thinking		✓		• Carry out multistep calculations
S5. Basic IT skills		✓		• Use spreadsheets and a word processing package
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis				
S9. Entrepreneurial awareness				

Equations and graphs: summary of content, teaching notes and materials

Topics	Suggested content	Teaching notes and materials
Use of graphical techniques	• linear graphs; translating information from graphical, numerical and algebraic forms • gradient of a line • logarithmic plots	Graphs will have been plotted in *Numeracy* and so can be revised again here and additional graphs drawn and interpreted using logarithmic and exponential plots. Examples can be taken from biology (population and raptor/pray graphs), chemistry (plots of pH, absorbance or activation energies) or physics.
Use of vectors in calculations	• defining and classifying vector and scalar quantities • what is meant by the resultant of a number of forces • calculating the rectangular components of a vector • calculating the magnitude and direction of the resultant of a number of forces	Use examples from physics and chemistry at **http://nrich.maths.org/public/index.php** where there are examples on velocity and bond angles.
Using and applying algebraic techniques	• Indices and logarithms • laws of indices • laws of logarithms, eg common logarithms (base 10), natural logarithms (base e) • exponential growth and decay • pair of simultaneous linear equations in two unknowns • quadratic equations, solving by factorization and use of formula	Examples of use of logs in spectrophotometric problems can be given. Some can be found on the nrich site (**nrich.maths.org**). Examples of pH, buffers and radioactive decay can also be used. Quadratic equations can be used to solve equilibrium calculations.

Topics	Suggested content	Teaching notes and materials
Understanding and manipulating trigonometric expressions and applying trigonometric techniques	• circular measure (radian, degree measure to radians and vice versa) • angular rotations (multiples of π radians) • length of arc of a circle • area of a sector • triangular measurement • functions (sine, cosine and tangent) • sine/cosine wave over one complete cycle • periodic properties of the trigonometric functions • the sine and cosine rules • trigonometrical graphs (amplitude, period and frequency) • phase angle, phase difference • combination of two waves of the same frequency • trigonometrical formulae and equations (the compound angle formulae for the addition of sine and cosine functions, eg sin $(A \pm B)$; expansion of $R \sin (wt + a)$ in the form $a \cos wt + b \sin wt$ and vice versa)	**http://asistm.duit.uwa.edu.au/synchrotron/downloads/pdfs/chapter06_1.pdf** gives information on wavelengths and trigonometric graphs and various investigations that can be carried out involving a synchrotron, radiowaves, earthquakes and heartbeats. **http://www.cimt.plymouth.ac.uk/projects/mepres/allgcse/as4act1.pdf** gives projects on the use of trigonometry in measurement and navigation using the sine and cosine rules. Practical wave problems, eg calculation of the phasor sum of two alternating currents, should be given. Graph sketching, eg sin x, 2sin x, ½sin x, sin $2x$, sin ½x for values of x between 0 and 360°. **http://mathforum.org/library/drmath/sets/high_trigonometry.html** is a good website for examples involving trigonometry.

Topics	Suggested content	Teaching notes and materials
Mathematical modelling techniques	• use of mathematical modelling techniques to solve real-world problems	Students should be presented with a problem to solve where they are not given all the required information but are asked to find out for themselves and to make assumptions. They will then need to formulate the mathematical problem, solve this problem, interpret the solution and verify the solution. Finally they will need to report and explain their prediction. Problems are available in ecology, physics and medicine at **http://www.indiana.edu/~hmathmod/** A mathematical modelling article, with details of the modelling approach, examples and problems, is available at **http://www.curriculumsupport.education.nsw.gov.au/secondary/mathematics/assets/pdf/s6_teach_ideas/cs_articles_s6/cs_model_s6.pdf** There are also epidemic modelling problems on the nrich website, **http://nrich.maths.org**

Study of a domestic appliance

The primary purpose of this Unit is to bring together as much as possible of the work of the programme covered so far, in an applied situation.

Introduction to the Unit

This Unit will provide an indication of how well the material in the preceding Units has been assimilated. Studying a domestic appliance allows students to appreciate the complexity of objects with which they are familiar in the home. This almost entirely hands-on Unit is the first one with a substantial engineering component.

The exemplar uses a domestic washing machine but any domestic appliance or collection of appliances which allows similar complexity or meets the learning objectives of the lecturer could be used. Students will be required to remove and examine some of the components in an appliance and investigate material composition and function in relation to the working environment, consider possible methods of manufacture, suitability of the component for the function for which it was designed, and issues of health and safety, sustainability and disposal. Students will be expected to design, construct and test electronic devices to mimic some of those in the appliance. Where possible, students could be asked to work on different aspects of each topic and report back to the rest of the class in order to further develop their transferable skills. Individuals could work together to produce a final joint report and presentation.

Within this project, several aspects can be carefully studied: conceptual studies; scaled prototyping; structural engineering; materials selection; CAD/CAM (computer-aided design/computer-aided manufactured) mould making; advanced sandwich composite-structure manufacture; automation (programming and control); and testing. There are fewer directly

related websites for this essentially practical project; however, some useful support may be obtained at:

http://www.unitjuggler.com/convert-energy-from-kWh-to-kJ.html

http://ieeexplore.ieee.org/search/srchabstract.jsp?tp=&arnumber=4025375&queryText%3DWashing+Machine+Control+Systems%26openedRefinements%3D*%26searchField%3DSearch+All.

The site **http://ieeexplore.ieee.org** is particularly useful. If you type 'domestic washing machine' into the search box you get links to many of the electronically/electrically related topics in this Unit.

On completion of this Unit students should be able to:

- describe the function and design and manufacturing characteristics of a component in a domestic appliance
- use simple finite analysis to determine the factors governing the design characteristics, including fitness for purpose
- use a CAD modelling approach to design
- determine the forces on the drum bearing during operation
- understand the chemistry of corrosion protection and the criteria determining the properties of protective enamels
- produce flow charts of the basic control loops, and design and test simple control circuits
- acquire the entrepreneurial skills to ensure that the machine satisfies the customer requirements both functionally and aesthetically
- understand the environmental considerations in the design of the detergent, energy consumption and machine scrapping
- carry out a number of calculations relating to machine operation

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked with some sampled cross-marking by the lecturer. Any written assessment should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Study of a domestic appliance*

Code	Key concepts and storylines developed	Developed by the student being required to:
C4	Solution processes, including electrochemistry and reaction equilibrium	Explain the theory and applications of electrochemistry
P1	Applications in electricity and electronics	Study the practical applications of electricity, electromagnetism, transducers, measurement devices and electrochemistry

Links from *Study of a domestic appliance* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Use of calculus to optimize design. Calculation of energy usage
Links back to *Forces, motion, energy*	Optimization of design. Forces on drum bearing
Links back to *Energy sustainability*	Calculation of energy usage
Links back to *Electricity*	Function and design of electrical components. Control circuits. Calculation of energy usage
Links back to *Equations and graphs*	Use of mathematical modelling in design
Links forward to *Commercial case studies*	Entrepreneurial aspects of domestic appliance design
Links forward to *Information systems*	Control circuits

Skills development in *Study of a domestic appliance*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning	✓			• Report on results of their investigations for the various topics
S2. Interpersonal communication and team working	✓			• Report on results of their investigations for the various topics
S3. Numeracy: assessing and manipulating data and quantity	✓			• Calculate forces and energy usage
S4. Critical and logical thinking				
S5. Basic IT skills	✓			• Design, build and test control circuits
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution	✓			• Work back to describe the design criteria for individual components and the whole machine
S8. Scientific analysis				
S9. Entrepreneurial awareness	✓			• Consider the design aspects present to meet customer's requirements

Study of a domestic appliance: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Dismantling of device	• material(s) • function • working environment • method of manufacture • suitability and functional design • health and safety issues • disposal	Working environment could include: pressure, force, temperature, corrosion and any others as appropriate. Suitability of a component could be discussed under a number of headings including cost and lifetime under working conditions. Health and safety issues during manufacture, use and servicing might be covered. For example the electroplating process might use cyanides and heavy metals, which need to be kept out of the sewage system.
Structural and functional design	• suitability for purpose of whole machine and individual components	Examination and report on individual components. Aspects of engineering design and materials science.
Simple finite element analysis	• visualization • optimization of design	Visualization of where structures bend or twist, and indication of the distribution of stresses and displacements. Calculus and algebra can be introduced as tools. Use an iterative approach to allow the entire design to be constructed, refined, and optimized. The study of the design for purpose might usefully include consideration of the customer requirements and ease of manufacturing and service. These considerations need not necessarily be covered here but could be raised under later topics in the Unit.

Topic	Suggested content	Teaching notes and materials
Drum-support frame structure	• forces • selection of materials	Calculate values of forces encountered by the drum bearing under full-load maximum-spin conditions.
Base and cover mould manufacture	• design criteria • materials science • manufacture • industrial processes	Some of this topic will have already been discussed under the finite analysis heading but might be further developed here to take into account the particular problems of forming different metals and alloys and the considerations (eg ease of manufacture, customer requirements, corrosion and recycling) governing the final choice of material.
Command buttons	• role • design • function	This topic should mainly cover the entrepreneurial aspects such as appearance, functionality, location and ease of use.
Assembly, painting and finishing	• corrosion protection • properties required of paint • method of application and curing	This topic provides an opportunity to discuss the reasons for painting (aesthetic and anti-corrosion) together with some of the physics and chemistry of paint/enamel formulations and application.
Conceptual design and CAD modelling	• applying CAD in a design environment	There is an opportunity here to introduce some engineering design principles and to allow students to experience and appreciate the power of CAD in practical work, particularly from a whole-machine viewpoint.

Topic	Suggested content	Teaching notes and materials
Programming and control	• switches • timers • pumps • bearings • protection from water • IT	Flow chart of basic controls required. In practical work, students could design and test circuits to mimic functions in the machine.
Customer requirements	• what the end user requires • how these requirements are met • role and action of detergents	The needs of the customer as final arbiter of the success or otherwise of the appliance might also include market research and marketing aspects of the design project.
Environmental considerations	• detergent design and functioning • detergent pollution • temperature reduction • energy usage • scrapping of machine	There are a number of moral, ethical, environmental and quality considerations that might be discussed here: • the effect of detergents on the environment versus the customers' requirements • the energy savings that might be made by operating at a lower temperature versus the customer's requirements • disposal issues and sustainability.

Topic	Suggested content	Teaching notes and materials
Calculations	• energy usage under different conditions • costs	The following are suggestions of calculations that might be carried out. Lecturers or students may wish to substitute different calculations to reflect their interests. It is recommended that the lecturer or students also write a simple programme to carry out these calculations under a range of conditions in order to study the effect that each of the variables has on the final result. The initial calculation should be carried out manually, so that students can appreciate how circular motion etc can be applied to real problems. Calculate the force on the drum bearing during a rotation of 30 degrees. Calculate the different energy requirements for washing at 30°C and 40°C, and consider the ways in which energy can be saved. Calculate the national power and financial saving if the whole population reduced their washing temperature from 40°C to 30°C (assume 10^7 washing machines are used once per week and that electricity costs 10p per kWh).
Presentation	• individual topics • whole Unit	In order to increase the learning potential, students should present for each topic where the class members have different assignments. If time permits, groups could work together to produce a joint final report and presentation. A sample report form is provided, which may be changed to suit requirements.

Report on a component of a domestic appliance

Name of component	Sketch	Comments/Notes
Material(s)		
Function		
Working environment Pressure Force Temperature Corrosive Other (name)		
Method of manufacture		
Suitability of component for function (in terms of cost, lifetime under working conditions, etc)		
Health and safety issue and solutions		

Name of Appliance

Name of student **Date**

Calculus

The primary purpose of this Unit is to develop a basic understanding of the mathematical techniques used in calculus and to appreciate how these techniques can be used in a wide range of scientific and engineering applications.

Introduction to the Unit

In this Unit the techniques of differentiation and integration are introduced and applied in the context of science and engineering.

On completion of this Unit students should be able to:

- carry out the basic mathematical techniques of integration and differentiation
- apply these techniques to the solution of scientific and engineering problems
- perform experiments related to the areas studied

Approaches to assessment

Assessment will mainly be by satisfactory completion of worksheets and production of laboratory reports. The worksheets will contain problems which will involve differentiation and integration and the application of calculus to the solution of problems of a scientific and engineering nature.

Key concepts/storylines in *Calculus*

Code	Key concepts and storylines developed	Developed by the student being required to:
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Calculate population growth in a predator—prey scenario using the Lotka Volterra equation
C3	Reactions, including mechanisms and yields	Solve problems relating to reaction kinetics
E1	Project planning and management	Perform calculations involving the design or construction of a large infrastructure project
M1	Exponentials and logarithms (including exp and ln)	Perform calculations involving activation energy and radioactive decay
M4	Basic introductory calculus	Perform calculations involving differentiation and integration
P1	Applications in electricity and electronics	Solve problems involving power consumption and electrical waves
P2	Study involving radiation (including lasers)	Solve problems involving radioactive decay and carbon dating
P4	Studies of forces, motion and energy	Solve problems involving falling objects, velocity and acceleration

Links from *Calculus* to other parts of the programme

Links to other Units	Topics involved
Links back to *Forces, motion, energy*	Velocity and acceleration, gravity; distance—time optimization; calculations of slopes and areas under a graph
Links back to *Ecosystems*	Predator/prey population growth and harvesting situations
Links back to *Energy sustainability*	Radioactivity and fission
Links back to *Electricity*	Power calculations and electrical waves
Links forward to *Investigation of a large infrastructure project*	Maximizing/minimizing volumes or surface areas for items in project
Links forward to *Industrial chemical processes*	Use of chemical kinetics in industrial processes
Links back to *Earth processes*	Agriculture in support of the human population: introduction to the idea of calculus when looking at population growth
Links back to *Equations and graphs*	Exponential growth and decay
Links forward to *Prosthetics*	Mathematical modelling of prosthetics; biomechanical calculations

Skills development in *Calculus*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Exercise initiative in pursuing study tasks
S2. Interpersonal communication and team working		✓		• Work as part of a team when carrying out experiments
S3. Numeracy: assessing and manipulating data and quantity		✓		• Handle calculations confidently using units expressed in scientific notation. Manipulate equations fluently
S4. Critical and logical thinking		✓		• Produce well-structured reports with references • Make a critical assessment of conclusions
S5. Basic IT skills		✓		• Use a spreadsheet to derive the equation for a linear regression fit to data
S6. Handling uncertainty and variability		✓		• Comment on uncertainties when reporting conclusions
S7. Experimentation and prototype construction: design and execution			✓	• Plan and design experiments on chemical kinetics
S8. Scientific analysis		✓		• Assess conclusions of experiment and write a report
S9. Entrepreneurial awareness				

Calculus: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
The basic techniques of calculus	• differentiation • differential coefficient • gradient of a curve $y = f(x)$ • rate of change • Leibniz notation • differentiation of simple polynomial functions, exponential functions and sinusoidal functions; problems involving evaluation, eg gradient at a point • review of standard derivatives • differentiation of a sum • function of a function • product and quotient rules • numerical values of differential coefficients, second derivatives • turning points (maximum and minimum) • Integration • integration as reverse of differentiation • basic rules for simple polynomial functions, exponential functions and sinusoidal functions; indefinite integrals • constant of integration • definite integrals	The tutor is free to select the method most suitable for the particular class. It may be that in some circumstances formal teaching of calculus first, followed by the introduction of the chosen examples will be the best approach. An alternative method would be to look at a particular application, say reaction rate, and perform an experiment to measure this and see how the results can be calculated. The aim of this Unit is to demonstrate the use and application of calculus in a variety of situations. It is suggested that at least one example should be taken from each of the following areas: chemistry, physics, ecology and engineering (other applications). Websites have been given below with details of calculations and experiments. Practical work should include at least two experiments performed by students which involve the use of calculus in the calculation of results. There are examples given below for radioactive decay and reaction rate. The website **http://www.idea.wsu.edu/projects.php** gives projects on a range of science topics from salmon migration to bungee jumping.

Topic	Suggested content	Teaching notes and materials
	• limits • evaluation of simple polynomial functions • area under a curve • review of standard integrals, indefinite integrals, definite integrals, eg area under a curve, mean and RMS values	
Uses of differentiation /integration	• ecology (exponential growth of a population, in the predator—prey scenario — Lotka Volterra equations — and in harvesting situations) • physics (falling objects; Newton's law of cooling; a resistor/inductor circuit; velocity and acceleration calculations; power versus consumption; distance—time optimization; radioactive decay, half-life and carbon dating) • chemistry (reaction kinetics — zero, first- and second-order reactions; rate constants and half-life equations) • other applications (calculating minimum/maximum volumes, surface areas of different shapes, applications in the large-scale infrastructure project, when to replace a car)	There are a huge number of useful references in **http://www.calculus.org/**. Other useful websites: **http://www.geom.uiuc.edu/education/calc-init/population/** (population growth) **http://www.geom.uiuc.edu/education/calc-init/population/unbounded.html** (toad population and population simulator) **http://www.phschool.com/atschool/phbio/active_art/predator_prey_simulation/index.html** (moose predator prey simulation with a lot of variables) **http://www.chem.uci.edu/undergrad/applets/sim/simulation.htm** (kinetics simulation) **http://www.analyzemath.com/calculus.html** (good examples and graphs of equations: problems involving distance/time optimization; minimization of surface area; obtaining maximum power and exponential growth) **http://www.succeed.ufl.edu/papers/99/00266.pdf** (gives details of a problem on when to replace a car)

Topic	Suggested content	Teaching notes and materials
Practical applications	Two possible applications: • as an example of first-order kinetics, radioactive decay can be measured first as a simulation to show the random nature (reference to *Statistics* Unit here) of the decay process and then by measuring the decay of protoactinium • an experiment to measure reaction rate, such as the iodine clock reaction; simulations of experiments are also available on the web which allow changes in concentrations of reactants and temperature	Practical work at: **http://www.practicalphysics.org/go/Experiment_579.html** (simulation of radioactive decay using coins) **http://www.practicalphysics.org/go/Experiment_577.html** (radioactive decay of protoactinium) **http://www.practicalchemistry.org/experiments/intermediate/rates-of-reaction/iodine-clock-reaction,55,EX.html** (the iodine clock reaction) **http://www.siraze.net/chemistry/sezennur/subjects/experiment/023.pdf** (another reaction involving iodine)

Eukaryotic cells

The primary purpose of this Unit is to allow the student to develop an understanding of cell structure and function (including the role of DNA in protein synthesis and transfer), photosynthesis and cellular respiration, and the uses of DNA technology.

Introduction to the Unit

This Unit contains, in addition to the composition and function of cells, the basic chemistry of proteins, lipids, carbohydrates and nucleic acids. The chemistry content can either be taught separately or, as is suggested here, it can be integrated with the rest of the material. As this is a cycle 3 Unit, it is hoped that students will increasingly be finding their own information on the web and with the aid of textbooks.

Chemistry covered in this Unit includes the following:

- natural materials are mainly polymers
- lipids are made of long-chain fatty acids linked to glycerol
- proteins are formed from amino acids which contain a central carbon atom bonded to a carboxyl group, an amino group, a hydrogen atom and the fourth group, which has the rest of the carbon side-chain attached; the link between amino acids is called the peptide bond; proteins have different shapes — primary, secondary and tertiary structures
- carbohydrates are formed from monosaccharides, which contain carbonyl and OH groups
- nucleic acids — DNA and RNA.

On completion of this Unit students should be able to:

- understand cell structure and function
- have some knowledge of DNA technology
- understand cellular respiration
- understand methods of cell reproduction
- have some knowledge of basic microbiology

Approaches to assessment

Evidence for the five topics will be gathered in open-book conditions at appropriate points throughout the Unit and presented in a student folio. Progress will be discussed with the lecturer at appropriate points during the investigations to ensure that the folio is the student's own work. A record of each discussion must be retained.

Key concepts/storylines in *Eukaryotic cells*

Code	Key concepts and storylines developed	Developed by the student being required to:
B1	Organization and operation of the cell, and the nature, roles and management of the key chemicals of life	Relate cell structure to function, understand methods of respiration and reproduction and the role of DNA, RNA and ATP in the cell
B3	Cell division, reproduction, heredity	Begin to understand about cell reproduction, mitosis and meiosis
C2	Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts	Understand cell structure and function (lipids, carbohydrates, proteins, DNA and RNA) and cellular respiration (ATP)
P3	Study of a wide range of materials properties	Appreciate the structure of natural polymers
P4	Studies of forces, motion and energy	Revise basic energy concepts and calculate energy value of foods

Links from *Eukaryotic cells* to other parts of the programme

Links to other Units	Topics involved
Links back to *Forces, motion, energy*	Basic energy concepts such as energy conservation and conversion, plus units
Links back to *Numeracy*	Idea of scale and the size of cells, bacteria and viruses
Links back to *Atoms and molecules* and *Reactivity*	Chemical structures of lipids, proteins, carbohydrates and nucleic acids
Links forward to *The human organism*	Energy and exercise, dealt with in more detail in *The human organism*
Links back to *Earth processes*	The biosphere and human impact: photosynthesis and respiration
Links forward to *Materials*	Natural polymers, such as carbohydrates, proteins and lipids

Skills development in *Eukaryotic cells*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Plan relatively open ended tasks, acquiring information and processing this in a logical way, and make critical reviews
S2. Interpersonal communication and team working		✓		• Work as part of a team to produce a report
S3. Numeracy: assessing and manipulating data and quantity		✓		• Calculate energy values from foods, and energy expended in exercise
S4. Critical and logical thinking		✓		• Produce a structured report on the use of DNA technology, presenting the case logically
S5. Basic IT skills		✓		• Produce reports
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution		✓		• Plan and perform experiments
S8. Scientific analysis		✓		• Draw valid conclusions from experimental details
S9. Entrepreneurial awareness				

Eukaryotic cells: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Cell structure and function	• prokaryote and eukaryote cells • parts of cells (membrane, nucleus and cytoplasm with organelles) • membrane structure and function • lipids (structure and hydrophobic nature) • proteins (amino acids; peptide links; primary, secondary and tertiary structures; denaturation) • diffusion and osmosis across membranes of small molecules, facilitated diffusion, active transport, transfer of large molecules by exo- and endocytoses • the nucleus and ribosomes (genetic control of the cell by DNA) • nucleic acids (DNA; RNA and the four bases, adenine, guanine, thymine and cytosine; the double helix; genes and chromosomes)	Students should compare the sizes of different types of cells, eg human red blood cells, bacteria, viruses, proteins and small molecules, and write up a brief comparison of prokaryotic and eukaryotic cells. Interactive pictures of cells can be found on the web with all parts named and their functions explained. There are also quizzes on this knowledge on the web. Students could be asked to produce information on a particular part of a cell, and then information on all cell parts could be brought together in the class. **http://www.johnkyrk.com/DNAreplication.html** is an excellent website with animations covering amino acids, proteins, cell structure, photosynthesis, DNA replication and much more, updated in July 2010. **http://www.people.eku.edu/ritchisong/301notes1.htm** includes a 'tour of a cell', a good clip on how a cell works and animations of DNA replication, respiration, cell reproduction and respiration. **http://neon.chem.ox.ac.uk/vrchemistry/LivingCells/HTML/page16.htm** is good for information on eukaryotic cells. Details of an experiment to isolate DNA from a kiwi fruit can be obtained at **http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/how-to-extract-dna-from-a-kiwi-fruit/**

Topic	Suggested content	Teaching notes and materials
	• DNA replication; semi-conservative hypothesis; protein synthesis including role of mRNA, tRNA and the triplet code • the endomembrane system, manufacturing and distributing cellular products (endoplasmic reticulum, Golgi apparatus, lysosomes and vacuoles) • energy conversion (chloroplasts and mitochondria)	Practical work can include an experiment on osmosis, diffusion and enzymes; examples can be found at: **http://www.lessonplansinc.com/science.php/biology/types/Experiment/P0/**
DNA technology	• use in forensics (DNA fingerprinting) • recombinant DNA technology (genetic modification, gene therapy with examples and possible ethical issues)	This topic is designed to give an insight into the uses of DNA technology. Examples in forensics can be chosen from DNA fingerprinting to solve crimes and to identify parentage or ancestry, and students can be asked to play the 'detective'. There is a video on forensics at **http://www.teachers.tv/videos/chemistry-in-forensics** and a website on DNA fingerprinting at **http://protist.biology.washington.edu/fingerprint/dnaintro.html** Examples of uses of this technology are production of humulin (human insulin), human growth hormone, EPO (Erythropoietin), GM foods. Consideration should be given to possible ethical issues involved. A bioethics education programme can be found at **http://www.beep.ac.uk/content/index.php** Ethical issues are discussed but the site is also a good source of

Topic	Suggested content	Teaching notes and materials
		information covering what a student needs to know to discuss these issues. There are also good articles on the human genome and on the structure of cells on the beep site.
Cellular respiration	• revision of basic energy concepts (energy conservation and conversion, different forms of energy, energy units) • chemical energy from foods • food calories and calories spent on different activities • energy and exercise • structure of simple sugars and carbohydrates (eg glucose, fructose, sucrose, starch) • ATP and cellular work; structure of ATP • ATP creation by respiration • glycolysis • Kreb's cycle • cytochrome system • enzymes (activation energy, induced fit, enzyme inhibitors, factors affecting enzyme function) • photosynthesis (photolysis and the Calvin cycle)	Students could obtain information on the energy content of different foods and compare this with the amount of energy expended in different activities. They could also relate the energy of a type of food to its molecular structure. A starter website is **http://en.wikipedia.org/wiki/Food_energy** See **http://www.sciencebyjones.com/energy_content_of_food.htm** for an experiment on energy values in food. **http://www.biology-online.org/1/2_ATP.htm** gives an introduction to ATP and cellular work. Possible practical work could include experiments on the effect of temperature on enzyme reaction, osmosis and diffusion, analysis of carbohydrates and lipids in foodstuffs, and isolation of DNA in fruit. Various experiments on diffusion, osmosis and enzymes can be found at **http://www.lessonplansinc.com/science.php/biology/types/Experiment/P0/** Another useful website: **http://www.biology-online.org/1/4_photosynthesis.htm**

Topic	Suggested content	Teaching notes and materials
	• limiting factors in photosynthesis (temperature, light intensity, carbon dioxide concentration) • metabolic pathway of cellular respiration, aerobic and anaerobic • glycolysis, the citric acid cycle and electron transport, anaerobic pathway to produce lactic acid	
Cell reproduction	• cell cycle and mitosis in eukaryotic cells, chromosome duplication • meiosis and sexual reproduction (introduction only as this will be progressed in *Genetics*)	Animation and details for mitosis can be found at **http://www.cellsalive.com/mitosis.htm** and for meiosis at **http://www.cellsalive.com/meiosis.htm**
Microbiology	• characteristics of bacterial, viral and fungal cells • identification (Gram stain and aseptic techniques) • factors affecting growth (nutrients, temperature, pH, aerobic or anaerobic conditions, antibiotics, disinfection) • extremophiles	This topic could be discussed in an industrial context such as brewing or baking and/or a medical context such as prevention and control of MRSA. Some useful websites: **http://en.wikipedia.org/wiki/Microorganism** **http://rpi.edu/dept/chem-eng/Biotech-Environ/beer/yeast/yeast2.htm** **http://www.wisegeek.com/what-is-fermentation.htm**

Topic	Suggested content	Teaching notes and materials
		http://www.yobrew.co.uk/fermentation.php http://www.nhs.uk/Conditions/MRSA/Pages/Introduction.aspx http://www.patient.co.uk/health/MRSA.htm http://www.theguardians.com/Microbiology/gm_mbm04.htm http://www.bacteriamuseum.org/cms/Evolution/extremophiles.html http://www.daviddarling.info/encyclopedia/E/extremophile.html

Radiation

Introduction to the Unit

The primary purpose of this Unit is to familiarize students with the properties of the electromagnetic spectrum. Students will investigate the laws of reflection and refraction, the structure of the eye and the different types of lenses. Wave properties of light will also be looked at, namely interference and diffraction. Students will research how radiation interacts with matter and look at instrumental techniques in forensic chemistry which use radiation such as emission and absorption spectroscopy and IR (infrared) and UV (ultraviolet) spectroscopy. Medical uses such as MRI (magnetic resonance imaging) and X-rays, industrial uses and general applications are also investigated. It is envisaged that the bulk of the work of this Unit will be project based and that students will work both individually and in groups on projects related to the different topics. Practical work plays a large part in this Unit and various experiments are suggested in the Teaching notes.

On completion of this Unit students should be able to:

- appreciate the different types of electromagnetic radiation in the spectrum and identify typical uses
- investigate the properties of radiation
- investigate the interaction of radiation with matter

Approaches to assessment

Assessment of this Unit will be by completion of reports on selected topics and laboratory reports on experimental work performed.

Key concepts/storylines in *Radiation*

Code	Key concepts and storylines developed	Developed by the student being required to:
B2	Organization and systems operation of an organism; homeostasis & control; healthy living & combating disease	Have a knowledge of how the human eye is constructed and its part in the central nervous system, and know how common eye defects can be corrected
C2	Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts	Relate the structure of organic compounds to their IR and UV/visible spectra
C5	Processes involving light absorption/emission	Understand the way in which radiation is absorbed and emitted by material and how this relates to structure
M1	Exponents and logarithms (including exp and ln)	Use logarithms and exponentials in the calculation of light absorbance and use the Lambert—Beer relationship
M2	Trigonometry, coordinate geometry	Use trigonometry to solve problems involving refraction
M6	Key tools from numeracy, algebra, proportion and graphs	Perform calculations involving waves, reflection, refraction and diffraction
P1	Applications in electricity and electronics	Have a knowledge of analogue and digital signals
P2	Study involving radiation (including lasers)	Have a knowledge of the EMR spectrum and how different parts of the spectrum can be used in instrumentation
P3	Study of a wide range of materials properties	Know the structures of different organic and inorganic molecules

Links from *Radiation* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	The electromagnetic spectrum: scientific notation and wavelength calculations Interaction of radiation with matter: calculations involving the inverse square law
Links back to *Energy sustainability*	The electromagnetic spectrum: nature and properties of gamma radiation
Links back to *Equations and graphs*	Properties of radiation: the use of trigonometry and geometry in light calculations
Links forward to *The human organism*	Properties of radiation: structure of the eye and its links to the central nervous system
Links back to *Atoms and molecules*	Interaction of radiation with matter: functional groups in organic chemistry
Links back to *Reactivity*	Interaction of radiation with matter: structure of functional groups
Links forward to *Statistics*	Measurement of radioactive decay
Links forward to *Prosthetics*	Diagnostic imaging using MRI and CT (computed tomography) methods
Links back to *Forces, motion, energy*	Methods of energy transfer

Skills development in *Radiation*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Plan an experiment and carry through all steps successfully
S2. Interpersonal communication and team working		✓		• Work as part of a team on lab and search projects
S3. Numeracy: assessing and manipulating data and quantity		✓		• Collect and process lab data • Perform calculations in reflection, refraction, diffraction, absorption and emission spectra
S4. Critical and logical thinking		✓		• Design an experiment and analyse results • Draw conclusions from a project and identify materials from spectra
S5. Basic IT skills		✓		• Produce reports, using spreadsheets to draw calibration graphs
S6. Handling uncertainty and variability		✓		• Appreciate the uncertainty in a given experimental result
S7. Experimentation and prototype construction: design and execution		✓		• Design an experiment to investigate a given topic
S8. Scientific analysis		✓		• Analyse experimental results
S9. Entrepreneurial awareness				

Radiation: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
The electromagnetic spectrum	• electromagnetic spectrum • waves (frequency, amplitude, wavelength and the relationship $E = hc/\lambda$) • calculations involving above with units and powers of 10 • comparison of light and sound waves • comparison of gamma and X-rays • generation and detection of waves • radiowaves, microwaves, infrared, visible, ultraviolet, X-ray and gamma • uses of radiowaves	Students can investigate different parts of the electromagnetic spectrum and identify uses of the different parts. They should also be able to calculate energy and frequencies and identify the energy associated with different parts of the spectrum. Examples of uses of different parts of the EMR (electromagnetic radiation) spectrum can be chosen from: radio, wireless routers, analogue and digital signals, DAB (digital audio broadcasting), microwave ovens, mobile phones, IR-remote control, photography or other examples Some useful websites: **http://www.cem.msu.edu/~reusch/VirtualText/Spectrpy/spectro.htm#contnt** **http://hyperphysics.phy-astr.gsu.edu/%E2%80%8Chbase/hframe.html** **http://www.chemguide.co.uk/index.html#top** **http://www.sep.org.uk** (the booklet 'Light and Matter', which contains experiments on light, can be obtained from this site)
Properties of radiation	• light as a beam • reflection (law of reflection and angle of incidence, total internal reflection, fibre optics) • refraction (refractive index, Snell's law)	Students should find the laws of reflection and refraction by practical work. Experiments on reflection and refraction can be found at: **http://www.iop.org/activity/education/Projects/Teaching%20Advanced%20Physics/Vibrations%20and%20Waves/Reflection%20and%20refraction/file_4249.doc**

Topic	Suggested content	Teaching notes and materials
	• use of prism in binoculars, optical fibres as a tool in medicine • use of prism to disperse white light • lenses (converging and diverging, focal length, thin lens formula) • structure of the eye and how it sees; far sight and near sight, and how it can be corrected • wave properties of light • interference (wave interference, constructive and destructive) • diffraction (effect of grating on a beam of monochromatic light; calculations involving the relationship between wavelength, order, slit separation and angle for a grating) • use of a grating to measure wavelength	**http://www.iop.org/activity/education/Projects/Teaching%20Advanced%20Physics/Vibrations%20and%20Waves/Reflection%20and%20refraction/file_4254.doc** Use of a grating to measure wavelength from a laser can be found at **http://www.iop.org/activity/education/Projects/Teaching%20Advanced%20Physics/Vibrations%20and%20Waves/Superposition/file_4265.doc** Students should investigate the uses of a prism, optical fibres and lenses in general. The website **http://www.practicalphysics.org/go/Collection_20.html** gives several experiments on diffraction and interference.

Topic	Suggested content	Teaching notes and materials
Interaction of radiation with matter	• emission and absorption • intensity of radiation, inverse square law • Doppler effect, red and blue shifts and similarity to sound waves • structure of the hydrogen atom, ground and excited states and ionization energy; how emission and absorption line spectra are produced • difference between atomic absorption and atomic emission spectroscopy; similarities/differences compared with UV/visible spectroscopy • IR spectroscopy (vibrational energy of stretching and bending, as a tool for identifying organic compounds, matching frequencies to specific functional groups, IR spectroscopy and its use as an analytical tool) • UV/visible spectroscopy (radiation causes electronic transitions, use in quantitative determination of	Instrumental techniques are used in forensic chemistry, and students can research the use of different techniques, giving the advantages and disadvantages. Techniques can include atomic emission, absorption, IR and UV spectroscopy. Examples of uses in forensics can be investigated. A useful source is a booklet entitled 'Forensic Chemistry', which can be obtained from the SEP website: **http://www.sep.org.uk/** To investigate the Intensity of radiation an experiment on the Inverse square law can be carried out. A simulated experiment on light intensity can be found at **http://jersey.uoregon.edu/vlab/InverseSquare/index.html** if equipment is not available. The following website gives an introduction to spectroscopy: **http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Spectrpy/spectro.htm#contnt** The Royal Society of Chemistry has a good website at: **http://www.rsc.org/images/SIASStudents_tcm18-159244.pdf** which gives good descriptions of spectroscopy and a forensic example — body in the lab. **http://www.cem.msu.edu/~reusch/VirtTxtJml/Spectrpy/InfraRed/infrared.htm** **http://www.chemguide.co.uk/index.html#top** gives a description of IR spectroscopy and sample spectra. IR spectroscopy: examination of spectra to identify functional groups. Tutorial plus spectra can be obtained at **http://orgchem.colorado.edu/hndbksupport/irtutor/tutorial.html**

Topic	Suggested content	Teaching notes and materials
	transition metals and 'highly conjugated' organic compounds) • absorbance and the Beer–Lambert law; calculations of concentration of metal ions • lasers (how they operate, stimulated emission, ruby laser and metastable states) • uses of radiation (medical – MRI and X-rays, industrial, general applications)	Students should determine the concentration of a cation using UV or visible spectroscopy. Other useful websites: **http://www.ccd.edu/chemistry/Handouts%202009/Beer's%20Law%20Experiment%20(One%20Week)%20FY09.pdf** **http://www.kii.ntf.uni-lj.si/analchemvoc/experiments.htm** Students should research a use of lasers and a medical or industrial use of an instrument which uses radiation. For details on MRI scans etc see **http://www.magnet.fsu.edu/education/tutorials/magnetacademy/mri/**

The human organism

The primary purpose of this Unit is to develop an understanding of the structure and organization of the human organism.

Introduction to the Unit

This Unit takes a novel approach to human biology, using infections, diet and exercise as key motivators to arouse the interest of students in how the human body is constructed and functions. It is more important that students have a firm understanding of the underlying principles than a detailed knowledge of each system of organs. This will allow new systems to be introduced as and when necessary and avoid the tedium of a traditional system-by-system approach. While it is not deemed mandatory that all the body systems should be covered, all students should cover the section on human cells as this is the key to understanding the remainder of the Unit. A minimum of three other topics should be researched. Two key 'tags' by which interest may be aroused are infections (relevant to most systems) or exercise and diet (cardiovascular, respiration).

The Unit is intended to be mainly research-based. For example, groups of 2-4 students can each be given a specific infection and asked to make a presentation to the class of their findings with regard to its cause, symptoms and treatment, together with some investigation into at least one of the body systems affected. Each group should investigate a different infection/body system to maximize the learning of the group as a whole. The universities of Delaware (**http://www.udel.edu/pbl/articles.html**) and Montreal (McGill) (**http://www.jdentaled.org/cgi/reprint/69/11/1186.pdf**) have examples of medical problem-based learning on their websites, although lecturers should consider supplementing these materials with lists of supporting resources in order to direct students' use of internet sites.

There is a wealth of biology websites available and lecturers may not wish to restrict themselves to those included in the Unit teaching notes. Mathematical modelling (of eg energy balances as related to diet, exercise and respiration) should be carried out as appropriate. Some that are of general use for this Unit are:

http://capewest.ca/pbl.html
http://www.uclan.ac.uk/health/schools/school_of_nursing/studying_in_school_of_nursing/sonic/scenarios/doris/doris.php
http://www.vts.intute.ac.uk/tutorial/medicine
http://www.pakmed.net/college/forum/?p=2715

The level of practical work should be as much as time allows, and experiments should be devised to complement and provide answers to problems arising from the theoretical sections of this Unit.

A separate publication with a number of infections scenarios is available to assist with enquiry-based exercises. It is recommended that the enquiry-based approach is used as much as possible.

On completion of this Unit students should be able to:

- describe the structure and function of the main human cells
- describe the causes and treatment of various human diseases
- relate the use of energy to nutritional requirements
- carry out energy balance calculations
- relate the use of energy to cardiovascular and respiratory functions
- describe the structure and function of at least three human body systems

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to carry out a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *The human organism*

Code	Key concepts and storylines developed	Developed by the student being required to:
B1	Organization and operation of the cell, and the nature, roles and management of the key chemicals of life	Describe the structure and function of the main human cells
B2	Organization and systems operation of an organism; homeostasis & control; healthy living & combating disease	Describe the structure and function of at least three human body systems
B3	Cell division, reproduction, heredity	Describe the structure and function of the main human cells
P4	Studies of forces, motion and energy	Measure and calculate human energy usage

Links from *The human organism* to other parts of the programme

Links to other Units	Topics involved
Links back to *Energy sustainability*	Exercise, diet, energy balance calculation
Links back to *Equations and graphs*	Mathematical modelling of exercise, respirations and diet
Links back to *Eukaryotic cells*	Human cells: structure and function. Energy and exercise
Links back to *Ecosystems*	Study of the spread and control of infections
Links to *Radiation*	Properties of radiation. The human eye and its links to the central nervous system
Links forward to *Statistics*	Interpretation of data on human exercise (particularly in the enquiry-based exercises)
Links forward to *Prosthetics*	Musculoskeletal system, nervous systems and drainage of tissue fluid. Computer modelling of biomechanical systems
Links forward to *Nanotechnology*	Medical applications of nanomaterials as diagnostic tools and as a means of delivering treatments
Links forward to *Genetics*	Stem cells and gene therapy. Meiosis and mitosis

Skills development in *The human organism*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Carry out several enquiry-based exercises
S2. Interpersonal communication and team working		✓		• Carry out several enquiry-based exercises
S3. Numeracy: assessing and manipulating data and quantity				
S4. Critical and logical thinking				
S5. Basic IT skills				
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis		✓		• Relate infections to structure and function of human body systems
S9. Entrepreneurial awareness				

The human organism: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Human cells	• cell structure seen through light microscope and images from electron microscope, eg plasma membrane • cytoplasm • organelles (nucleus) ribosomes, endoplasmic reticulum, mitochondria, centrioles and centrosomes) • flagella and cilia • cell products, eg melanin, lipids, glycogen • use of slides, illustrations and electron micrographs • structure in relation to function • specialist cells • the cell cycle (mitosis)	This is the only mandatory part of this Unit. Much of this topic will be fact-based but judicial use of practical work (eg non-human cells) may be used to stimulate interest and enquiry. Students could present a poster highlighting the structure of an animal cell as seen under the electron microscope or/and outline processes associated with the plasma membrane. Some useful websites: **http://www.bbc.co.uk/scotland/learning/bitesize/standard/biology/investigating_cells/cells_and_diffusion_rev1.shtml** **http://www.bbc.co.uk/scotland/learning/bitesize/standard/biology/investigating_cells/cell_division_rev1.shtml** **http://www.cellsalive.com/**
Tissues	• differentiation of cells to form tissues • structure in relation to function	Tissues could include epithelial (glandular, lining, covering), connective (cartilage, bone, areolar, adipose, elastic, reticular, collagen, muscle — smooth, skeletal, cardiac), nerve tissues (neurons, neuroglia).

Topic	Suggested content	Teaching notes and materials
		Given a diagram of the human body, students could prepare a poster showing an example in diagrammatic form of a particular tissue found in each highlighted area. The function of each tissue chosen should be specified. Some useful websites: **http://www.bartleby.com/107/** **http://www.meddean.luc.edu/lumen/MedEd/GrossAnatomy/dissector/mml/index.htm** **http://web.jjay.cuny.edu/~acarpi/NSC/14-anatomy.htm**
Organs	• concept of division of labour • organ systems • role of the body's organ systems • central nervous system	Organ systems could include skin, circulatory, lymphatic, urinary, nervous, endocrine, skeletal, muscular, or reproductive. The role of the body's organ systems could include identification of some abnormalities such as those associated with the heart (failure of *ductus arteriosus* or closure of *foramen ovale* after birth) or diverticulitis (infected sac-like pouches of the colon). Discussion of the central nervous system should cover its role in transmitting information between the brain and the organs etc (eg the eye). Students could compile a table highlighting the main organ systems, stating the main function of each, and should research at least three examples of a disease/disorder/malfunction affecting a system.

Topic	Suggested content	Teaching notes and materials
		Students could select one organ and prepare a coloured poster showing its histological structure, eg wall of the small intestine/stomach. Some useful websites: **http://www.bartleby.com/107/** **http://www.meddean.luc.edu/lumen/MedEd/GrossAnatomy/dissector/mml/index.htm** **http://web.jjay.cuny.edu/~acarpi/NSC/14-anatomy.htm**
Digestion	• mouth • pharynx • oesophagus • stomach • pancreas • liver • gall bladder • small intestine • large intestine • details of cell structure in relation to function • ingestion	Cell structure and function could include gastric glands in the stomach (oxyntic and peptic cells), pancreas (alpha and beta cells), liver, small intestines (Crypts of Lieberkühn), and large intestine (goblet cells). Ingestion could include mechanical digestion, functions of the stomach, pancreas, liver, small and large intestines, chemical digestion, absorption, assimilation and egestion. Students could present a poster showing the structure of the human digestive tract and specifying the function of each part shown. Some useful websites: **http://digestive.niddk.nih.gov/ddiseases/pubs/yrdd/** **http://www.bbc.co.uk/schools/ks3bitesize/science/organisms_behaviour_health/diet_drugs/revise1.shtml** **http://en.wikipedia.org/wiki/Digestion**

Topic	Suggested content	Teaching notes and materials
		Practical work could include an investigation into the action of amylase in the breakdown of carbohydrate, or the action of lipase on the breakdown of fat. Some useful websites: **http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/Carbohydrates.html** **http://www.biotopics.co.uk/nutrition/lipase.html**
Cardiovascular system	• blood • heart • simple laboratory techniques for the examination of blood components • role of haemoglobin in the uptake and transportation of respiratory gases • blood clotting mechanisms • measurement of blood pressure and pulse before and immediately after exercise	Study of blood could include erythrocytes, leucocytes, platelets, roles of the different cell types, normal values and plasma. Study of the heart could include its detailed structure, conduction system, cardiac cycle, structure of blood vessels (arteries, veins, capillaries, blood pressure, pulmonary, systemic and hepatic portal circulations). This topic readily gives the opportunity to engage interest through consideration of exercise and diet, and some numeracy could be introduced here, eg to calculate energy balances. The exercise 'tag' also facilitates the introduction of aerobic and anaerobic respiration cycles. Some useful websites: **http://www.bbc.co.uk/scotland/learning/bitesize/standard/biology/investigating_cells/enzymes_and_aerobic_respiration_rev1.shtml** **http://www.bbc.co.uk/scotland/learning/bitesize/standard/biology/**

Topic	Suggested content	Teaching notes and materials
		the_body_in_action/the_need_for_energy_rev1.shtml **http://www.ftexploring.com/me/me2.html** **http://en.wikipedia.org/wiki/Metabolism** **http://library.med.utah.edu/kw/pharm/** Practical work could include an examination of slides of human blood. Students could identify the different cell types and produce a table specifying the function of each cell type. Students could present a report describing the pulmonary and systemic circulations or the pathology of coronary heart disease. Some useful websites: **http://www.wadsworth.org/chemheme/heme/microscope/celllist.htm** **http://www.funsci.com/fun3_en/blood/blood.htm** **http://www.fi.edu/learn/heart/systems/systemic.html** **http://www.wisc-online.com/objects/ViewObject.aspx?ID=AP12704** **http://library.thinkquest.org/C0115080/?c=circ_sys** **http://www.ivy-rose.co.uk/HumanBody/Blood/Systemic_Circulation.php**
Lymphatic system	• lymphatic vessels • lymph organs • drainage of tissue fluid and formation of lymph • outline of defensive role of lymph	Lymph organs could include spleen, thymus gland, tonsils, lymph (gross structure only). Students could make a presentation outlining one of the functions of the lymphatic system, eg production of tissue fluid; uptake of tissue fluid; circulation of lymph, including the internal structure of a lymph node; role of the lymphatic system in the response to infection. A useful website: **http://www.healcentral.org/healapp/showMetadata?metadataId=4535**

Topic	Suggested content	Teaching notes and materials
Urinary system	• kidneys (nephron structure, blood supply) • ureters • bladder • urine production • urine storage and release by bladder • regulation of urine volume and composition • laboratory tests carried out by pathology laboratories	Students could investigate the urinary system including bladder, urethra, filtration, absorption, constituents of urine (normal and abnormal). The research might focus on one or more aspects of renal function, such as an explanation of filtration, explanation of reabsorption in different segments of the nephron, regulation of water balance, mentioning the role of the hypothalamus and pituitary. Some useful websites: **http://medicalcenter.osu.edu/patientcare/healthcare_services/urinary_bladder_kidney/anatomy_urinary_system/pages/index.aspx** **http://www.getbodysmart.com/ap/urinarysystem/menu/menu.html** **http://www.ivy-rose.co.uk/HumanBody/Urinary/Urinary_System.php** Practical work could include simple tests on mock urine samples and the relevance of abnormal results in relation to protein and glucose levels. Some useful websites: **http://www.medicinenet.com/urinalysis/article.htm** **http://www.creative-chemistry.org.uk/activities/documents/urinalysis.pdf** **http://www.creative-chemistry.org.uk/activities/urine.htm** **www.youtube.com/watch?v=TuWiy4_VDWY**

Topic	Suggested content	Teaching notes and materials
Respiration	• mouth • trachea • bronchi • bronchioles • alveoli • mechanics of breathing (inspiration, expiration) • action of intrinsic and extrinsic intercostal muscles and diaphragm • gaseous exchange (diffusion of gases) • recording of lung volumes (interpretation of spirometer readings) • measurement of the functions of the respiratory system in a range of conditions, eg exercise and asthma	Study of the mouth could include nasal cavities, pharynx and larynx. Students might explain the functional changes in asthma and present a labelled explanatory diagram of the respiratory system including the bronchial system. Explanation could be given as to the action of the internal intercostals and external intercostal muscles/diaphragm in the process of breathing. Some useful websites: **http://www.fi.edu/learn/heart/systems/respiration.html** **http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Pulmonary.html** **http://www.le.ac.uk/pa/teach/va/anatomy/case2/frmst2.html** Practical work could include students producing a graph showing gas values obtained by a spirometer, ie tidal volume, vital capacity, inspiratory reserve, expiratory reserve. Some useful websites: **http://www.patient.co.uk/health/Spirometry.htm** **http://www.patient.co.uk/doctor/Spirometry.htm** **http://priory.com/med/spiromet.htm** **http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1429904/pdf/brjclinpharm00230-0006.pdf**
Infections	• viruses as intracellular parasites, infection of cells (virus life cycle as demonstrated by phage) • bacteria as prokaryotic	Modes of transmission of pathogenic microorganisms could include: • inhalation (mycobacterium tuberculosis, influenza, pneumonia)

Topic	Suggested content	Teaching notes and materials
	microorganisms; examples of commensal floras (in skin, colon, mouth) and their roles • fungi as eukaryotic microorganisms, unicellular (eg yeast) and filamentous (moulds) • protozoa as unicellular organisms; examples of pathogens • modes of transmission of pathogenic microorganisms • response to infection • natural active immunity (outline of the immune response; roles of B and T lymphocytes, plasma cells and memory cells)	• ingestion (salmonella, vibrio, listeria, giardia) • penetration of skin (tetanus, hepatitis, plasmodium) • sexual transmission (HIV, syphilis, gonorrhoea, chlamydia) • mother to child (German measles, toxoplasmosis) Response to infection could include natural barriers (skin), secretions (eg lysozyme), mucus and cilia, phagocytes, macrophages, elevation of temperature. Students could present a report on an infection caused by a bacterium, protozoon, virus, or fungus. Examples that could be used are: • virus (HIV) • protozoa (malaria) • bacterium (TB, gonorrhea, typhoid, helicobacter) • fungus (ringworm) The study should include mechanism of invasion, pathogenesis and treatment, and incidence in UK (graphical presentation should be included). Students could be divided into groups, each group researching a different infection. The class as a whole should cover each of the four categories: virus, protozoa, bacterium, fungus.

Topic	Suggested content	Teaching notes and materials
		Some useful websites: http://microbewiki.kenyon.edu/index.php/Coxiella http://www.immunologyclinic.com/caseIndex.asp http://human-infections.suite101.com/ http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2603093/pdf/08-0305_finalD.pdf http://en.wikipedia.org/wiki/List_of_latent_human_viral_infections http://en.wikipedia.org/wiki/Hiv_infections http://ezinearticles.com/?Causes-of-Bacterial-Infections-and-Treatment&id=2028266 http://www.myoptumhealth.com/portal/Information/item/What+Causes+a+Bacterial+Infection %3F?archiveChannel=Home%2FArticle&clicked=true http://www.netdoctor.co.uk/health_advice/facts/virusbacteria.htm http://www.epigee.org/health/vaginal_infection.html

Investigation of a large infrastructure project

The primary purpose of this Unit is to encourage the student to apply some of the science, mathematics and technology principles learned through application to a recent, real-life, large engineering infrastructure project.

Introduction to the Unit

The project will involve the students probing issues of design, materials, logistics, quality and costs of the project, together with an environmental impact assessment and a brief analysis of what problems occurred and any lessons that can be drawn from them. The initial project selected is the construction, commissioning and problem resolution of the Glendoe hydroelectric power facility by Scottish and Southern Energy (SSE) on the banks of Loch Ness. Glendoe is Scotland's second-largest conventional hydroelectric station. It is the first large-scale station to be built since 1957 (when Errochty station in Perthshire, which has a capacity of 75MW, was opened). Glendoe can produce around 180 million units of green electricity, with a maximum capacity of 100MW: enough electricity to power almost 250,000 homes. It does not provide base power to the SSE's supply but comes online when the company's other power stations are working at peak capacity.

If additional case studies are required, a number of other hydropower projects are well documented. Where students are encouraged to contact commercial companies or other organizations directly, this should be managed in such a way as to minimize the burden on any organization.

On completion of this Unit students should be able to:

- take an overview of the Glendoe project
- understand methods of project planning and management
- appreciate the principles of project design
- apply scientific principles to materials selection
- appreciate project/process control methodologies
- research quality methodologies, including sustainability issues
- formulate and present conclusions of the case study

Approaches to assessment

In small groups or independently, students should research and discuss how the project was planned and managed, under the broad headings given. Small groups may be assigned different areas to research, with opportunities provided to feed back to and discuss findings with other groups.

The lecturer has the choice of getting the class to work in small groups or individually, and can also choose the amount of detail required and the format in which it is to be presented, ie a written report or perhaps in the form of a business presentation to help develop the students' communication skills.

While a fair amount of information can be researched from web sources, students may need to access other sources such as company annual reports etc, to be able to structure their report around the suggested key project issues headings.

Key concepts/storylines in *Investigation of a large infrastructure project*

Code	Key concepts and storylines developed	Developed by the student being required to:
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Realize the impact of the environment on the design and siting of a large infrastructure
E1	Project planning and management	Investigate the way in which the Glendoe hydroelectric power station was planned and project managed
E2	Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact	Investigate the design of important parts of the project
E3	Materials selection to meet required needs and to minimize costs	Investigate material choice in certain components
E4	Process control methodologies	Investigate project management methodology, material logistics and progress plan
E5	Quality methodologies and sustainability issues	Research quality control methods used in the project
G4	Study involving weather, climate and interplay with the biosphere	Relate the impact of weather conditions on the project to site selection
M2	Trigonometry, coordinate geometry	Appreciate the use of trigonometry and geometry as used in planning and design
M3	Vectors in two and three dimensions, components, products	Use vectors in structural design
M4	Basic introductory calculus	Use calculus to optimize conditions
M5	Basic statistics, variability, risk assessment	Carry out a risk analysis
P1	Applications in electricity and electronics	Have a knowledge of how electricity is generated and transmitted
P3	Study of a wide range of materials properties	Understand the rationale underlying material selection
P4	Studies of forces, motion and energy	Appreciate stress/strain in structures, and energy efficiency

Links from *Investigation of a large infrastructure project* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Numerical calculations throughout the Unit
Links back to *Forces, motion, energy*	Calculations involving power, acceleration and energy Possible link to causes of bridge failure
Links back to *Earth processes*	A knowledge of ecosystems
Links back to *Energy sustainability*	Methods of energy production, including hydroelectric
Links back to *Electricity*	Review of electricity in simple circuits and power transmission
Links back to *Equations and graphs*	Use of vectors, geometry, graphs, logarithms and exponentials in engineering calculations
Links back to *Calculus*	Use of calculus to calculate optimum conditions
Links forward to *Materials*	Identification of best materials for construction of different components

Skills development in *Investigation of a large infrastructure project*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Plan activities
S2. Interpersonal communication and team working		✓		• Work on the project as part of a team
S3. Numeracy: assessing and manipulating data and quantity		✓		• Perform engineering calculations
S4. Critical and logical thinking		✓		• Arrive at conclusions in a consistent and logical manner
S5. Basic IT skills		✓		• Use online research
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis		✓		• Make reasoned evaluations of the benefits and effectiveness of the infrastructure
S9. Entrepreneurial awareness				

Investigation of a large infrastructure project: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Overview of the Glendoe project	A brief overview of the project, including: • reasons for initiating the project • proposed impacts of the project on the economy, environment, local area and population • engineering disciplines used on the project • scope of work within the different disciplines, and how they link together	There would be considerable benefit if students were introduced to the Glendoe project through an initial session taking the form of a PowerPoint presentation, video/DVD overview presentation or introductory talk by an external expert. If not from the company itself, suitable speakers may be available from the STEM Ambassadors programme: **http://www.stemnet.org.uk/content/ambassadors** Opportunities should be provided for students to activate prior knowledge through small-group and whole-class discussion. Students should also be given an introduction to the case study process and what form the assessment of the Unit will take. These websites have useful articles about the Glendoe project: **http://www.newenergyfocus.com/do/ecco/view_item?listid=1&listcatid=125&listitemid=2777** **http://en.wikipedia.org/wiki/Glendoe_Hydro_Scheme** **www.mining-journal.com/__data/assets/issue_file_attachment/0004/121756/WT0810scr.pdf** (see page 16 for article 'All Systems Go for Glendoe') **http://scottishrenewables.com/MULTIMEDIAGALLERY/1DF99F66-E5BD-4823-82C3-10F3F501D30D.PDF** (economic impact)

Topic	Suggested content	Teaching notes and materials
Project planning and management	• goals and objectives • deliverables • schedules • any other plans such as risks, assumptions, dependencies, change management • handling and resolution of technical problems	In small groups and independently, students should research and discuss how the project was planned and managed, under the broad headings given. Small groups may be assigned different areas to research, with opportunities provided to feed back to, and discuss findings with, other groups. These websites have useful teaching materials: **http://miranda.hemscott.com/ir/sse/pdf/Annual_Report_020609.pdf** (Scottish & Southern Annual Report 2009: see pages 14, 15, 38) **http://www.scottish-southern.co.uk/SSEInternet/uploadedFiles/Corporate_Responsibility/Our_Performance/Reports/Report_items/CorporateResponsibility2009.pdf** (Scottish & Southern Corporate Responsibility Report 2009: see pages 54–55) **http://en.howtopedia.org/wiki/How_to_Plan_a_Micro_Hydro-power_Plant** (planning aspects for a hydropower plant)
Project design	• handling of a complex design process — how the project was broken down into sub-projects • investigating the major sub-contractors for the project and what technologies/ engineering disciplines they provided; coordination of overall design, build and commissioning	In small groups and independently, students should research and discuss how the project was designed, under the broad headings given. Small groups may be assigned different areas to research, with opportunities provided to feed back to, and discuss findings with, other groups. Calculations should be carried out by all students either individually or in small groups.

Topic	Suggested content	Teaching notes and materials
	• calculation of theoretical expected output from this hydropower development, using information found out about the development and this equation: $P_{th} = \rho\, qgh$ where P_{th} is the power theoretically available (W) ρ is the density (kg/m^3) (~1,000 kg/m^3 for water) *q* is the water flow (m^3/s) *g* is the acceleration of gravity (9.81 m/s^2) *h* is the falling height, head (m)	These websites have useful information on hydropower calculations: **http://www.engineeringtoolbox.com/hydropower-d_1359.html** **http://www.reuk.co.uk/Calculation-of-Hydro-Power.htm**
	• types of losses in practice that will reduce power output from the theoretical value; computation of likely actual value of power output • calculation of load factor using information available	NB if some of the losses and load factor parameters are not available for the hydro project being researched, data for other worldwide hydro projects can be found and used to complete the sample calculations.
Materials selection	• key materials used in construction, including infrastructure/access, buildings, machinery, power transmission, control and monitoring equipment, etc	In small groups and independently, students should research and discuss how project materials were selected, under the broad headings given. Small groups may be assigned different areas to research, with opportunities provided to feed back to, and discuss findings with, other groups.

Topic	Suggested content	Teaching notes and materials
	• special considerations regarding materials used in terms of function, product life cycle, geographic location, exposure to the elements, etc • discovery and investigation of major fault suffered shortly after commissioning Glendoe (consideration of design, materials, workmanship/ quality, other)	These websites have useful teaching materials: Articles about Glendoe project at **http://www.newenergyfocus.com/do/ecco/view_item?listid=1&listcatid=125&listitemid=2777** **http://en.wikipedia.org/wiki/Glendoe_Hydro_Scheme** Articles about the rock fall problem at **http://www.waterpowermagazine.com/story.asp?sc=2057146** **http://www.heraldscotland.com/business/corporate-sme/sse-in-30m-dispute-over-glendoe-tunnel-collapse-1.1029747**
Project/process control methodologies	Control of project on a day-to-day basis, including: • project management methodology used • material logistics (ie ensuring the right material/components are on site at the right time) • actual vs planned progress • change management	In small groups and independently, students should research and discuss project/process control methodologies for the project, under the broad headings given. Small groups may be assigned different areas to research, with opportunities provided to feed back to, and discuss findings with, other groups.

Topic	Suggested content	Teaching notes and materials
Quality methodologies, including sustainability issues	• processes used for manufacture of major components, such as turbines and generation equipment, as well as the overall project • testing (destructive, non-destructive, etc) of construction materials quality (eg concrete, steel, etc) • environmental impact assessment — major impacts and actions to minimize these impacts	In small groups and independently, students should research and discuss the quality methodologies used in the project, under the broad headings given. Small groups may be assigned different areas to research, with opportunities provided to feed back to, and discuss findings with, other groups. This website has useful teaching materials: **http://www.nepjol.info/index.php/HN/article/view/2496/2225** (article about turbine testing)
Formulation and presentation of conclusions of case study	• Either in small groups or individually, students should document and present their conclusions, with reasons, to the key project issues	Students should prepare independently or in small groups their conclusions and recommendations, under one or each of the headings given. If possible, student groups could be asked to present their findings orally to other groups, using PowerPoint if available. Written conclusions and oral presentations could be used for the purposes of assessment. Students can be asked to consider the following key project issues, and prepare a written report by individuals/groups: 1. Can the Glendoe hydropower project achieve its original objectives? Please explain with examples. 2. Could the rock fall problem have been avoided by better planning/use of materials/engineering etc? Please comment with reasons.

Topic	Suggested content	Teaching notes and materials
		3. Have the expected benefits/impacts of the project on the areas such as the economy, environment, local area, etc materialized? Please explain with examples.

Statistics

The primary purpose of this Unit is to develop a basic understanding of the mathematical techniques used in statistics and to appreciate how these techniques can be used in a wide range of scientific and engineering applications.

Introduction to the Unit

In this Unit the ideas of uncertainty and variability in the context of science and engineering applications are introduced and linked to mathematics. The lecturer is free to select the method most suitable for the particular class. It may be that in some circumstances formal teaching of statistics first, followed by the introduction of the chosen examples, will be the best approach. An alternative method would be to look at a particular application and see how the results can be calculated. The aim of this Unit is to demonstrate the use and application of statistics in a variety of situations.

On completion of this Unit students should be able to:

- understand the basic idea of a statistical distribution, ideas of mean, median, mode and standard deviation, and recognize variability within samples and in populations
- handle basic examples involving random events and their probability
- identify random and systematic errors that occur in experimental measurements and show how these can be quantified
- examine the parameters considered in the scientific modelling of a complex situation and identify the inherent uncertainties
- analyse reliability and breakdown data for manufactured equipment and design issues
- perform quantified risk assessment exercises for practical activities
- discuss risk versus benefit issues for a technology development

Approaches to assessment

Assessment will mainly be by satisfactory completion of worksheets and production of laboratory reports, which will include risk assessments.

The following websites are generally useful for this Unit:
http://www.analyzemath.com/statistics.html
http://www.analyzemath.com/appliedmath.html
http://www.mathsrevision.net/alevel/statistics/
http://www.colorado.edu/physics/phys1140/phys1140_sp05/Experiments/O1Fall04.pdf
(counting statistics and background radiation)
http://www.math.ucdavis.edu/~kouba/ProblemsList.html
http://www.emathzone.com/tutorials/basic-statistics/
http://www.internetworldstats.com/stats4.htm
http://www.doh.wa.gov/Hanford/publications/overview/epidemiology.html

Key concepts/storylines in *Statistics*

Code	Key concepts and storylines developed	Developed by the student being required to:
B2	Organization and systems operation of an organism: homeostasis and control; healthy living and combating disease	Interpret statistical charts containing information on accidents and diseases
C3	Reactions, including mechanisms and yields	Perform volumetric experiments
E2	Product design including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact	Examine and interpret reliability data which may originate from an industrial source
E5	Quality methodologies and sustainability issues	Examine and interpret data related to quality control procedures
G2	Study implicating major seismic processes	Investigate results of volcanic activity
G4	Study involving weather, climate and interplay with the biosphere	Investigate the parameters to be considered in modelling weather patterns
M5	Basic statistics, variability, risk assessment	Perform basic statistical calculations and carry out a risk assessment
P3	Study of a wide range of materials properties	Perform an experiment using QTC (quantum tunnelling composite) to test reliability and reproducibility of results
P5	Study involving spontaneous processes	Measure radioactive decay of an isotope

Links from *Statistics* to other parts of the programme

Links to other Units	Topics involved
Links back to *Radiation*	Measurement of radioactive decay
Links back to *The human organism*	Interpretation of data on human disease
Links back to *Atoms and molecules*	Laboratory quantitative measurements
Links forward to *Materials*	QTC material
Links forward to *Industrial chemical processes*	Experimental work involving acid-base or redox reactions
Links back to *Investigation of a large infrastructure project*	Use of data analysis to improve operational methods of manufacture or to alter design specification or replan maintenance
Links forward to *Commercial case studies*	Use of data analysis to improve operational methods of manufacture or to alter design specification or replan maintenance
Links forward to *Nanotechnology*	Assessing the benefits and risks involved in the use of nanomaterials
Links forward to *Genetics*	Variation, calculation of standard deviation in populations. Hardy—Wineberg equation

Skills development in *Statistics*

(Skills and levels refer to *A new educational framework for progression in science and engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Analyse, summarize and produce reports using statistical data
S2. Interpersonal communication and team working		✓		• Perform experiments as part of a team
S3. Numeracy: assessing and manipulating data and quantity		✓		• Handle statistical data
S4. Critical and logical thinking		✓		• Produce a well-structured report involving analysis of statistical data
S5. Basic IT skills		✓		• Use spreadsheets and word processing packages
S6. Handling uncertainty and variability		✓		• Calculate variance, estimate probability and perform a risk assessment
S7. Experimentation and prototype construction: design and execution		✓		• Plan and perform experiments involving a titration and testing material
S8. Scientific analysis		✓		• Analyse statistical and experimental data
S9. Entrepreneurial awareness				

Statistics: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Statistical distribution, mean, median, mode and standard deviation; variability within samples and in populations	• mean, mode and median • normal distribution • standard deviation • variance	Examples can be taken from published statistics or from experimental results. The statistics of counting for a radioactive source could be used (see *Calculus*) as a data source, or information can be accessed at websites given below. A risk assessment could also be carried out on the experiment looking at the nuclide, exposure times, shielding and dose rate, etc. Some useful websites: **http://www.des.umd.edu/rs/material/tmsg/rs4.html** (University of Maryland radioactive decay) **http://www.sprawls.org/ppmi2/STATS/** (errors in counting) **http://www.blackcatsystems.com/GM/experiments/ex5.html** (effect of altitude on background radiation) **http://www.blackcatsystems.com/GM/experiments/ex4.html** (statistics of counting)
Random events and their probability	• probability • probability distributions for binomial, Poisson and normal distributions • risks from data; risk vs benefit balance judgements	Risks from data such as rates of incidence of specific diseases or accidents can be estimated, risks ranked and judgements made balancing risks against benefits. Some useful websites: **http://www.americanheart.org/downloadable/heart/1265665152970DS-3241%20HeartStrokeUpdate_2010.pdf** (statistics on heart disease and smoking)

Topic	Suggested content	Teaching notes and materials
		http://www.cehjournal.org/0953-6833/10/jceh_10_24_060.html (epidemiology in practice: disease incidence blindness due to cataract) **http://www.cehjournal.org/0953-6833/10/jceh_10_23_042.html** (sampling size for cataract survey) **http://en.wikipedia.org/wiki/1918_flu_pandemic** **http://en.wikipedia.org/wiki/2009_flu_pandemic** (comparison of Spanish and Swine flu statistics) **http://www.seer.cancer.gov/** (cancer statistics for the US including effects of smoking) **http://www.seer.cancer.gov/stdpopulations/stdpop.19ages.html** (US population statistics by age groups) **http://www.ncbi.nlm.nih.gov/bookshelf/br.fcgi?book=gbd** (demographic and epidemiological characteristics of nations) **http://www.roseville.ca.us/civica/filebank/blobdload.asp?BlobID=4119** (analysis of likely hazards in Roseville, California) **http://www.ktl.fi/monica/** (data tables on risk of cardiovascular disease associated with smoking, blood pressure and weight)
Random and systematic errors in experimental measurements, and their quantification	• reliability of results • methods of expressing accuracy and precision, relative error • determinate and indeterminate errors	Class results from practical work such as a titration (or other quantitative measurement) could be used to see how results can vary from person to person and titration to titration. There is an experiment in the SEP (Science Enhancement Programme) booklet on QTC ('QTC: A Remarkable New Material

Topic	Suggested content	Teaching notes and materials
		to Control Electricity') available from **http://www.sep.org.uk/** which involves making and testing a tactile sensor. The focus of this experiment is on accuracy, precision, errors, reliability and reproducibility as, owing to the present structure of the material, results are not always very reproducible. (QTC is also investigated in *Materials*.)
Parameters to be considered in the scientific modelling of a complex situation and identification of inherent uncertainties	• examples of scientific modelling used in a complex situation, such as predicting the weather or dispersion of volcanic ash	The Met Office has a large amount of information on its website and there are some useful factsheets. One on the use of radar in forecasting is good as it shows how radar can be used to track rain and clouds and gives information on interference of the signal and the associated uncertainties. In the science section of the Met Office site there is information on how forecasts are obtained and also about improvements being made to the process. There is also information on volcanic activity worldwide and how dust clouds are monitored and tracked. Some useful websites: **http://www.metoffice.gov.uk/science/creating/** (the science of weather forecasting) **http://www.metoffice.gov.uk/corporate/library/factsheets/factsheet15.pdf** (use of radar in weather measurements) **http://www.metoffice.gov.uk/corporate/library/factsheets/factsheet11.pdf** (interpreting weather charts) The SEP (Science Enhancement Programme) booklet available from **http://www.sep.org.uk/** suggests lab experiments that can be carried out and also gives instructions on the use of the interactive climate model that can be found at **http://www.walker-institute.ac.uk/climatemodel/**

Topic	Suggested content	Teaching notes and materials
Reliability and breakdown data for manufactured equipment and design issues	• use of data analysis in industry to improve methods of manufacture, reduce outage time, replan maintenance or alter design specification	An example can be found for an offshore oil platform plant reliability data analysis at **http://www.emeraldinsight.com/Insight/ViewContentServlet;jsessionid= 61C8182B88A43373F79BC4C4FE1949C8?Filename=Published/EmeraldFullTextArticle/Pdf/1540060406.pdf.** Other useful websites: **http://www.riskamp.com/files/RiskAMP%20-%20Monte%20Carlo%20Simulation.pdf** (risk/Monte Carlo simulation) **http://www.riskamp.com/library/pertdistribution.php** (Pert distribution)
Quantified risk assessment exercises for practical activities; risk versus benefit issues for a technology development	• distinction between risk and hazard • quantification of probability • risk factors • perception of risk	This can be linked to practical work in various Units. For example, risk assessments can be carried out for a range of experiments. Discuss risk versus benefit for a suitable technology development. Information on risk assessment can be obtained from the Health and Safety Executive website; the address for a relevant leaflet can be found at **http://www.hse.gov.uk/pubns/indg163.pdf.**

Materials

The primary purpose of this Unit is to develop an understanding of the structure, properties and uses of different types of materials.

Introduction to the Unit

The Unit begins with metals and their alloys and looks at the effect of additives on the properties of different metals. Polymers can be looked at in some detail, and both addition and condensation polymers can be investigated. Natural and man-made polymers can also be discussed. Based on the knowledge gained on electronic structure in earlier Units, students can develop their understanding of the way in which semiconductors and superconductors operate and they can investigate different types of smart materials. Finally there is a section on recycling and the sustainable use of different types of materials.

On completion of this Unit students should be able to:

- understand the structure, properties and uses of metals and alloys
- understand the structure, properties and uses of polymers
- understand the structure, properties and uses of smart materials
- understand the structure, properties and uses of semiconductors and superconductors
- understand the sustainable use of materials (disposal and recycling)

Approaches to assessment

Assessment of this Unit will be by completion of project reports and laboratory reports on experimental work performed.

Key concepts/storylines in *Materials*

Code	Key concepts and storylines developed	Developed by the student being required to:
C1	The periodic table as a key explainer	Relate the properties of metals and alloys to atomic structure and bonding Relate the structure and properties of polymers to types of bonding and functional groups
C2	Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts	Relate the structure and properties of polymers to types of bonding and functional groups
C3	Reactions, including mechanisms and yields	Study the mechanisms of polymerization
C5	Processes involving light absorption/emission	Study the properties of smart materials which interact with radiation
P1	Applications in electricity and electronics	Investigate the electrical properties of metals, alloys and semiconductors
P3	Study of a wide range of materials properties	Study the properties of metals, alloys and smart materials
P6	Study involving non-classical physics	Investigate channel tunnelling

Links from *Materials* to other parts of the programme

Links to other Units	Topics involved
Links back to *Atoms and molecules*	Structure and properties of metals and alloys; bonding in carbon compounds
Links back to *Electricity*	Electrical properties of metals and alloys; properties of semiconductors
Links back to *Reactivity*	Condensation and addition polymerization
Links back to *Energy sustainability*	Revision and extension of work done on semiconductors
Links back to *Eukaryotic cells*	Natural polymers, such as carbohydrates, proteins and lipids
Links back to *Statistics*	QTC material and its variability in performance
Links forward to *Nanotechnology*	Revision of semiconductors
Links back to *Investigation of a large infrastructure project*	Identifying best materials for construction of different components
Links forward to *Prosthetics*	Selection of materials for upper and lower extremity prosthetics

Skills development in *Materials*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Find, summarize and produce notes on selected parts of this Unit, individually and as part of a team
S2. Interpersonal communication and team working		✓		• Communicate and work as part of a team working to perform experiments
S3. Numeracy: assessing and manipulating data and quantity		✓		• Draw phase diagrams and calculate composition of an alloy
S4. Critical and logical thinking			✓	• Produce a well thought out and logical report on polymers, metals, smart materials or semiconductors
S5. Basic IT skills		✓		• Use PowerPoint, draw graphs and prepare word documents
S6. Handling uncertainty and variability		✓		• Measure conductivity of QTC with applied force and reproducibility of results (errors, systematic and random variability of results)
S7. Experimentation and prototype construction: design and execution		✓		• Plan experiments to prepare and test a polymer
S8. Scientific analysis		✓		• Analyse experimental data
S9. Entrepreneurial awareness		✓		• Research and find new uses for smart materials

Materials: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Structure, properties and uses of metals and alloys	• properties and bonding in metals • how bonding is related to structure • lattice types and dislocations • crystal grains and grain boundaries • how grain size can be controlled and how this affects properties • simple alloys; cooling curves and phase diagrams; eutectic mixtures • the effect on strength of adding carbon to steels • thermal, electrical and mechanical properties of some metals and alloys and how these govern their use	This is a cycle 4 Unit and by this time students will have been encouraged to be more independent, to find information themselves and to work as part of a team. Details of a curriculum project on the structure and properties of metals and alloys can be found at **http://www.nsec.northwestern.edu/S.Zaucha_Curriculum%20Project.pdf** The Science Enhancement Programme booklet 'Metals, Alloys and Smart Materials' compares the properties of these materials and gives experiments. This booklet can be downloaded from **http://www.sep.org.uk**
Structure, properties and uses of polymers	• typical uses of polymers such as polyethylene, polystyrene, PVC and nylon • structure of polymers • monomer unit, chain length, branching and cross-linking; addition polymerization (initiation, propagation and termination stages)	Students can learn about polymers, their history, their uses and their recycling. They can also produce some polymers (slime and gluep) in practical work in the laboratory. There are lesson plans and experiments at **http://www.grc.nasa.gov/WWW/k-12/Summer_Training/Magnificat/Polymer_Project.html#Objective.** Other experiments such as making a rubber ball or a rubber band are found in the SEP publication 'Fantastic Plastic', which can be obtained from **http://www.sep.org.uk**

Topic	Suggested content	Teaching notes and materials
	• condensation polymerization and step growth reaction; properties of a polymer and dependence on chain length, branching and cross-linking • selection of material's properties for given uses • revision of some natural polymers (carbohydrates, proteins and lipids — a more detailed look at structure) • preparation of a polymer and an examination of two of its properties	Details of how to make nylon can be found on the RSC website at **http://www.rsc.org/Education/EiC/issues/2006Mar/ExhibitionChemistry.asp.**
Structure, properties and uses of smart materials	• types of smart materials (piezoelectric, pH-sensitive polymers, chromogenic systems and QTC materials, conductive plastic, liquid crystal displays)	Students can work in groups to gather information and share with the class. Research should focus on **piezoelectric materials** (produce a voltage when stress is applied and increase in volume with application of current; use as sensors, eg airbag sensor in car, and as an igniter; piezoelectric effect and piezoelectric crystals), **pH-sensitive polymers** (swell or collapse on change of pH; use in controlled drug delivery; advantages of controlled drug delivery; swelling of polymer in situ and delivery of drug; structure of polymer and the monomer unit, eg polyvinyl alcohol and polyacrylic acid; general uses of biomaterials in joint replacements, dental implants, contact lenses, breast implants), **chromogenic systems** (**electrochromic** materials change their colour on the application of a voltage, eg **liquid crystal displays**; **thermochromic** materials change in color depending on their temperature; **photochromic** materials change colour in response to light, eg light-sensitive **sunglasses** that darken when

Topic	Suggested content	Teaching notes and materials
		exposed to bright sunlight), **quantum tunnelling composite or QTC** consists of nickel particles in a rubbery polymer; properties of QTC and how it can act as a sensor Measurement of conductivity of QTC with applied force and reproducibility of results (errors, systematic and random variability of results). **Conductive plastic** consists of conjugated polymers such as polyacetylene, which are conducting and could be used for electroluminescent displays in phones. **Liquid crystal displays (LCD)**: Liquid crystals; the two main phases, nemetic and smectic. How an LCD works. Polarization of light and the effect of a liquid crystal on polarized light. Colour LCD. It is suggested that students work in groups to produce a PowerPoint presentation on two different types of smart materials to the class. These websites may be useful: **http://smart.tamu.edu/overview/overview.html** (smart materials and demonstrations) **http://smart.tamu.edu/overview/smaintro/detailed/detailed.html** (shape memory alloys) **http://computer.howstuffworks.com/boolean.htm** (boolean logic) **http://nobelprize.org/educational_games/physics/liquid_crystals/history/index.html** (liquid crystals) **http://electronics.howstuffworks.com/lcd2.htm** (introduction to how LCDs work, nematic phase liquid crystals, creating an LCD)

Topic	Suggested content	Teaching notes and materials
		http://webdocs.cs.ualberta.ca/~database/MEMS/sma_mems/smrt.html (piezoelectric materials) Students should also think of a novel use of a smart material and explain the advantages of its use.
Semiconductors and superconductors	• silicon (valency, bonding and conductivity) • doping, N and P type, the diode, transistor (3 layers) NPN and PNP sandwich acting as a switch or amplifier, silicon chip and microprocessor chips • uses of chips, their development and Moore's law • superconductors; superconductivity and critical temperature • Meissner effect (magnet levitation) • elementary theory of superconductivity and tunnelling • super magnets and magnetic levitated trains	Students can be asked to research how semiconductors work and their use. Semiconductors have been mentioned in *Energy sustainability* and so this Unit should consolidate ideas. Some useful websites: **http://media.rsc.org/Classic%20Chem%20Demos/CCD-89.pdf** (the electrical conduction of silicon — a semiconductor) **http://www.howstuffworks.com/diode.htm** (semiconductors) **http://en.wikipedia.org/wiki/Semiconductor** (semiconductors) **http://www.howstuffworks.com/framed.htm?parent=superconductivity.htm&url=http://www.ornl.gov/reports/m/ornlm3063r1/contents.html** (note on superconductors)
Sustainable use of materials	• the need for recycling and the need to use materials more effectively	Useful material on recycling can be obtained at the SEP site **http://www.sep.org.uk**

Topic	Suggested content	Teaching notes and materials
	• methods of waste separation (density, electrostatic properties, IR) • methods of converting waste into a fuel (incineration, gasification and anaerobic digestion) • methods of waste disposal, problems with asbestos	

Prosthetics

Introduction to the Unit

This Unit is intended to develop an understanding of the processes involved in designing an item to meet the needs and requirements of the user. It involves an extensive application of materials science in terms of properties and manipulations of different materials to match the prosthesis to the needs of the wearer. There is also an element of mathematical modelling and practical design of prosthetics to suit the special needs of the end-user.

The content is included as a guideline only. Lecturers/students may choose to concentrate on particular areas of interest. Students should work in groups of 2-4 investigating different topics and report back to the rest of the class at the end. The most important aspect of this project is for the student to gain experience in scientific/engineering enquiry of a real prosthesis (which could be any device that is complex enough to cover most of the suggested topics).

It is envisaged that individual students will undertake different tasks and that no students may tackle all the topics in the suggested content. Nevertheless students will gain experience in areas outwith the standard curriculum.

Within this project, several aspects can be carefully studied: conceptual studies; scaled prototyping; structural engineering; materials selection; CAD/CAM mould making; advanced sandwich composite-structure manufacture; automation (programming and control); and testing. It has been shown that teaching—learning based on projects gives excellent results in terms of transferable skills enabling students to gain experience in facing the problems encountered by practising engineers and scientists. Each team should investigate a (different) prosthetic and report back to the class.

There are a number of useful general websites for this Unit:

http://ngm.nationalgeographic.com/2010/01/bionics/fischman-text
http://science.jrank.org/pages/5527/Prosthetics.html
http://emedicine.medscape.com/article/317358-overview
http://www.slideshare.net/usapuka/prosthetic-joint-infection
http://www.biomaterials.group.shef.ac.uk/prosthesis/index.php

On completion of this Unit students should be able to:

- select materials for a particular device for a particular user
- relate structure to function for a number of materials
- use CAD/CAM as a design tool
- understand methods of manufacturing for prosthetics
- use cybernetics and design and test control systems
- carry out biomechanical calculations and analysis
- analyse body systems, eg upper/lower extremities, in terms of the forces encountered in different environments

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to carry out a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Prosthetics*

Code	Key concepts and storylines developed	Developed by the student being required to:
C2	Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts	Relate structure and properties of materials. Select appropriate materials
CI6	Analysing design issues in a number of applications (from in-built control devices in appliances to large scientific and technological information processing systems)	Design and test control systems particularly for upper and lower extremity replacements
E2	Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact	Select appropriate materials for functionality and user comfort
E3	Materials selection to meet required needs and to minimize costs	Select appropriate materials for functionality and user comfort
M6	Key tools from numeracy, algebra, proportion and graphs	Carry out biomechanical calculations and model human systems
P1	Applications in electricity and electronics	Design and test control systems particularly for upper and lower extremity replacements
P3	Study of a wide range of materials properties	Relate structure and properties of materials. Select appropriate materials
P5	Study involving spontaneous processes	Design and test control systems particularly for upper and lower extremity replacements

Links from *Prosthetics* to other parts of the programme

Links to other Units	Topics involved
Links back to *Calculus*	Mathematical modelling of prosthetics. Biomechanical calculations
Links back to *Materials*	Selection of materials for (mainly) upper and lower extremity prosthetics
Links forward to *Information systems*	Designing and testing control systems. Using CAD/CAM systems in a design environment. Cybernetics and artificial intelligence
Links back to *The human organism*	Musculoskeletal system, nervous systems and drainage of tissue fluid. Computer modelling of biomechanical systems
Links back to *Radiation*	Diagnostic imaging using MRI and CT methods
Links back to *Numeracy*	Biomechanical calculations
Links back to *Electricity*	Designing and testing control systems

Skills development in *Prosthetics*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Carry out enquiry-based exercises
S2. Interpersonal communication and team working		✓		• Carry out enquiry-based exercises
S3. Numeracy: assessing and manipulating data and quantity		✓		• Use mathematical modelling of upper and lower extremity action and transfer to prosthetics
S4. Critical and logical thinking				
S5. Basic IT skills		✓		• Use computer modelling of upper and lower extremity action and transfer to prosthetics. Use CAD/CAM
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution		✓		• Design prosthetics
S8. Scientific analysis				
S9. Entrepreneurial awareness		✓		• Design prosthetics to suit patients' requirements

Prosthetics: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Design	• mathematical modelling • development of biomaterials	Some useful websites: **http://www.cbte.group.shef.ac.uk/** **http://www.amputee-coalition.org/inmotion/sep_oct_98/matinprs.html**
CAD/CAM methods	• practical application	Some useful websites: **http://infinitycadsystems.com/** **http://www.dentsply-friadent.com/downloads/CC_FRIALIT_EN_002.pdf** **http://www.oandpbusinessnews.com/view.aspx?rid=58917**
Manufacturing systems	• moulding • working with a vacuum	A useful website: **http://www.indymogul.com/post/9521/wesleys-weekly-presents-slush-mold-prosthetics**
Cybernetics	• mathematical modelling techniques • science underlying cybernetic systems • design of systems • engineering practice	Students should be able to appreciate the usefulness of mathematics as a tool to analyse systems and for communicating results. The concept of systems design, including relevant design methods, and the use of appropriate technology, should be included. Teams should calculate the forces that would be experienced by particular prosthetics (eg limbs) and design the prosthetic (material, controls, power of motors, etc).
Artificial intelligence		Some useful websites: **http://en.wikipedia.org/wiki/Cybernetics** **http://en.wikipedia.org/wiki/Robotics** **http://www.well.com/~abs/curriculum.html**

Topic	Suggested content	Teaching notes and materials
		http://carbon.cudenver.edu/~mryder/itc_data/complexity.html http://edition.cnn.com/2006/TECH/science/04/10/cybernetics.profile/ http://wordinfo.info//words/index/info/view_unit/3396/?letter=P&spage=15
Human biology	• musculoskeletal system • nervous system	
Biomechanics	• gait analysis • kinesiology • vector and tensor calculus • computer modelling • forces	Hooke's law could be used as the basis for carrying out computer modelling of the stress—strain relationships in bones. The concepts of the moment and the fulcrum should be used when discussing the forces experienced at joints for example. Calculations should be carried out using problems taken from real problems arising in biomechanics. Some useful websites: http://en.wikipedia.org/wiki/Biomechanics http://www.oandp.org/jpo/library/1997_03_113.asp
Diagnostic Imaging	• MRI • CT	There should be some discussion about the theory behind MRI and CT approaches, and if possible students should gain some experience interpreting real scans. Some useful websites: http://en.wikipedia.org/wiki/Magnetic_resonance_imaging http://health.howstuffworks.com/medicine/tests-treatment/mri.htm http://www.netdoctor.co.uk/health_advice/examinations/ctgeneral.htm

Topic	Suggested content	Teaching notes and materials
		http://www.cancerhelp.org.uk/about-cancer/tests/ct-scan http://www.slideshare.net/keshrad/basics-of-mri http://www.slideshare.net/guest22ef299/mri-2868265
Materials	• sheet thermoplastics • thermosetting resins • strengtheners in laminates • co-polymers: advantages and disadvantages of different materials • lamination process, fitting and modifying • silcones and metals: advantages and disadvantages of different materials • choice of material vs function/ working environment / patient comfort • testing of materials • liners and sleeves, cosmetic finishing • biocompatibility and durability issues • synthesizing and working with a selection of materials	As many as possible of the following materials should be covered: • sheet thermoplastics: polypropylene, polyethylene • thermosetting resins: acrylic, epoxy and polyester • strengtheners in laminates: fibreglass, nylon, dacron, carbon, and Kevlar; advantages and disadvantages of different materials • silcones and metals: aluminum, stainless steel and titanium. Teams should be set up to investigate the properties and applications of several materials and to determine their advantages and disadvantages for manufacturing particular prosthetics. This should include suitability for end-users with special requirements (perhaps linked to lifestyle or age). Teams should also link structure to properties. The requirements of ex-service personnel amputees, for example, might serve as a good 'tag'. Some useful websites: http://www.me.mtu.edu/~mavable/MoM2nd.htm http://www.amputee-coalition.org/inmotion/sep_oct_98/matinprs.html http://www.amputee-coalition.org/inmotion/nov_dec_98/primer.html

Topic	Suggested content	Teaching notes and materials
Hip	• materials • tribology concepts	A useful website: **http://en.wikipedia.org/wiki/Tribology**
Sight	• camera-implant—optic-nerve systems • control systems • performance requirements • clinical evaluation	Some useful websites: **http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2724470/** **http://www.seeingwithsound.com/sensub.htm**
Hearing	• cochlear implants	Some useful websites: **http://www.slideshare.net/em5883/modelling-the-human-cochlea-ku-2008**
Upper and lower extremities	• materials • requirements • plaster casts	Some useful websites: **http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04524162** **http://www.oandplibrary.org/alp/chap12-04.asp** **http://books.google.co.uk/books?id=rlX20jOFWT4C&pg=PA285&lpg=PA285&dq=uppere+extremity+prosthetic+design&source=bl&ots=BdTd2E_71Q&sig=GPpRbpJyA8-i1N5-lt3FnYV7Apk&hl=en&ei=tI9WTOOWM4WUjAef6IHDBA&sa=X&oi=book_result&ct=result&resnum=9&ved=0CD8Q6AEwCA#v=onepage&q&f=false** **http://www.musculographics.com/pdf/1990_interactive.pdf** **http://www.ijpmr.com/ijpmr01/200107.pdf**

Topic	Suggested content	Teaching notes and materials
Dental	• materials: glass ceramics, glass cements, acrylics	Some useful websites: **http://webcache.googleusercontent.com/search?q=cache:EFA5RplcwqMJ:hudsonvalleydentalprosthetics.com/yahoo_site_admin/assets/docs/CAM_StructSURE_Precision_Milled_Bars.253420.ppt+design+of+dental+prothetics&cd=6&hl=en&ct=clnk&gl=uk** **http://en.wikipedia.org/wiki/Dentures**
Heart valves	• materials: titanium, graphite, pyrolitic carbon polyester • performance and design requirements • monitoring and modelling blood flow • use of anticoagulants	Design and performance requirements are very closely linked, and topics such as durability, reliability and powering of devices should be covered. Some useful websites: **http://www.slideshare.net/mohamadobedat/adult-patient-with-functioning-prosthetic-mitral-valve-without** **http://www.slideshare.net/monayoussef/prosthetic-heart-valves-3363872**
Presentations	• individual • group	Teams should research the use of prosthetics in one area (eg sight, hearing, etc) and produce a report detailing the history, development and current state of artificial replacement.

Industrial chemical processes

The primary purpose of this Unit is to develop an understanding of the chemical principles which underpin the industrial preparation of many chemicals and pharmaceuticals.

Introduction to the Unit

It is important to produce chemicals and pharmaceuticals in the most economic way and this can be achieved through an understanding of the factors which control chemical reactions. Energy, usually in the form of heat, may need to be supplied to a chemical reaction, or the reaction itself may release energy. Such energy changes have economic and safety consequences if not controlled. These energy changes and their implications are studied in the first part of this Unit. The principles of chemical equilibrium, reaction rates and acid base theory are explained in relation to examples in the chemical or pharmaceutical industries, and the key role played by catalysts and buffers in many processes is emphasized. There is also an introduction to 'green chemistry' and the concept of atom efficiency.

Chemistry storylines are central to this Unit, and engineering aspects should be engaged whatever the specific chosen applications. Some science and mathematics themes are likely to be revisited throughout the Unit, depending on the specific applications chosen for analysis.

A useful general resource for this Unit is the film *Industrial Chemistry for Schools and Colleges* (The Royal Society of Chemistry).

On completion of this Unit students should be able to:

- relate the influence of enthalpy changes to industrial chemical reactions
- understand and apply the principles of chemical equilibrium to industrial chemical reactions
- apply the principles of acid-base and redox equilibria to industrial chemical reactions or to drug delivery
- understand the importance of reaction mechanism and reaction rate in industrial processes
- have a knowledge of 'green chemistry'

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked with some sampled cross-marking by the lecturer. It may be possible to carry out a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *Industrial chemical processes*

Code	Key concepts and storylines developed	Developed by the student being required to:
C1	The periodic table as a key explainer	Relate chemical properties of elements to their atomic and electronic structure
C2	Understanding bonding and 3D structures of molecules, notably in organic and biological and materials contexts	Relate bonding type and molecular shape to electronic structure and deduce the properties of compounds by bond type
C3	Reactions, including mechanisms and yields	Investigate the reaction mechanisms of the polymerization process Investigate a 'green' industrial synthesis Investigate enthalpy changes
C4	Solution processes, including electrochemistry and reaction equilibrium	Investigate the equilibrium concept in industrial processes Investigate the electrolytic process in industry Study acid-base equilibria
E2	Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact	Investigate the factors involved in maximizing the cost effectiveness in chemical industrial processes
E4	Process control methodologies	Investigate methods of control in chemical manufacture
P1	Applications in electricity and electronics	Investigate electron transfer processes and electrolysis in industry
M1	Exponentials and logarithms (including exp and ln)	Perform acid-base and buffer calculations
M6	Key tools from numeracy, algebra, proportion and graphs	Manipulate equations and perform numerical and algebraic tasks

Links from *Industrial chemical processes* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Enthalpy changes: calculations involving Hess's law Chemical equilibrium: calculations involving equilibrium, the second law of thermodynamics and free energy Green chemistry: calculations of atom efficiency
Links back to *Equations and graphs*	Reactions in solution: calculations involving pH, buffer solutions and electrolysis Calculations involving acids/bases, buffers, equilibrium constants
Links back to *Atoms and molecules*	Enthalpy changes: writing chemical equations Chemical equilibrium: writing acid-base and redox equations
Links back to *Reactivity*	Reaction mechanism and type: polymerization
Links back to *Electricity*	Electrode processes: electron transfer processes, electrolysis
Links back to *Energy sustainability*	Enthalpy changes and Hess's law
Links back to *Calculus*	Revision of reaction rates
Links back to *Earth processes*	Agriculture in support of the human population: links into aspects of industrial manufacture
Links back to *Calculus*	Use of chemical kinetics in industrial processes
Links back to *Statistics*	Experimental work involving acid-base and redox reactions
Links forward to *Nanotechnology*	Revision of catalysts and fuel cells

Skills development in *Industrial chemical processes*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning		✓		• Plan experiments and produce a detailed report, with précis on an industrial process
S2. Interpersonal communication and team working		✓		• Perform experiments as part of a team • Produce a report on an industrial process
S3. Numeracy: assessing and manipulating data and quantity		✓		• Perform calculations relating to chemical equilibrium, enthalpy changes, thermodynamics, acid-base reactions and atom efficiency
S4. Critical and logical thinking		✓		• Produce well-structured, more extensive reports, including references and a critical assessment of conclusions
S5. Basic IT skills		✓		• Draw graphs using a spreadsheet, and produce written reports
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution		✓		• Design and execute an experiment to calculate an equilibrium constant
S8. Scientific analysis		✓		• Draw appropriate conclusions from results
S9. Entrepreneurial awareness				

Industrial chemical processes: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
The influence of enthalpy changes on industrial chemical reactions	• definition and units of enthalpy change; standard molar enthalpy change of reaction; enthalpy change of formation, combustion, atomization and neutralization; sign convention; exothermic and endothermic reactions; internal energy and work • principle and law of conservation of energy; Hess's law • measurement of standard molar enthalpy change for a reaction; calculation of standard molar enthalpy changes for reactions from supplied data • enthalpy changes in industrial processes; implications for process design and operating conditions	Delivery of this topic can be through lectures, discussions, laboratory practical work and calculations involving Hess's law. It could also be delivered using the example of a car and the fuel it uses as a means to investigate enthalpy and Hess's law. The efficiency of a car engine could be investigated and there is information on this at the ChemCases website at **http://chemcases.com/fuels/fuels-a.htm#Thermochemistry** (efficiency of combustion in cars). The industrial importance of temperature control, the economics of heat exchange and their influence on process and plant design should be covered in relation to specific examples such as the Haber or Contact process. Some useful websites: **http://www.rsc.org/education/teachers/learnnet/alchemy/index2.htm** (Haber process) **http://www.chemguide.co.uk/physical/catalysis/introduction.html#top** (Haber process) **www.ausetute.com.au/haberpro.html** (Haber process) **www.chemguide.co.uk/physical/equilibria/contact.html** (Contact process) There is also a Royal Society of Chemistry video on the chemical industry called *Industrial Chemistry for Schools and Colleges*.

Topic	Suggested content	Teaching notes and materials
The principles of chemical equilibrium and thermodynamics as applied to industrial chemical reactions	• principles of chemical equilibrium • reversible processes • equilibrium law • Kc • effects of changes in concentration, pressure and temperature on equilibrium position (Le Chatelier's principle) • effects of changes in concentration, pressure and temperature on Kc • catalysts (also enzymes) and equilibrium • determination of Kc for a reaction in aqueous solution • second law of thermodynamics • free energy • criterion for the spontaneity of a reaction • industrial processes involving chemical equilibria • use of pressure and temperature to drive equilibria • reasons for operation under non-equilibrium conditions	This topic relates to aspects of equilibrium and may be delivered through lectures, discussions, presentations, laboratory practical work, data interpretation and calculation exercises. Students should determine Kc for a reaction such as ester formation or hydrolysis. Several interactive programs illustrate the effects of changing conditions on the equilibrium position, and these would be useful to students. Students should be encouraged to research the industrial importance of chemical, acid-base and redox equilibria in specific industrial processes, such as the Haber process, Contact process, oxidation of ammonia, use of buffers in biochemical processes, stabilizers in food and pharmaceutical products. The role of acid-base chemistry and chemical equilibrium in the discovery, development and use of drugs such as phenobarbitol and penicillin could also be used to teach the principles. There are a series of simulated experiments on the web at: **http://www.chm.davidson.edu/vce/Equilibria/index.html** Chemcases.com have produced comprehensive material on drug pathways and chemical concepts which relate the concepts of chemical equilibrium and acid-base theory to drug development and delivery. This can be found at **http://chemcases.com/pheno/index.htm** Some useful websites: **http://www.chemguide.co.uk/physical/equilibria/haber.html** (details of equilibrium and operating temperatures and catalysts)

Topic	Suggested content	Teaching notes and materials
	• free energy considerations in industrial reactions • the Haber and Contact processes, including methods of preparing hydrogen for the ammonia production, preparation of nitric and sulfuric acids • production of nitrogen from the air • materials from ammonia and nitric acid including explosives and fertilizer	**http://www.schoolscience.co.uk/search.cfm?search_text=catalysts&subject_id=4749&x=8&y=7** (details of equilibrium and catalysts) **http://www.chemguide.co.uk/physical/catalysis/introduction.html#top** (action of catalysts, homogenous and heterogenous) **http://www.catalysis-ed.org.uk/pages/cat_frames.htm** (a good site for mechanism of catalysis and industrial applications including polymers, ammonia, ibuprofen and fuel cell development)
The principles of acid-base and redox equilibria applied to industrial chemical reactions or to drug delivery	• proton transfer in aqueous solution • pH scale and definition of pH • sources of H_3O^+ and OH^- ions • Lewis definition of acids and bases • conjugate acids and bases • dissociation of water, Kw and pKw • calculation of pH of strong acid and base solutions • acid-base strength, Ka, pKa • calculation of pH from Ka • acid-base indicators • pH titration curves	This topic relates to aspects of equilibrium and may be delivered through lectures, discussions, presentations, laboratory practical work, data interpretation and calculation exercises. Alternatively a more case study approach can be taken using the case given below. **http://www.sciencecases.org/acids_buffers/notes.asp** gives a medical case study about a girl who has swallowed a large number of aspirins and how she may be treated. It covers chemical equilibrium, pH, buffers and dissociation constants. **http://chemcases.com/pheno/index.htm** gives drug pathways and chemical concepts and also covers pH and buffers Another useful website: **http://www.riotintoalcan.com/index.asp** (aluminium smelting)

Topic	Suggested content	Teaching notes and materials
	• choice of indicator • buffer mixtures • calculation of pH of buffer mixtures • electron transfer processes • definitions of oxidation and reduction; equilibrium • revision of electrode processes and electrolysis • use of electrolysis in metal production, eg aluminium or copper • industrial applications of proton and electron transfer • pH control in processes and products • chlor-alkali industry (electrolysis of brine); corrosion control • use of buffers to control conditions in chemical/ biological reactions	
The importance of reaction mechanism and reaction rate in industrial processes	• revision of reaction rates • catalysts used in industry • homogenous and heterogenous • mode of action • poisoning	In this topic the influences of temperature and catalysts on reaction rates should be emphasized. Students should explore the economics of the choice of conditions for an industrial process such as the Haber process, Contact process, or nitric acid manufacture. At this stage students should bring together aspects of previous topics within this Unit to appreciate that compromise of choice of conditions between those giving high

Topic	Suggested content	Teaching notes and materials
	• polymerization processes; condensation; addition • mechanism and stages of reaction • addition reaction • manufacture of nylon • reaction rate in continuous and batch processes • process design to maximize rate • examples of industrial catalysis	equilibrium yield and those giving rapid rate of formation is often necessary for maximum economic benefit. Website for catalysis: **http://www.catalysis-ed.org.uk/pages/cat_frames.htm**
'Green chemistry'	• principles of 'green chemistry' and atom efficiency • controlling the production of waste material and contamination of the environment • multistage synthesis and overall efficiency • recycling of reactants and re-use of materials such as polymers and glass • manufacture of ibuprofen or similar 'green' approach to industrial production • use of enzymes as catalysts	In this topic, material produced by the Royal Society of Chemistry on 'green chemistry' is very helpful and the example of the 'green' approach to manufacture ibuprofen is given on their website at **http://www.rsc.org/education/teachers/learnnet/green/index2.htm** Other useful websites: **http://chemcases.com/pheno/index.htm** (information on drug pathways and chemical concepts) **http://www.catalysis-ed.org.uk/pages/cat_frames.htm** (mechanism of catalysis and industrial applications including ibuprofen)

Commercial case studies

The primary purpose of this Unit is to allow the student to develop and apply skills and information from other Units through carrying out research, analysis, and developing opinions and conclusions, and to learn about successful entrepreneurial activity in Scotland.

Introduction to the Unit

Scottish universities are renowned for producing ground-breaking research in many areas within science, engineering and technology. The higher education sector punches well above its weight in terms of the international impact of its research, in terms of both quantity and quality. With just 0.1% of the world's population, Scotland produces 1% of the world's published research. A recent independent survey also found that Scotland had the highest rate of citations (a peer reviewed mark of quality) per level of expenditure on higher education research in the world for the five-year average between 1999 and 2003 (Universities Scotland — Facts & Figures: International — Public Information Briefing 13 at **http://www.universities-scotland.ac.uk/uploads/briefings/international F&F.pdf**). However, when it comes to translating this research into successful commercialization, Scotland does not rate so highly. Nevertheless there are a good number of successful entrepreneurial companies where products have been researched, developed and produced in Scotland. This Unit offers three examples in different technology areas and operating in different market sectors, to learn lessons from this entrepreneurial activity as part of the on-going education process to improve Scotland's commercialization record. These areas cover sectors of the economy where Scotland has real strengths — computer games development, high-quality design and manufacture of niche consumer products and cutting-edge medical technology.

In this Unit, for each company, the student is asked to develop a case study, the content of which can be structured around a set of questions designed to bring out the key success factors for the company and the entrepreneur who started it, the risks taken by the founder and how the business was initially funded. Students can work independently and as part of a group to conduct research in more or less detail. The case study findings can be presented in various ways, for example as a written report or perhaps in the form of a business presentation to help develop students' communication skills. The findings can also form the basis for whole-class discussions and further study.

While a fair amount of information can be researched from web sources, students will need to access other sources such as product brochures and company annual reports to be able to structure their report around the suggested questions. Care should be taken to ensure that companies are not bombarded by multiple requests for similar information when one approach would be sufficient.

Efforts should be made to engage the interest of students at the outset; some ways in which this can be done are:

- arrange a visit to the company (if possible)
- contact the company for product brochures, annual reports, etc (this should be managed in such a way as to avoid multiple requests)
- show a video/DVD overview presentation of the company and its products
- organize an introductory presentation (this should be by a representative of the company, if possible; failing that, suitable speakers may be available from the STEM Ambassadors programme which is run by the STEMNET organization: **http://www.stemnet.org.uk/**
- arrange for students to have hands-on use of the company's product where possible (eg computer games).

Some useful websites for this Unit:

'Evolution of a Start-up Company'

http://en.wikipedia.org/wiki/Startup_company

http://en.wikipedia.org/wiki/Entrepreneurship

'Games Industry in Dundee given Cash Boost'
http://news.bbc.co.uk/1/hi/scotland/tayside_and_central/8398106.stm

'Will the UK Government Dare to Rescue Technology Start-ups from the Mire?'
http://www.businessweekly.co.uk/index.php?option=com_content&view=article&id=33035:will-the-uk-government-dare-to-rescue-technology-start-ups-from-the-mire&catid=416:technology-archive&Itemid=1490

'The 50 most Influential Britons in Technology'

http://www.telegraph.co.uk/technology/6221732/The-50-most-influential-Britons-in-technology-part-one.html http://www.telegraph.co.uk/technology/6226334/The-50-most-influential-Britons-in-technology-part-two.html

On completion of this Unit students should be able to:

- research the history of the company
- identify the key business opportunity and how it is different from anything else that currently existed in the product/market area
- identify the product manufactured
- identify the key business methodologies to its products
- identify the risks that the founders took during the formation of their companies
- identify how funding capital to drive forward company development was found
- identify how important to the success of this company the original founder was
- explain the future plans for the company

Approaches to assessment

In small groups or independently, students should research and discuss the case studies using the questions provided. Small groups may be assigned different case studies to research, with opportunities provided to feed back to and discuss findings with other groups.

The lecturer has the choice of getting the class to work in small groups or individually, and can also choose the amount of detail required and the format in which the case study findings are to be presented, ie a written report or perhaps a business presentation to help develop the students' communication skills.

While a fair amount of information can be researched from web sources, students will need to access other sources such as product brochures and company annual reports to be able to structure their report around the suggested questions.

Key concepts/storylines in *Commercial case studies*

Code	Key concepts and storylines developed	Developed by the student being required to:
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Realize the impact of environmental factors on design of the product
E1	Project planning and management	Investigate the way in which the business was planned and project managed in the case study
E2	Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact.	Investigate the design of important parts of the equipment
E3	Materials selection to meet required needs and to minimize costs	Investigate material choice in certain components
E4	Process control methodologies	Investigate project management methodology, material logistics and progress plan
E5	Quality methodologies sustainability issues	Research quality control methods used in the project
M5	Basic statistics, variability, risk assessment	Carry out a risk analysis
P3	Study of a wide range of materials properties	Understand the rationale underlying material selection
P4	Studies of forces, motion and energy	Appreciate stress/strain in structures, and energy efficiency

Links from *Commercial case studies* to other parts of the programme

Chosen activities should seek to demonstrate links to as many other Units as possible so it will be helpful to choose contexts that will be encountered elsewhere in the programme. This Unit is likely to provide an opportunity to revisit a number of science, engineering and mathematics themes, depending on the specific applications chosen for analysis.

Skills development in *Commercial case studies*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning			✓	• Research, collate and produce material for report
S2. Interpersonal communication and team working			✓	• Work in groups to research, collate and produce material for report
S3. Numeracy: assessing and manipulating data and quantity				
S4. Critical and logical thinking			✓	• Produce clear, concise and logically thought through report on the chosen case study
S5. Basic IT skills		✓		• Use the internet to find material and produce a report using a word processing package
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis				
S9. Entrepreneurial awareness			✓	• Identify why the company was successful and the traits required by the founder

Commercial case studies: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Case study: computer games developer, Realtime Worlds	Realtime Worlds was founded in 2002 by David Jones, who is a graduate of Abertay University and now a Visiting Professor of Games Design and Technology. The company employs about 170 people in Dundee, plus a further 30 in Korea and Colorado. David Jones and other team members have created some of the world's best-selling video games, including the global hit franchises 'Lemmings' and 'Grand Theft Auto'. The international computer games industry is estimated to be worth around $42-44 billion annually.	For each case study students should structure their investigation around these key questions: 1. What is the history of the company, ie its product, how it came into being, etc? 2. What was the business opportunity spotted by the founder and what did he or she do to successfully exploit it? A business opportunity consists of four integrated elements all of which need to be present within the same timeframe (window of opportunity) and most often within the same domain or geographical location, before it can be claimed as a business opportunity (**http://en.wikipedia.org/wiki/Business_opportunity**). These four elements are: a need and/or gap in the market; the means to fulfil the need; a method to apply the means to fulfil that need; a method to benefit. 3. How was the business opportunity unique/different from anything else that currently existed in its product/market area? 4. What product(s) does the company produce? Include a brief description of how the products work and the main science/ engineering/technology principles employed. 5. How does the company successfully employ any of the following key business methodologies to its products: project planning, product design, material selection, control methodologies, quality and sustainability? 6. What were the risks that the founder took during the formation of the company?

Topic	Suggested content	Teaching notes and materials
		7. How did the founder raise the funding capital to drive forward the company's development? 8. How important to the success of this company was the original founder? What entrepreneurial traits did he or she display in setting up the company? What type of leadership qualities did he or she show? 9. How did the founder successfully commercialize the ideas/inventions? Did he/she do this on their own or involve other organizations? How has the Intellectual Property (IP) been protected? 10. Who/where are the company's main sources of competition and how does the company plan to tackle them? 11. What are the future plans for the company? Realtime Worlds information at: **http://www.realtimeworlds.com/** **http://en.wikipedia.org/wiki/Realtime_Worlds** **http://www.eurogamer.net/articles/realtime-worlds-david-jones-interview**
Case study: consumer products designer and manufacturer, Linn Products	Linn Products Limited was started by Ivor Tiefenbrun in Glasgow's Castlemilk district near Linn Park in 1972 in order to manufacture a quality hi-fi turntable, developed from his personal interest in music reproduction. It began as an offshoot of Castle Precision	For each case study students should structure their investigation around these key questions: 1. What is the history of the company, ie its product, how it came into being, etc? 2. What was the business opportunity spotted by the founder and what did he or she do to successfully exploit it? A business

Topic	Suggested content	Teaching notes and materials
	Engineering (Glasgow) Ltd, a company now specializing in CNC (computer numerical control) machining, and many of the methods and processes of precision engineering form the philosophy behind the production of Linn's audio components. The superior quality of Linn's audio products is internationally recognized, and in 2002 Linn Products Ltd was awarded the Royal Warrant of Appointment as a Tradesman to His Royal Highness, Prince Charles, the Prince of Wales, as a provider of entertainment systems.	opportunity consists of four integrated elements all of which need to be present within the same timeframe (window of opportunity) and most often within the same domain or geographical location, before it can be claimed as a business opportunity (**http://en.wikipedia.org/wiki/Business_opportunity**). These four elements are: a need and/or gap in the market; the means to fulfil the need; a method to apply the means to fulfil that need; a method to benefit. 3. How was the business opportunity unique/different from anything else that currently existed in its product/market area? 4. What product(s) does the company produce? Include a brief description of how the products work and the main science/ engineering/technology principles employed. 5. How does the company successfully employ any of the following key business methodologies to its products: project planning, product design, material selection, control methodologies, quality and sustainability? 6. What were the risks that the founder took during the formation of the company? 7. How did the founder raise the funding capital to drive forward the company's development? 8. How important to the success of this company was the original founder? What entrepreneurial traits did he or she display in setting up the company? What type of leadership qualities did he or she show? 9. How did the founder successfully commercialize the ideas/inventions? Did he/she do this on their own or involve other organizations?

Topic	Suggested content	Teaching notes and materials
		How has the Intellectual Property (IP) been protected? 10. Who/where are the company's main sources of competition and how does the company plan to tackle them? 11. What are the future plans for the company? Linn Products information at **http://www.linn.co.uk/about_linn** **http://en.wikipedia.org/wiki/Ivor_Tiefenbrun**
Case study: medical technology life sciences company, Optos	Founded in 1992 by Douglas Anderson, Optos, based in Dunfermline, was one of only two UK companies to be named 'Technology Pioneers' by the World Economic Forum. To be selected as 'Technology Pioneers', companies must be involved in life-changing technology innovation with the potential for long-term impact on business and society. Optos has developed retinal image technology which enables the diagnosis of eye disease at a much earlier stage than was previously possible. Optos has recently won the MacRobert Award, Britain's most prestigious prize for engineering innovation.	For each case study students should structure their investigation around these key questions: 1. What is the history of the company, ie its product, how it came into being, etc? 2. What was the business opportunity spotted by the founder and what did he or she do to successfully exploit it? A business opportunity consists of four integrated elements all of which need to be present within the same timeframe (window of opportunity) and most often within the same domain or geographical location, before it can be claimed as a business opportunity (**http://en.wikipedia.org/wiki/Business_opportunity**). These four elements are: a need and/or gap in the market; the means to fulfil the need; a method to apply the means to fulfil that need; a method to benefit. 3. How was the business opportunity unique/different from anything else that currently existed in its product/market area? 4. What product(s) does the company produce? Include a brief description of how the products work and the main science/

Topic	Suggested content	Teaching notes and materials
		engineering/technology principles employed. 5. How does the company successfully employ any of the following key business methodologies to its products: project planning, product design, material selection, control methodologies, quality and sustainability? 6. What were the risks that the founder took during the formation of the company? 7. How did the founder raise the funding capital to drive forward the company's development? 8. How important to the success of this company was the original founder? What entrepreneurial traits did he or she display in setting up the company? What type of leadership qualities did he or she show? 9. How did the founder successfully commercialize the ideas/inventions? Did he/she do this on their own or involve other organizations? How has the Intellectual Property (IP) been protected? 10. Who/where are the company's main sources of competition and how does the company plan to tackle them? 11. What are the future plans for the company? Optos information at: **http://www.optos.com/** **http://www.sm2strategic.com/files/2009%20Apr%20-%20Optos%20A%20Breakthrough%20in%20Diagnostic%20Imaging.pdf** **http://www.archangelsonline.com/article.asp?aid=717**

Information systems

The primary purpose of this Unit is to develop an understanding of the computational challenges of handling, communicating and processing information over a very diverse range of scientific or technical applications.

Introduction to the Unit

Computer applications are ubiquitous in the modern world, whether in the form of embedded 'chips' (eg in washing machines, cars, telephones) or in sophisticated information-handling systems (eg Driver and Vehicle Licensing Agency records, DNA databases, medical records, weather forecasting systems). All such applications involve programming. This Unit aims to develop basic skills in analysing a computer application, to identify the specific programming issues to be addressed. The Unit offers two detailed case studies: a practical study of the programming of the control operation of a specific type of appliance, and a team investigation of the design issues for a complex scientific or engineering system. The diversity of computer applications can be illustrated by reviewing a number of other applications more briefly. In this way, both relatively simple and much more complex applications can be reviewed. The main aim is to identify and analyse the information processing and communication issues involved in a number of applications, but for one simpler application a practical simulation exercise could be carried out involving control of a process through an interfaced computer. This should include examining basic software provided for the exercise, and experimenting with program modifications.

A number of possible applications are presented in detail in the Unit notes. These are exemplars: other choices could be substituted. Different kinds of case study applications can be found in other STEM-relevant areas. For example, engineering project management systems

would be a source of good exemplar systems, such as those used to track manufacturing progress and after-sales performance of manufactured goods.

On completion of this Unit students should be able to:

- use technology for learning (eg online research)
- apply scientific knowledge and understanding to a case study
- learn independently and/or as part of a small team
- prepare written reports, suitably referenced, and make oral presentations to peers
- analyse and discuss high-level programming issues in the design of specific devices and scientific or engineering information-handling and processing systems
- appreciate the nature of some of the intellectual challenges inherent in applying computer science

and understand, at a basic level:

- classes of information processed by digital computers: numbers (integer, real, vector arrays), text (introduce string handling), logical (T/F)
- classes of quantitative information (eg prices, dates, temperatures, volumes) and how these can be distinguished in professional high-level languages through declaration statements
- representation of numbers and alphanumeric characters in binary code
- principles of transmission of data to a computer from an external device (eg keyboard or sensor) or from a computer to an external device (eg printer or motor) — parallel interface only, handshaking, parity check, analogue to digital conversion
- data transmission carried by electromagnetic radiation, including transmission rates (bandwidth)

Approaches to assessment

Detailed reports on at least two topics in the Unit should be produced and one oral presentation given. One practical investigation should be carried out involving interfacing and programming an external computer.

Key concepts/storylines in *Information systems*

Code	Key concepts and storylines developed	Developed by the student being required to:
CI3	Solution specification for a general problem — algorithms	Draft a flow chart to show the operational control algorithm for the menu of wash cycles in a washing machine
CI4	Basic introduction to programming	Design a programme in justBASIC to operate the washing machine
CI5	General ideas of how digital computers store, input, transform and output information	Produce a short report on how computers operate
CI6	Analysing design issues in a range of applications	Examine the detailed design of different pieces of equipment and make recommendations for improvement
E1	Project planning and management	Plan the steps required in the investigation and manage the outcomes
E2	Product design, including fitness for purpose, reliability, safety and efficiency in use, cost effectiveness and aesthetic impact	Comment on the design of equipment inspected and state whether fit for purpose
E4	Process control methodologies	Identify methods of control in processes studied

Links from *Information systems* to other parts of the programme

Chosen activities should seek to demonstrate links to as many other Units as possible so it will be helpful to choose contexts that will be encountered elsewhere in the programme. This Unit is likely to provide an opportunity to revisit a number of science and mathematics themes, depending on the specific applications chosen for analysis. A typical illustration is given below.

Links to other Units	Topics involved
Links back to *Numeracy*	There are many opportunities for calculations in this unit
Links back to *Forces, motion, energy*	Calculations involving distance, motion and forces
Links back to *Electricity*	Many of the devices mentioned in the unit are electronic; their mode of operation will be investigated
Links back to *Equations and graphs*	There are many opportunities to use algebra, geometry and other mathematical operations in almost all topics, from the GPS, to weather forecasting
Links back to *Study of a domestic appliance*	There is a direct link here as a computer may be used to operate a washing machine cycle
Links back to *Eukaryotic cells*	If a bioinformatics strand is selected as an application this will involve knowledge of DNA fingerprinting
Links forward to *Genetics*	Knowledge of genes
Links forward to *The universe*	Weather forecasting

Skills development in *Information systems*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning			✓	• Plan, research and investigate projects covering different aspects of computer information systems
S2. Interpersonal communication and team working		✓		• Work in groups to plan, research and carry out work on practical investigations, research applications and information management systems
S3. Numeracy: assessing and manipulating data and quantity		✓		• Perform calculations involved in the practical and GPS investigations
S4. Critical and logical thinking			✓	• Produce clear, concise and logically thought through reports on IMS (IP multimedia subsystem) and other applications
S5. Basic IT skills			✓	• Produce a programme to operate the wash cycle of a washing machine
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution			✓	• Plan and carry out an investigation into the method of operation of a washing machine
S8. Scientific analysis			✓	• Make judgements and come to conclusions from material gathered
S9. Entrepreneurial awareness				

Topic	Suggested content	Teaching notes and materials
Practical investigation of the control of a domestic washing machine	Arrange the interfacing and programming of an external computer to operate a washing machine cycle: • water filling to a defined level • heating to a specified temperature • slow rotation (starting with the previous step) • emptying water • slow spin with pump still operating • filling for rinse cycle • slow rotation, then emptying • final fast spin	This exercise links directly to one proposed exercise in *Study of a domestic appliance*, which involved dismantling and studying the detailed design of a domestic washing machine. This would include the machine's in-built wash cycle control mechanism. It would be useful if that exercise included the drafting of a flow chart depicting the operational control algorithm for the menu of wash cycles as this could provide a useful starting point for this case study application. Depending on the resources available: if the actual washing machine is reassembled and in working order, and the expertise is available to rewire the control circuitry so that it can be operated through an interfaced computer (perhaps via intermediate programmable logic controllers — PLCs), it would be appealing to work with software to drive the machine itself, varying cycle characteristics through keyboard input. a simplified model system could be built, involving a suitable container, with a water feed pump operated by a motorized valve, an extraction pump that can be electronically switched, a water level (or total weight) sensor, a temperature sensor, and a variable speed rotor of some sort. Some of these features are available in an inexpensive bioreactor kit, available from the Science Engagement Programme at **http://www.sep.org.uk/**.

Topic	Suggested content	Teaching notes and materials
		A starting package could be provided to students that will separately operate most of the machine's components (perhaps in the wrong order with, say, one of the sensor inputs not programmed in). This program can then be modified by students to establish the required cycle, and to run it with different set parameters (temperature, speeds, timings). The program could be written in the justBASIC language, which may be encountered in other Units.
Applications of computer systems in today's world	Analyse a number of practical computer applications: • a precise specification of the task to be accomplished by the device • what inputs it has to gather • what outputs it has to drive • the basic operational algorithm that must be applied	A number of cases, spanning a range of complexity, can be discussed on a brainstorming basis initially. The questions around which the discussion is based should include what the device does, what inputs and outputs are required, and what operational algorithm must be applied. After such a discussion a small number of cases should be selected and allocated to groups of students to be researched more fully (through the internet). Each group can then give a presentation of their short case study, to be discussed in a plenary review session. Many possible case studies could be discussed, ranging in complexity. Examples are: a domestic central heating control system various control subsystems in a car such as anti-locking breaks, fuel flow and combustion control and average mpg recording and display

Topic	Suggested content	Teaching notes and materials
		automated toaster with darkness control traffic light sequence control at a junction, sensitive to traffic flow and pedestrians automatic focus and exposure control in a digital camera incoming and outgoing call control by a mobile phone handset Cases for team investigation might be supported by providing one starting web lead. Reports should reference sources used.
Operation of a GPS (Global Positioning System) handset	How a walker's handset can provide: • current position • output as a grid reference • altitude above sea level	This is in principle a complex case study, and can be pursued to different depths, depending on the time allocated and the abilities of the group concerned. (We exclude consideration of how the handset might display output on the backdrop of an electronically stored map.) In essence the handset must receive signals emitted from at least four satellites. (It is best, at least to begin with, to assume that just four satellites are 'in view'.) The satellites are in orbit round the earth and have very accurate atomic clocks on board, so their times of transmission are extremely precisely known. Their orbital positions are also precisely known and are available in an almanac. The handset records the time of arrival of each signal, and these differ, as they have travelled different distances (at the speed of light) from the satellite. While the handset records, accurately, the differences in the times of arrival of the different signals, its own clock is less accurate (matching ordinary crystal-based digital watches). A handset clock correction has also therefore to be determined from the signals received. There are therefore four unknowns to be applied: the 3D coordinates of the handset's position, and the time correction. The (x_1, y_1, z_1)

Topic	Suggested content	Teaching notes and materials
		coordinates of satellite 1 at its time of transmission are known. The position of the GPS (x, y, z) is unknown, but its distance d_1 from the satellite is given by the distance formula $d_1^2 = (x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2$ The signal travelled at the speed of light c, left the satellite at a time t_1^{sent} (known from the almanac), and was received at a recorded time $t_1^{recorded}$. This latter time has to be corrected by adding a small but unknown adjustment (Δt), so $d_1 = c \times \{(t_1^{recorded} + \Delta t) - t_1^{sent}\}$ There are four unknown values, the x, y and z coordinates of the handset and Δt. If we substitute the expression for d_1 from the second equation into the first we have one equation relating these. If we then write down the corresponding equations for satellites 2, 3 and 4 (simply replacing all the values with subscript '1' by their counterparts for each satellite) we then have four simultaneous equations in four unknowns, which can be solved to identify the precise handset position, and to correct its internal clock. The manipulation required to solve the equations can readily be seen to be complicated (an outline is given in the Wikipedia article referenced below). From the point of view of this Unit, it is enough to recognize that programming to do this has to be in-built in the internal GPS programming. There are also several further complications, such as that the position coordinates to be

Topic	Suggested content	Teaching notes and materials
		displayed are not Cartesian coordinates, but effectively latitude and longitude on the surface of the (pseudo)-spherical earth, and height above sea level. A study group might comment about errors more generally, including the presence of more precise satellite signals, intended for military use, that are transmitted in encrypted form. These websites have useful teaching materials: **http://en.wikipedia.org/wiki/Global_Positioning_System** **http://electronics.howstuffworks.com/gadgets/travel/gps.htm**
Group analysis of a complex information management system	• detailed investigation of air traffic control — a complex information management system	This is a suggested large-scale science and engineering computer information system case study for relatively extended study. (Other suitable examples are presented more briefly below.) The basic approach for this or other large-scale systems case studies is as follows: (a) Begin with an un-researched whole-class 'brainstorming' discussion of the requirements for air traffic control management, identifying the main issues, the information requirements, and the roles of different players in the system. (b) Break into subgroups, each to attempt to summarize the necessary system reasonably concisely, then to present summaries for discussion in a plenary session. (c) Given a few lead web sources for all individuals to study, refine the system specification summarized under (b). (d) Identify teams, ask one member in each team to research

Topic	Suggested content	Teaching notes and materials
		some aspects of the system in more depth, giving individuals from different teams who are investigating the same areas an opportunity to touch base with each other. (e) Each team comes together to produce a written report on air traffic control issues as a whole, with a particular emphasis on computation and communication issues. The report should be formally structured, including an abstract and an introduction, and giving references to all information sources used. There are air traffic control simulation packages for running on PCs available relatively cheaply. Experiencing these is not the point of this Unit, but could offer a very engaging way to introduce this case study. Another approach could be to review the historical development of air traffic management control systems as air travel intensity grew over the last century. On board a plane, there is a need to manage flight systems and to plan and monitor navigation. There are information inputs from GPS positioning signals and radar, radio communications from and to ground air traffic control centres and other aircraft in the general vicinity. Different ground-based units are involved in different stages of the flight. One plans and controls take-off, landing and ground movements. Other units control the ascent and descent phases of the flight, and yet other controllers oversee the main en route phase. Weather conditions affect planning. Reliability has to be assured (eg in case of computer breakdown) and possibilities of human error must be minimized. Safe aircraft separation is the key function of air traffic management (ATM). The systems have to be

Topic	Suggested content	Teaching notes and materials
		able to cope with contingencies, such as responding to a need for an emergency landing, or a sudden need to close a runway. There are numerous information handling issues involved. For instance, the positions and trajectories of numerous aircraft must be monitored and projected, to ensure that safe separation distances will be sustained at all times. The management of aircraft movements on the ground, including gate-berthing allocation, is a complex process for a busy airport. Transferring information and control between management units responsible for different regions of airspace also requires careful specification. A useful review presentation of the issues, delivered to a specialist audience, can be downloaded at **http://www.caasd.org/library/documents/global_atm.pdf**
Other scientific or engineering applications	• brief investigation of a range of other scientific or engineering applications	A range of other systems can be discussed and briefly reviewed. This will illustrate the diversity of systems in place and under continuing development. Alternatively, an investigation could centre on a specific project aiming to make use of an available information base, perhaps involving data mining. In general a study will start with a need to review the underlying science, the nature and extent of the data to be accessed and the processing requirement of the specific application considered. In some cases key information may have to be continually updated, and may come from a number of different sources. There may be issues of verification and a need to ensure consistency. It is suggested that each case study is first approached through a general discussion.

Topic	Suggested content	Teaching notes and materials
		These exercises are intended to reinforce the main outcome of this Unit, that a student would be able to make a start on describing the information and processing requirements for an unfamiliar application. Three possible example areas are briefly reviewed below. Bioinformatics There is a basic introduction to this area in Chapter 9 of *An Introduction to Genetic Engineering*, 3rd edition, by D.S.T. Nicholl (Cambridge University Press, 2008). Access can be made to databases through scientific society websites. The European Bioinformatics Society's education site at **http://www.ebi.ac.uk/2can/** may be particularly useful. Depending on the application considered, significant effort may be required first to review the underlying biology. For instance, in analysing the application of human DNA databases it is vital to understand some detail of the nature of individual variability in DNA sequences. DNA fingerprinting involves somewhat simpler databases, compared with full base sequencing, though these are not openly accessible. Direct matching is relatively trivial in computing terms; relationship tracking involves more sophisticated programming but also depends on understanding a lot of detailed genetics. It may, for instance, be possible to study a topic recently reported in the media, such as where certain genes are revealed to have a strong association with a particular medical condition. There is a broader spectrum of applications available if one extends the range of interest to include areas categorized as health informatics, medical informatics and biomedical informatics.

Topic	Suggested content	Teaching notes and materials
		Weather forecasting This is an area involving very complex data collection and processing, using models that are very demanding in programming terms. The underlying science of atmospheric behaviour is also complex. A study could be based on the operations of the UK Met Office. A useful brief introduction to this organization is available through Wikipedia at **http://en.wikipedia.org/wiki/Met_Office** Some introduction and study is required of the atmospheric processes at the heart of weather evolution, though this cannot be studied in detail at this level. Most important is to understand the sensitivity of forecasts to detailed initial conditions. There are issues as to how the 'current' conditions are set, using information from weather satellites, ground-based weather stations and other observations, and how the local evolution of the weather still involves judgement on the part of the forecaster. An alternative to looking at how day-to-day regional forecasts are made could be to study more specific local climatic predictions, for example the likely (and changing) frequency of extreme weather events, such as local flash flooding. Geographical Information Systems There is a huge variety of possible case studies in this area, involving collection and interpretation of information, often involving remote sensing through satellites. There is a good introduction, including several projects of specific relevance to Scotland, at a University of Edinburgh website: **http://www.geos.ed.ac.uk/geography/research/gis/purple.html**

The universe

The primary purpose of this Unit is to develop some understanding of the processes taking place in the world and universe in which we live.

Introduction to the Unit

There is ample opportunity in this Unit to develop an appreciation of magnitude and scale. Some of the Earth's processes may be described in other Units but the difference here is that they are discussed from a scientific viewpoint. Very few (if any) other programmes at this level have any content related to non-classical physics. The inclusion of relativity allows students to appreciate and discuss the related phenomena. From a 'trigger' point of view it may be useful to include some of the theories proposed by Stephen Hawking.

The suggested content of the Unit is included as a guideline only. Lecturers may choose to concentrate on particular areas of interest to themselves or their students. A project-based learning approach to much of this Unit is recommended, with students investigating in groups of 2-4 and reporting back to the rest of the class. No student is expected to tackle all of the suggested content. It is important that students work on real science or engineering problems that are sufficiently complex to address the Unit's learning outcomes.

On completion of this Unit students should be able to:

- describe elementary aspects of the physics underlying weather phenomena
- perform calculations to derive planetary orbits
- describe the life cycle of a star
- understand the mechanism by which the sun generates energy
- explain the consequences arising from application of special relativity
- explain the formation of the earth's natural phenomena
- describe the formation of the universe

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to include a written assessment, which should have plenty of optional questions in order not to disadvantage any student.

Key concepts/storylines in *The universe*

Code	Key concepts and storylines developed	Developed by the student being required to:
G2	Study implicating major seismic processes	Understand plate tectonics and their role in earthquake formation
G3	Study involving evolution of the earth, the solar system and the universe	Study aspects of cosmology
G4	Study involving weather, climate and interplay with the biosphere	Describe the physical cause of various weather phenomena

Links from *The universe* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Calculation of planetary orbits and gravitation effects
Links back to *Force, motion, energy*	Circular motion, Newtonian mechanics
Links back to *Earth processes*	The source of the earth's natural phenomena
Links back to *Ecosystems*	Meteorology

Skills development in *The universe*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning			✓	• Carry out enquiry-based exercises
S2. Interpersonal communication and team working			✓	• Carry out enquiry-based exercises
S3. Numeracy: assessing and manipulating data and quantity			✓	• Calculate planetary orbits and gravitation effects
S4. Critical and logical thinking				
S5. Basic IT skills				
S6. Handling uncertainty and variability				
S7. Experimentation and prototype construction: design and execution			✓	• Carry out enquiry-based exercises on eg habitation of Mars
S8. Scientific analysis				
S9. Entrepreneurial awareness				

The universe: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Meteorology	• wind • rain • hail • snow • lightning • tornado • hurricane • weather prediction • climate change	This is an area we have not exposed in depth elsewhere. It involves fairly complicated physics (non-equilibrium thermodynamics, major issues of flow and mixing, Coriolis forces, energy absorption and transmission, diurnal and annual cycles, change extremely sensitive to small local variations in conditions, etc). It could be studied at a level of brainstorming to understand just how complicated it is, giving a general understanding of the uncertainty in local forecasting, even with the use of highly sophisticated models and enormous computation. This leads quite naturally to discussion of the moral and ethical issues relating to climate change. Some useful websites: **http://en.wikipedia.org/wiki/Meteorology** **http://www.metoffice.gov.uk/climatechange/science/explained/** **http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/home.rxml** **http://bubl.ac.uk/link/m/meteorology.htm** **http://library.thinkquest.org/C0112425/main.htm**
Cosmology	• *g* and *G* • Newton's law of gravitation • Kepler's laws • tides • our planets (sizes, distribution, atmospheres now and in the past,	It is not obvious what can be pulled out in terms of gravitation leading to the sun's formation, with conserved angular momentum ensuring that some of the matter ends up in orbit round the sun. This connects back to orbiting satellites from circular motion in *Forces, motion, energy*, applied here on a grander scale ($G\, m_1 m_2 / r^2$ will have been met there, alongside $a = v^2/r$, so this could be used to calculate the periods for the

Topic	Suggested content	Teaching notes and materials
	gravity, period of orbit, rotation, their moons) • sun mechanism • Hubble's law ($v = Hd$)	orbits of the moon, Uranus, etc). It was gravitation that first heated the sun and perhaps some interesting order of magnitude calculations could be attempted of how much energy this generated (there's a simple bit of calculus integrating $F\delta r$ for a mass initially at the edge of the solar system falling to the solar surface). If one could assume Gauss's law that an inverse square law attraction to material spread on a spherical shell is equivalent to the situation where the whole mass was at the centre, one could go rather further, but simply doing the easier calculation for 1% of the solar mass would possibly make the point. Fission energy will have been mentioned in *Energy sustainability*, with perhaps the one previous relativistic reference, $E = mc^2$. The issues of generating fusion power are the need for strong confinement forces and high starting temperatures (very energetic thermal collisions), conditions that are provided inside the sun. This opens up a storyline about the life cycle of a star, and it may be possible to estimate current typical power output, how much mass of hydrogen the sun loses (per millennium?) and how much net mass loss this represents. On the other hand, inside the earth, fusion could not be triggered (even if there was local hydrogen available). Cue for Kelvin's prediction that the bible was roughly right on the age of the earth for it to have reached its current temperature (possibly a calculation that could be reviewed?), then noting that its actual temperature, and seismic activity, are driven by fission.

Topic	Suggested content	Teaching notes and materials
		Some useful websites: **http://www.kidsastronomy.com/earth/moons.htm** **http://www.bbc.co.uk/solarsystem/** For gravity resources see **http://www.slideshare.net/eliseb/universal-gravitation-ppp** **http://www.slideshare.net/RobLynch/universal-gravitation-1765712** **http://www.slideshare.net/wjerlinger/042308-law-of-universal-gravitation.** The mode of formation of the moon is discussed at **http://www.herald.ie/world-news/how-earths-only-natural-satellite-formed-2220932.html**
Special relativity	• Michelson—Morley experiment • constancy of *c* • change in space and time for a moving object relative to a stationary observer; $E = mc^2$ • time dilation • mass increase • length contraction • Doppler effect • space travel • time travel	In terms of the programme, relativity is inevitably a bit isolated. Unlike quantum physics, it does not appear to have strong links to any other Unit. On the other hand the Unit connects with others in relation to global issues, though for once not highlighting human impact. It has significant connections to key concepts/storylines, but has to be relatively descriptive in approach in some aspects. It should be sufficient to undertake a general review of relativity here. The scale of galaxies, clusters of galaxies and the visible universe might come first. Special relativity has a natural introduction as necessary to understand anything in greater detail. It is sensible to discuss Michelson and Morley, their thinking about the ether and the expected conclusion of their experiment

Topic	Suggested content	Teaching notes and materials
		(note the change in the relative velocity of the earth compared with the sun 6 months apart). The implication of the actual findings could include a clever derivation of the time dilation formula 'from simple geometry'. **http://www.astro.gla.ac.uk/users/martin/outreach/biography.html** (How distances and the age of the universe are derived) There are further slide shows available at the following websites: **http://www.slideshare.net/mrmeredith/einstein-and-relativity-3269004** **http://www.slideshare.net/AutoSurfRestarter/einsteins-brainchild-relativity-made-relatively-easy-by-barry-r-parker** **http://www.slideshare.net/guest57c9b2/einstein-albert-and-hawking-stephen-the-relativity-of-the-big-time-1921** **http://www.slideshare.net/Vette05/six-not-so-easy-pieces-einsteins-relativity-symmetry-and-space-time-by-richard-p-feynman** **http://www.slideshare.net/muguu_908/how-to-solve-the-special-relativity-time-dilation** **http://www.slideshare.net/vbdotnetnrew/how-special-relativity-works** **http://www.slideshare.net/praveens/special-relativity**
Earth	• continental drift • age of the earth • carbon dating	Viewed historically this topic links to evolution of the earth (and to the development of life). Major factors are atmospheric composition, radiation absorption and emission, periodic variations in solar activity, surface temperature (ice)

Topic	Suggested content	Teaching notes and materials
	• plate tectonics cycle, earthquakes, volcanoes (origin and effect on climate), ice ages, glaciation • ocean currents (el niño, la niña) • climate variation • radiation from the sun and space • sun spots, meteorites, comets, asteroids; diverting collisions • origin and development of life • seasons (tilt) • magnetic field (and reversals over time), Newtonian mechanics as applied to satellites and rockets (escape velocity), satellite communications and surveying	and the impact of comet or asteroid collisions (dinosaurs and nuclear winters). Major regional variations are greatly influenced by ocean currents. This could give a useful background to review current issues of global warming (and CO_2 versus other possible suspects such as solar cycles), and the possible explanation of a lag in further warming in recent years (solar activity). Though it breaks the progression from the earth to the universe, there is a cue here to come back to evolution of the earth's surface, connecting back to the first topic above, but introducing tectonic plates, the major geological processes at work, in relation to not just volcanoes and earthquakes, but also the generation of minerals (erosion and sedimentary processes are a possible side issue). The impact of continental shift on evolution etc could reconnect to *Earth processes*. Some information and exercises about plate tectonics can be found at: **http://www.slideshare.net/jacksonthree/physical-geography-plate-tectonics** For further information on the Yucatan peninsular collision see **http://www.kidsastronomy.com/solar_system.htm.** There is also a video of a meteorite impact at **http://www.kidsastronomy.com/mercury.htm.**

Topic	Suggested content	Teaching notes and materials
Practical investigations	• enquiry-based exercises	This topic is intended to be practical in nature. Students could be asked to research and report on one of the following areas which are relevant to this Unit: • research how the moon or Mars could be made habitable (eg provision of water, oxygen) • produce a timeline of the human explorations of space • report on the requirements for future exploration of space • report on the feasibility of time travel • report on how an asteroid might be diverted
Universe	• Big Bang (red shift) • age of the universe • size of the universe • black holes (Hawking theories) • quasars • life and death of a star	Big Bang: expansion, accelerated expansion, dark matter, dark energy. The Big Bang will need to be dealt with concisely. There's a calculation that if you could sustain a propulsion force giving a (from rest) acceleration of the order of *g*, you could arrive at a distant galaxy after a very few years travel (though it would seem a lot longer on an earth-based clock). There is a general relativity mass effect to take account of as well. Measuring muon decay is the standard terrestrial demonstration of special relativity.

Nanotechnology

The primary purpose of this Unit is to develop an understanding of the structure, properties and uses of nanoparticles and to appreciate the benefits and risks involved in their use.

Introduction to the Unit

In this Unit students carry out a survey of common items which contain nanoparticles and investigate the advantages gained in the product through implementing this technology. The properties of different types of nanoparticles are investigated, from fullerenes and quantum dots to quantum tunnelling composites (QTC) and colloidal suspensions. Medical and industrial applications of nanotechnology are reviewed. Different methods of manufacture are investigated. and the benefits and risks involved in the use of nanomaterials are identified and debated.

On completion of this Unit students should be able to:

- understand the uses and properties of nanomaterials
- understand the methods of manufacture of nanomaterials
- know and debate the benefits and risks involved in the use of nanomaterials

Approaches to assessment

Assessment can be of laboratory reports, written reports for each topic, perhaps concentrating on one particular type of nanoparticle, stating its properties, how it is fabricated, its uses — medical and or technological — and the risks and benefits it poses.

Key concepts/storylines in *Nanotechnology*

Code	Key concepts and storylines developed	Developed by the student being required to:
B2	Organization and systems operation of an organism; homeostasis & control; healthy living & combating disease	Investigate medical application of nanoparticles in diagnosis and treatment of disease
C2	Understanding bonding and 3D structure of molecules, notably in organic/ biological and materials contexts	Investigate the structure of fullerenes
C4	Solution processes, including electrochemistry and reaction equilibrium	Prepare a ferrofluid and investigate its properties
C5	Processes involving light absorption/ emission	Relate the light-emitting properties of quantum dots to their structure
P1	Applications in electricity and electronics	Relate the properties of semiconductors to their structure
P3	Study of a wide range of materials properties	Understand and predict the properties of nanomaterials
P6	Study involving non-classical physics	Understand how quantum dots and QTC materials function
M5	Basic statistics, variability, risk assessment	Assess the benefits and risks involved in the use of nanomaterials
M6	Key tools from numeracy, algebra, proportion and graphs	Appreciate the nanoscale

Links from *Nanotechnology* to other parts of the programme

Links to other Units	Topics involved
Links back to *Numeracy*	Nanotechnology: the nanoscale
Links back to *Atoms and molecules*	Properties of nanomaterials: carbon allotropes and hybridization of carbon
Links back to *Materials*	Revision of semiconductors
Links back to *Industrial chemical processes*	Revision of catalysts and fuel cells
Links back to *The human organism* and *Eukaryotic cells*	Medical applications of nanomaterials as diagnostic tools and as a means of delivering treatments
Links back to *Statistics*	Assessing the benefits and risks involved in the use of nanomaterials

Skills development in *Nanotechnology*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning			✓	• Plan relatively open-ended tasks, acquire information and process this in a logical way, and make critical reviews
S2. Interpersonal communication and team working			✓	• Work in pairs to carry out experiments, discuss ethical issues as a group, and respond to group questioning effectively
S3. Numeracy: assessing and manipulating data and quantity		✓		• Understand scale; manipulate experimental data
S4. Critical and logical thinking			✓	• Produce structured reports and explain phenomena related to nanomaterials
S5. Basic IT skills		✓		• Produce a report
S6. Handling uncertainty and variability			✓	• Look at variability in experimental results; examine risks associated with nanoparticle use
S7. Experimentation and prototype construction: design and execution			✓	• Plan and perform experiments to prepare/test nanomaterials
S8. Scientific analysis			✓	• Analyse experimental data
S9. Entrepreneurial awareness			✓	• Research and find new uses for nanoparticles

Nanotechnology: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Use of nanotechnology at present	• atomic, nano- and micro-scales, units • use of nanotechnology today in everyday products • future developments and possibilities • multidisciplinary nature of the field (involving physics, biology, chemistry and engineering)	This topic can be used to develop a range of skills: literature and web search, team working, report writing, practical, experimental work. Uses and methods of manufacture can be dealt with when the properties of different nanomaterials are being discussed, rather than being the focus of this topic. However, if this topic is presented discretely, students can be asked to research which products currently contain nanoparticles. They are already in use in a large number of everyday products: sunscreen, skin products, materials that resist staining, self-cleaning glass, tennis rackets, electronic goods, instrumentation and catalysts in cars, etc. Students can investigate two common uses of nanoparticles, for example in sunscreen lotion or in another skin product, in an energy device or as a catalyst, by searching the internet and producing a short report on their findings. Results should then be discussed within the class. Some useful websites: **http://www.nanowerk.com/nanotechnology/introduction/introduction_to_nanotechnology_1.html** **http://cohesion.rice.edu/centersandinst/cnst/nano.cfm** **http://www.cosmeticsinfo.orgHBI/1**

Topic	Suggested content	Teaching notes and materials
Properties of nanomaterials	• carbon allotropes — graphite, diamond, graphene, buckyballs • fullerene applications; organic photovoltaics and as an antioxidant in biopharmaceuticals • quantum dots; structure and properties. Composition: CdSe. Uses: displays, LEDs, photovoltaics and in medical diagnosis. Toxicity of cadmium and alternative materials. • quantum tunnelling composites (QTC): composition and uses. • nanostructures: colloidal suspensions — ferrofluids; investigate its properties, uses of ferrofluids in electronic devices and in medicine (tumours) • uses of silver, gold and platinum nanoparticles, the bacteriocidal properties of silver and commercial uses • medical applications of gold nanoparticles in the diagnosis and treatment of cancer; phytomining for gold. • use of nanoparticles as a catalyst in car manufacture and in fuel cells	This topic provides an opportunity to develop skills in a number of areas: literature and web search, team exercise, report writing, experimental work. Carbon allotropes can be investigated using lab sheets from the following website: **http://www.discovernano.northwestern.edu/getinvolved/teachers** These lab sheets give pre-lab exercises and chemical tests for fullerenes and related compounds. Students are asked to construct models and to relate structure to properties. They then look for information on the physical and chemical properties using the internet. Suggested properties are: colour, density, hardness, melting point, boiling point, electrical conductivity, hybridization, crystal structure or shape. Applications can be researched at **http://www.nano-c.com/fullereneapp.html** A slideshow on quantum dots, introducing the subject, is available at **http://www.slideshare.net/mcleang1/quantum-dots** Quantum dots: special class of semiconductor, size 2-10nm, band gaps, excitons, Exciton Bohr Radius. Light emitted dependent on particle size, band gap energy inversely proportional to particle size squared. Can be made into films when bonded with appropriate molecules.

Topic	Suggested content	Teaching notes and materials
	• nanoshells and dendrimers; liposomes: structure and uses in medicine and skin care products	For information on quantum dots — uses and how they work: **http://www.evidenttech.com/quantum-dots-explained/how-quantum-dots-work.html** **http://en.wikipedia.org/wiki/Quantum_dot** QTCs metal filler and elastomer binder, spiked surface. Ability to act as an insulator and, when pressure is applied, as a conductor. Uses as pressure devices in instruments, medical instruments, security devices, etc. A useful introduction to QTCs is given at **http://www.peratech.com/qtcscience.php** Experiments on QTC material can be carried out looking at accuracy and variability of results. The experiments are in an SEP booklet, available from **http://www.sep.org.uk** Applications of QTC **http://www.electronicsinschools.org/page.php?m=3&ps=2&p=931**

Topic	Suggested content	Teaching notes and materials
		Experiment to make a ferrofluid and investigate its properties: lab instructions and sheets available by clicking on to ferrofluids at **http://www.discovernano.northwestern.edu/getinvolved/teachers** The rest of this outcome can be given as lectures or by student research and pulling the results of this together. As a starter, web references are given below. **http://health.howstuffworks.com/gold-nanotech.htm** (uses of gold nanoparticles) **http://www.sciencelearn.org.nz/contexts/nanoscience/nz_research/gold_nanoparticles_from_plants** (phytomining and fuel cells) **http://www.nanowerk.com/spotlight/spotid=14845.php** hydrogen production using solar power (gold nanoparticles) **http://www.accenture.com** (R. Hengerer and M. Illsley, 'Nanotechnology and Business: The Power of Being Small') **http://www.dickinson.edu/~crouch/** ('Ferrofluids and their Properties', Dickinson College) **http://www.helium.com/items/1683803-how-to-make-ferrofluids?page=2** **http://www.i-sis.org.uk/nanoshells.php** **http://en.wikipedia.org/wiki/Liposome**

Topic	Suggested content	Teaching notes and materials
Applications of nanomaterials	• medical applications (diagnostic, eg biosensors, delivering medicines, cancer and diabetes treatment, nanoshells, dendrimers and nanobots) • industrial applications (sun screen; liposomes in skin care products; electronic goods, eg lasers, DVDs, playstations; cars; catalysts; hydrogen storage; photovoltaic development)	Here a few applications can be looked at in some depth. The method of delivery can be either as a lecture or with mainly student input. Information on uses can be obtained from websites.
Fabrication of nanomaterials	• colloidal solutions and the role of the surfactant; Langmuir Blodgett films; self-assembled monolayers (SAMs) • top-down and bottom-up approaches; nanolithography and molecular assemblies using methods such as base pairing (DNA)	Two methods of preparation can be discussed in some detail, one involving colloidal solutions and the other involving a bottom-up approach. The websites below give useful summaries of nanotechnology and manufacturing processes. **http://www.nanoscience.gatech.edu/zlwang/research/nano.html** **http://occmed.oxfordjournals.org/cgi/content/full/56/5/300** **http://en.wikipedia.org/wiki/Nanomaterials**
Benefits and risks involved in the use of nanomaterials	• advantages of nanomaterials (miniaturization, novel combination of properties, increased reactivity due to particle size, ability to penetrate membranes, etc) • disadvantages of nanomaterials (some of the advantages may also be disadvantages, eg the ability	The students can be asked to itemize the advantages and disadvantages of nanotechnology and to decide on the risks and benefits of this technology in relation to a particular aspect, such as use in the food industry or use of silver nanoparticles. Not much is known about the toxicity of nanomaterials. Does it differ from the toxicity of the material in its normal form?

Topic	Suggested content	Teaching notes and materials
	to permeate membranes, nanoparticles may initiate an immune response reaction, may be toxic) • projected benefits to mankind (clean water, engineered food, nutritionally enhanced foods, cheap energy, clean and efficient manufacturing, better drugs, diagnostics and organ replacement, etc) • potential risks for mankind (health, environmental and societal impacts) • the 'grey goo' phenomenon; ethical and moral issues	Some useful websites: **http://www.iom-world.org/research/nanoparticles.php** (understanding the risks of nanotechnology) **http://www.ethicsweb.ca/nanotechnology/** (several articles on the ethics of nanotechnology) **http://www.nanotechproject.org/** (survey of public perceptions of nanotechnology) **http://www.publications.parliament.uk/pa/ld200910/ldselect/ldsctech/22/22i.pdf** (House of Lords report on Nanotechnology and Food) **http://www.sciencedaily.com/releases/2007/05/070523075416.htm** (Nanotechnology in everyday products(**http://www.sciencedaily.com/releases/2009/02/090214162746.htm** ('Could Nanotechnology Make An Average Donut Into Health Food?' *Science Daily* is a good source of articles on nanotechnology.) **http://en.wikipedia.org/wiki/Grey_goo** (article on grey goo)

Genetics

Introduction to the Unit

In this Unit we look at molecular genetics, classical genetics and genetic technology, to attempt to provide answers to the following questions:

- How does an organism produce new cells?
- How do genes control development in a cell?
- Why do people look like their parents and siblings but are not identical?
- How can we use genetic information?

On completion of this Unit students should be able to:

- understand the principles of molecular genetics
- explain the patterns of inheritance
- describe a range of applications of genetic technology

Approaches to assessment

Assessment may be by producing reports for the various projects, completing worksheets and contributing to a presentation on an ethical issue which meets the required standards.

Key concepts/storylines in *Genetics*

Code	Key concepts and storylines developed	Developed by the student being required to:
B1	Organization and operation of the cell, and the nature, roles and management of the key chemicals of life	Understand the role of DNA and RNA in the synthesis of proteins
B2	Organization and systems operation of an organism; homeostasis & control; healthy living & combating disease	Investigate the role of gene therapy in the treatment of disease
B3	Cell division, reproduction, heredity	Understand meiosis and mitosis Understand the principles of inheritance
B4	Ecosystems, biodiversity & interdependence; photosynthesis, waste processing, sustainability	Investigate the use of new phenotypes in animal and crop production
B5	Adaptation and evolution	Revise work on evolution and adaptation from *Ecosystems* and relate it to genetic and environmental effects
C2	Understanding bonding and 3D structure of molecules, notably in organic/biological and materials contexts	Relate the structures of DNA and RNA to their role in protein synthesis

Links from *Genetics* to other parts of the programme

Links to other Units	Topics involved
Links back to *Ecosystems*	Diversity and variation in populations, evolution and adaptation
Links back to *Reactivity* and *Atoms and molecules*	Molecular genetics: structure of biological molecules and amino acids
Links back to *The human organism* and *Eukaryotic cells*	Stem cells and gene therapy Meiosis and mitosis
Links back to *Numeracy* and *Statistics*	Variation, calculation of standard deviation in populations; Hardy—Weinberg equation

Skills development in *Genetics*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning			✓	• Plan relatively open-ended tasks, acquire information and process this in a logical way, and make critical reviews
S2. Interpersonal communication and team working			✓	• Work as part of a team to produce a report
S3. Numeracy: assessing and manipulating data and quantity				
S4. Critical and logical thinking			✓	• Produce a structured report to explain in detail the stance taken on an ethical issue
S5. Basic IT skills		✓		• Produce reports
S6. Handling uncertainty and variability			✓	• Look at variation in different populations and calculate standard deviation
S7. Experimentation and prototype construction: design and execution				
S8. Scientific analysis				
S9. Entrepreneurial awareness				

Genetics: summary of content, teaching notes and materials

Topic	Suggested content	Teaching notes and materials
Molecular genetics	• structure of nucleotides (phosphoric acid part, deoxyribose part and nitrogenous base); five bases in RNA and DNA, ie adenine, cytosine, guanine, thymine and uracil • structure of the polymer nucleotide (double strand helix, joined by hydrogen bonds between bases; complementary base pairs) • DNA functions of replication and expression • control of characteristics by genes through the proteins they code for • transcription (making RNA) and translation (making proteins) • the genome • structure and function of RNA (messenger RNA, single stranded containing one gene; ribosomal RNA which forms ribosomes with proteins; transfer RNA); codons and anticodons • DNA synthesis (replication mechanism) • the genetic code (sequence of bases on DNA codes for sequence of amino acids in proteins; 20 amino	The structures of DNA and RNA and the process of replication and expression will already have been looked at in *Eukaryotic cells*, but can now be revised and investigated in more detail. Most of the content of this Unit can be covered by the five projects at the National Institute of Health website **http://science.education.nih.gov/supplements/nih1/genetic/other/map.htm** • **Activity 1—Alike, But Not the Same** • **Activity 2—The Meaning of Genetic Variation** • **Activity 3—Molecular Medicine Comes of Age** • **Activity 4—Are You Susceptible?** • **Activity 5—Making Decisions in the Face of Uncertainty** Animation and details for mitosis can be found at **http://www.cellsalive.com/mitosis.htm** and for meiosis at **http://www.cellsalive.com/meiosis.htm**

Topic	Suggested content	Teaching notes and materials
	acids in nature but only four different bases; a group of three bases coding for an amino acid is called a codon; 64 codons in the genetic code) • cell cycle and mitosis in eukaryotic cells, chromosome duplication • meiosis and sexual reproduction	
Inheritance (classical genetics)	• Mendel's experiments with peas • phenotype and genotype • dominant and recessive forms (genes), alleles • monohybrid cross experiments • Mendel's first law • explanation of how the genotype controls the phenotype • sex determination and sex linkage • techniques for separating X and Y from sperm can be used in farm animals using in vitro fertilization (IVF) • the X and Y chromosomes contain other genes which can produce sex-linked characteristics • codominance: in some cases there are three phenotypes because neither allele is dominant over the other, so the heterozygous genotype has its own phenotype; this is called codominance — it can	This topic can be introduced by a whole-class activity looking at different traits within a class entitled 'Alike, But Not the Same' which can be found at: **http://science.education.nih.gov/supplements/nih1/genetic/guide/activity1.htm.** A second project, 'The Meaning of Genetic Variation', can be found at **http://science.education.nih.gov/supplements/nih1/genetic/guide/activity2-1.htm**. Here students investigate variation in the beta globin gene by identifying base changes that do and do not alter function, and by using several Internet-based resources to consider the significance in different environments of the base change associated with sickle cell disease. Students will learn about Mendelian patterns of inheritance, especially autosomal-recessive inheritance; the basic structure of DNA; the transcription of DNA to messenger RNA; and the translation of messenger RNA to protein.

Topic	Suggested content	Teaching notes and materials
	be seen in plants and also in the genetic disorder called *sickle cell anaemia* • lethal alleles • in humans, genetic diseases such as cystic fibrosis and muscular dystrophy are caused by lethal alleles • multiple alleles; blood groups in humans — A, B, AB and O • dihybrid cross — Mendel studied the inheritance of two different characteristics at the same time • Mendel's second law: alleles of different genes are inherited independently; ratio in F2 is 9:3:3:1 • Meiosis is a form of cell division used to produce gametes and has two main purposes, to form haploid cells with half the normal number of chromosomes and to arrange the chromosomes with a new combination of genes. • meiosis occurs in two successive divisions with no DNA replication in between; each division has five phases • genetic variation in sexual reproduction; three sources of genetic mutation; independent assortment during meiosis, crossing	A third project, 'Molecular Medicine Comes of Age', at **http://science.education.nih.gov/supplements/nih1/genetic/guide/activity3-1.htm** deals with targeted drug therapy and is a role-playing activity where students assume the roles of employees of two fictional pharmaceutical companies. The fourth project on the National Institute for Health site, 'Are You Susceptible?', at **http://science.education.nih.gov/supplements/nih1/genetic/other/map.htm** deals with ethical issues and the concept of risk and uncertainty in genetic testing to identify individuals who have variations that make them susceptible to certain diseases. For a good introduction to genetics, including good diagrams, see: **http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookgenintro.html** There is a multiple choice questionnaire on monohybrid crosses at **http://www.biology.arizona.edu/mendelian_genetics/problem_sets/monohybrid_cross/monohybrid_cross.html**

Topic	Suggested content	Teaching notes and materials
	over in meiosis and random fertilization • gene mutation also causes variation; mutagens • variation — the difference in characteristics within a species • genetic and environmental effects • variation can be studied in a large number of individuals and a frequency histogram plotted • calculation of standard deviation • variation can be continuous or discontinuous • variation, gene pool and populations, gene frequency • Hardy—Weinberg equation	
Applications of genetic technology	• gene products (eg insulin production, penicillin) • new phenotypes (altering the characteristics by genetic engineering) in animal and crop production, eg insect-resistant crops, long-life tomatoes, etc • gene therapy (alters the genotype of a tissue or even a whole human), eg used to treat cystic fibrosis • stem cells, embryonic and adult (how they work, how they can be acquired and replicated in the lab, use to treat disease, controversy)	Students should research one example from each group, eg manufacture of humulin for insulin production. Research into cloning can start at the BEEP site at **http://www.beep.ac.uk/content/345.0.html** where there is information and activities such as cloning your own mouse! **http://www.biotechnologyonline.gov.au/biotechnologyonline/popups/int_dnaprofiling.html** gives a paper-based project on DNA profiling.

Topic	Suggested content	Teaching notes and materials
	• cloning, natural occurrence in some plants and animals (identical twins are clones), and cloning techniques; advantages and disadvantages of cloned animals • forensics, eg DNA analysis, uses in crime scenes, body identification, proof of paternity, etc	
Bioethical issues	• human reproduction (contraception, abortion, designer babies and assisted reproduction) • uses of DNA profiling for testing parentage and in forensics • use of genetic information in health issues such as vaccination, alcohol, diet and drugs in sport	Students should study one topic in detail. **http://science.education.nih.gov/supplements/nih1/genetic/guide/activity5-1.htm** gives a useful project about genetic screening and its implications for a family.

Analysis of a commercial application

The primary purpose of this Unit is to develop an understanding and appreciation of the complex considerations required to set up a commercial exploitation of a science or technology application.

Introduction to the Unit

In this Unit students are expected to give presentations on a range of topics that, collectively, provide a relatively broad insight into the modern (chemical) industry. Students are asked to consider the process by which a chemical company decides on where it will site its new operations (predominantly manufacturing but with a substantial R&D component). The example selected is in fact a real case. However, before reflecting on this economically important topic, students are asked to perform exercises on physicochemical properties, market demand, market geographical distributions, chemical processes, environmental concerns and geo-political initiatives. The emphasis of this Unit is on communication, with students given three opportunities to make oral presentations to their group and one presentation to the whole class.

This arrangement aims to ensure that everybody will have to actively engage and participate. Thus, the framework is in place. The role of the lecturer is to question the students, summarize the topics, encourage students in their presentations, keep approximately to the suggested timetable and guide a group discussion towards the end of the session.

There are exemplar PBL (problem-based learning) materials relating to the titanium oxide and chlor-alkali industries at the Royal Society of Chemistry website (see below). While the technology used in these exemplars is of a chemical nature, this should not preclude the use of other technologies which may be more appropriate to students' and the lecturer's interests and knowledge. In this case lecturers will need to develop their own materials, and the exemplars

can be used as a template for doing so. It is not envisaged that this will be a true PBL exercise as time constraints will mean that students will need to be given some material (plus websites) to direct their learning, making this more akin to case-based learning. The main aim is to identify and analyse the information processing and communication issues involved in an application and then demonstrate the effect of different pieces of information on the decisions made during the planning process.

In the group discussion the students are asked to consider whether a new TiO_2 manufacturing plant should be sited in Scotland or in China. The Unit should end with a plenary session. The online materials include a proposed timetable for delivering the various elements of the analysis. This may be modified by lecturers to suit individual limitations/requirements.

Further resources, including student and lecturer notes, can be found at:

http://www.rsc.org/Education/HElecturers/resources/itus.asp
http://www.rsc.org/Education/HElecturers/Resources/ITU2.asp
http://www.rsc.org/Education/HElecturers/Resources/ITU3.asp
http://cbe.wisc.edu/facstaff/casesPBL.html
http://capewest.ca/pbl.html
http://www.ukcle.ac.uk/resources/pbl/what.html

On completion of this Unit students should be able to:

- investigate a previously unknown area of knowledge; research, absorb and understand information, and present these new facts to peers
- use this information to make sound commercial decisions
- take part in discussions and defend or support a course of action (eg selecting the manufacturing process or manufacturing site)
- take part in presentations and discussions concerning ethical, environmental and political issues

Approaches to learning and teaching

General

Lecturers/students may choose to concentrate on particular areas of interest. The suggested project is therefore included as a guideline only. Students should work in groups of 2–4 investigating different aspects of the problem and report back to the rest of the class at the end. The most important aspect of this project is for the student to gain experience in scientific/engineering enquiry of a real problem (which could be different from the suggested topics, but complex enough to cover most of the criteria).

It is envisaged that individual students will undertake different tasks and that no students is expected to tackle all the topics. Nevertheless students will gain experience in areas outwith the standard curriculum.

It has been shown that teaching and learning based on projects give excellent results in terms of transferable skills, enabling students to gain experience in facing the problems encountered by practising engineers and scientists. It is envisaged that students will develop skills at a high level on completion of this Unit.

Specific: Titanium Oxide Industry Unit

In this Unit students are asked to give presentations on a range of topics that, collectively, provide a relatively broad insight into the modern (chemical) industry. The students are asked to consider the process by which a chemical company decides on where it will site its new operations (predominantly manufacturing but with a substantial R&D component). The example selected is in fact a real case. However, before they need to reflect on this economically important topic, they are asked to perform exercises on physicochemical properties, market demand, market geographical distributions, chemical processes, environmental concerns and geo-political initiatives. The emphasis of this Unit is on the interactive, with the students given three opportunities to give oral presentations to their tutorial group and one presentation to the whole class.

This arrangement aims to ensure that everybody will have to actively engage and participate. Thus, the framework is in place. The role of the lecturer is to question the students, summarize the topics, encourage the students in their presentations, keep approximately to the suggested timetable and guide a group discussion towards the end of the session. In the tutorial group discussion, the students are asked to consider whether a new TiO_2 manufacturing plant should be sited in Scotland or in China. The Unit finishes with a plenary session. The online materials include a proposed timetable for delivering the various elements of the programme. This may be modified by lecturers to suit individual limitations/requirements, Further resources, including student and lecturer notes, can be found at:

http://www.rsc.org/Education/HElecturers/resources/itus.asp
http://www.rsc.org/Education/HElecturers/Resources/ITU2.asp
http://www.rsc.org/Education/HElecturers/Resources/ITU3.asp
http://cbe.wisc.edu/facstaff/casesPBL.html
http://capewest.ca/pbl.html
http://www.ukcle.ac.uk/resources/pbl/what.html

Approaches to assessment

Assessment will be mainly carried out by report and/or presentation, which could be peer marked (to reduce lecturer workload) with some sampled cross-marking by the lecturer. It may be possible to carry out a written assessment, which should have plenty of optional questions in order not to disadvantage any student

The assessment task is a project. The project undertaken by the student must be a complex task involving:

- variables which are complex or unfamiliar
- relationships which need to be clarified
- a context which may be familiar or unfamiliar to the student.

The assessment task must require the student to:

- analyse the task and decide on a course of action for undertaking the project
- plan and organize work and carry it through to completion
- reflect on what has been done and draw conclusions for the future
- produce evidence of meeting the aims which this Unit has been designed to cover.

The assessment task should be an investigation requiring the student to undertake research, analysis, evaluation and reporting in the area of science or engineering. Within the investigation the student will be required to carry out at least one practical task, involving laboratory practice, applicable to the subject area.

Topics for study might include:

- Titanium oxide manufacture
- Chlor-alkali industries
- A major civil engineering project (eg the M74 extension)

- Development, production, testing, licensing and manufacture of a pharmaceutical product (eg swine flu vaccine)

Students who meet the minimum evidence requirements will have their achievement graded as C competent, A highly competent, or B somewhere between A and C. The grade-related criteria to be used to judge student performance for the final project are specified in the following table.

Grade A	Grade C
A seamless, coherent piece of work which: ✓ has comprehensive evidence for each of the three essential phases of the project that is produced to a high standard and is clearly inter-related ✓ demonstrates an accurate and insightful interpretation of the project investigation ✓ provides an initial project timetable containing a comprehensive list of project activities as well as milestones to be reached ✓ is clear and well structured throughout with language of a high standard in terms of level, accuracy and technical content used ✓ effectively consolidates and integrates required knowledge and practical skills ✓ shows a thorough use of research materials and tools ✓ shows that the student had a high level of self-motivation throughout the investigation and completed the stages of the project with infrequent and minimal lecturer support ✓ shows that the student clearly recognizes all areas for improvement or modification	**A coordinated piece of work which:** ✓ provides evidence of the three essential phases of the project ✓ demonstrates interpretation of the project investigation ✓ provides a project timetable containing the essential project activities and milestones ✓ is satisfactorily structured and uses language which is adequate in terms of accuracy and technical content ✓ consolidates and integrates required knowledge and practical skills ✓ shows that the student has made some use of research materials and tools ✓ shows evidence that the student sought additional lecturer intervention to keep the investigation on track ✓ shows that the student recognizes some areas for improvement or modification

Evidence requirements

The project consists of three phases or stages: planning, developing and evaluating. The following table specifies the minimum evidence required to pass each stage.

Project stage	Minimum evidence requirements
Stage 1 — Planning 10%	Preparation of a plan-of-action report that includes: • discussion of roles within the team • the rationale for the investigation • a set of aims and objectives for the investigation • identification of the main issues for research and the sources to be used • identification of materials and resources required and how they will be accessed • identification of the stages (milestones) involved in the project work and the timescales for completion of each stage (project plan) • identification of appropriate Health and Safety procedures The student conducts the investigation without seeking or requiring an excessive level of lecturer support.
Stage 2 — Developing 66%	Preparation of an investigation report that includes: • a contents page • a review of current up-to-date literature relevant to the investigation • details of the type of practical task, methodology, laboratory techniques and use of equipment involved in the investigation • identification, collection/collation of significant/insignificant data • manipulation and analysis of significant data

Project stage	Minimum evidence requirements
	• presentation of appropriate data (figures, graphs, tables, equations) • discussion of data and the findings • conclusions drawn from critical analysis of data • reference listing of sources used in literature review
Stage 3 — Evaluating 24%	Preparation of an evaluation report that: • contains an abstract • summarizes any unforeseen events and how they were handled • contains a personal statement by each member of the team to identify knowledge and/or skills that have been gained or developed • assesses the strengths and weaknesses of the output of the investigation • determines to what extent the investigation met the original brief • suggests potential development themes for the investigation

Key concepts/storylines in *Analysis of a commercial application*

This Unit does not directly relate to any of the key concepts/storylines. As this is the final Unit in the programme it will draw on the concepts and storylines relevant to the area chosen for study. The skills developed to a high level through following the programme will be used and can be assessed as part of this Unit.

Links to other parts of the programme

This Unit acts as almost a revision Unit of what has been covered in the preceding Units. It should be linked to earlier work wherever possible. The number and relevance of the links will depend very heavily on the project chosen.

Skills development in *Analysis of a commercial application*

(Skills and levels refer to *A New Educational Framework for Progression in Science and Engineering*)

Skill	Working at SCQF level 5	Working at SCQF level 6	Working at SCQF level 7	Developed in this Unit by the student being required to:
S1. Learning, study, self-organization and task planning			✓	• Carry out an enquiry-based exercise
S2. Interpersonal communication and team working			✓	• Carry out an enquiry-based exercise
S3. Numeracy: assessing and manipulating data and quantity			✓	• Perform financial and other calculations as required
S4. Critical and logical thinking			✓	• Consider a mass of conflicting information concerning a complex application and make a logical judgment
S5. Basic IT skills			✓	• Produce a final report including charts and tables as appropriate
S6. Handling uncertainty and variability			✓	• Consider a mass of conflicting information concerning a complex application and make a logical judgement
S7. Experimentation and prototype construction: design and execution			✓	• Use appropriate practical methods to gather data as required
S8. Scientific analysis			✓	• Consider a mass of conflicting information concerning a complex application and make a logical judgement
S9. Entrepreneurial awareness			✓	• Actively engage in discussions involving entrepreneurial innovation

Analysis of a commercial application: summary of content, teaching notes and materials

Content cannot be specified as this will inevitably depend on the topic chosen.