STEM-ED Scotland

Science storylines supporting entry to higher education

This note is extracted from Annex A of the Report on a study: ***Building a new educational framework to address the STEM skills gap: a fundamental review from a 21st century perspective.*** The Study was carried out by STEM-ED Scotland, funded by the Scottish Funding Council. More details are available at http://www.gla.ac.uk/colleges/scienceengineering/stemed/tackling%20the%20stem%20skills%20gap/

In approaching any new STEM-related area of study or application, a primary aim should be to understand how the new topic might fit in with the general framework of principles and concepts established from previous studies of science. This framework is described here through a range of basic "science storylines."

These, taken together, represent a model of our world as provided by science. The scope depth and sophistication of this model evolve as learning is pursued to higher levels. Here, the storylines are presented at a level judged both achievable and appropriate ahead of entry to higher education in Scotland, for a degree in any STEM subject.

The storylines are written as descriptive statements. They constitute the core scientific knowledge and understanding that provides the starting point for future study or application. This is not, however, the whole story. School studies in STEM subjects should also develop a solid basis of core skills, and familiarity with key mathematical and technological methodologies. These are described in Chapters 3 and 5 of our Report on *Building a New Educational Framework to Address the STEM Skills Gap* (STEM-ED Scotland, 2010).

The storylines are listed below 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.

An Appendix to this paper provides a much shorter summary checklist of 'key conceptual strands' embraced within the storylines.

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, which 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 inter-converted 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.

Appendix: Key conceptual strands in the sciences

It is perhaps useful also to give a much shorter summary checklist of 'key conceptual strands' embraced within the storylines. This is a concise way to highlight the range of ideas to be embraced. We must emphasize that this list, presented under a series of headings, should in no sense be viewed as a syllabus, let alone a sequential one. The storylines themselves, given above, should be regarded as the principal reference source to describe the underlying 'picture of the world' upon which learners at this level should be able to anchor their studies of STEM topics. The storylines were set out under science discipline headings, an approach not found appropriate for the balder list of conceptual strands below.

• **Mass and matter**

- atomic and molecular structure
- periodic table, atomic masses
- chemical bonding, including shape
- reactions and stoichiometry, the mole
- phases of matter and their properties
- gas laws, conductivity (thermal and electrical)
- intermolecular forces
- temperature and phase changes
- elementary particles

• **Energy**

- forms of energy and energy transfer
- heat and temperature including absolute temperature
- energy storage and dissipation
- energy states of atoms and molecules, transitions
- extreme processes, interconversion of mass and energy

• **Chemical and biochemical processes**

- bonding and energy
- the molecules of life and metabolism
- structures and function
- interaction and reactivity
- polarity, characteristics of functional groups
- solutions and solvation
- acids and bases, pH
- redox reactions
- chemical equilibrium
- reaction rates and yields
- biochemical steady states

- **Forces and motion**

- forces of nature
- laws of motion: velocity, acceleration, collisions
- momentum, torque, rotational motion
- vectors
- electrostatic forces
- cohesive and stress forces including pressure

- **The earth, solar system and universe**

- structure and evolution of the universe
- generation of the elements, stellar radiation
- development and structure of the earth
- seismic and cosmic processes and the earth
- evolution of the biosphere
- the atmosphere, weather and global warming
- some basics of relativity — time dilation, curvature of space

- **The biosphere**

- evolution of life
- interdependences of organisms, ecosystems
- agriculture and human population
- biodiversity

- **The global environment**

- processes and cycles
- resources, human exploitation, sustainability

- **Wave motions**

- general characteristics and propagation of waves
- reflection, refraction and diffraction

- **Sound**

- production and propagation, single and superimposed frequencies
- sound and hearing, sound and music
- sound recording and replay
- ultrasound

- **Magnetism**

• **Electricity**

- charge and current
- ions and electrochemical processes
- insulators, conductors, flows in circuits
- semiconductors, superconductors
- electrical signals, including via the nervous system
- electromagnetic induction
- electronics

• **Electromagnetic radiation**

- the electromagnetic spectrum
- frequency, wavelength, energy, photon
- reflection, refraction, diffraction, absorption/emission
- detection, including human vision, cameras and display devices
- lasers

• **Organisms**

- range and classification
- constitution in terms of cells
- physiology, organs
- control and homeostasis
- brain, nervous system and senses
- diet and activity, sustaining health
- infection and disease
- nature and scope of interventions through modern medicine

• **Structure and operation of cells**

- substructures
- cell division
- reproduction and heredity
- genetics