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Nature of science
Pilot guide

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Nature of science pilot guide

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Syllabus outline

Syllabus component	Recommended teaching hours
Introduction	**5**
Part A Concepts	**12**
A.1 Energy and particles	12
Part B The quest for understanding	**36**
B.1 The universe	12
B.2 Nature of our planet	12
B.3 Evolution	12
Part C The impact of science	**60**
C.1 Energy and physical resources	18
C.2 Transport	6
C.3 Communications	12
C.4 Food Security	12
C.5 Medicine	12
Part D Challenges and the future	**12**
Human impact on the environment/planet	12
Practical scheme of work	
Practical activities (25 hours) - composed of approximately 3 hours within each subtopic.	
Individual investigation (internal assessment – IA)	15
Group 4 project	10
Total teaching hours	**150**

The recommended teaching time is 150 hours to complete SL courses as stated in the document *General regulations: Diploma Programme* for students and their legal guardians (page 4, article 8.2).

Syllabus content

	Recommended teaching hours (125 hours*)
Introduction	**5**
Black box exercise	
Discussion questions	
Part A: Concepts	**12**
A.1 Energy and particles	**12**
A.1.1 What are fields?	
A.1.2 What is energy?	
A.1.3 Newton's laws of motion	
A.1.4 Fundamental particles	
Part B: The quest for understanding	**36**
B.1 The universe	**12**
B.1.1 Origin of the universe	
B.1.2 Galaxies	
B.1.3 Stars	
B.1.4 The solar system	
B.2 Nature of our planet	**12**
B.2.1 The origin of the Earth	
B.2.2 Plate tectonics	
B.2.3 Equilibrium	
B.3 Evolution	**12**
B.3.1 Ideas on the origin of life	
B.3.2 Evolution and the theory of natural selection	
B.3.3 Evidence for evolution	
B.3.4 Human evolution	

Part C: The impact of science	**60**
C.1 Energy and physical resources	**18**
C.1.1 Electrical energy	
C.1.2 Using electrical energy I—portable electricity	
C.1.3 Using electrical energy II—centralized electrical production	
C.1.4 Renewable and non-renewable energy	
C.1.5 Nuclear power	
C.1.6 Forces and physical properties	
C.1.7 Uses of physical resources	
C.2 Transport	**6**
C.2.1 Unbalanced forces	
C.2.2 Transportation systems	
C.3 Communications	**12**
C.3.1 Introduction to communications	
C.3.2 Electromagnetic induction and electromagnetic waves	
C.3.3 Digital signals	
C.3.4 Optical fibres	
C.3.5 Communication networks	
C.4 Food security	**12**
C.4.1 Nutritional requirements	
C.4.2 Agricultural science	
C.4.3 Biotechnology	
C.5 Medicine	**12**
C.5.1 Science and health	
C.5.2 Modern medicine	
Part D: Challenges and the future	**12**
Human impact on the environment/planet	
This is a 12-hour exercise in which students discuss human impact and propose possible solutions.	

***includes 25 hours of practical activities – approximately 3 hours per subtopic**

Nature of science

The nature of science (NOS) is the overarching theme in the nature of science course. This section, titled “Nature of science”, is in the guide to support teachers in their understanding of what is meant by the nature of science. The “Nature of science” section of the guide provides a comprehensive account of the nature of science in the 21st century.

It uses a numbered paragraph structure (1.1, 1.2, and so on) to link the significant points made to the syllabus content in the first column titled “Understanding the nature of science”. This column contains the nature of science aspects covered and the contextual subject matter that is used to illustrate them.

Technology

Although this section is about the nature of science, the interpretation of the word “technology” is important, and the role of technology emerging from and contributing to science needs to be clarified. In today’s world, the words science and technology are often used interchangeably, however, historically this is not the case. Technology emerged before science, and materials were used to produce useful and decorative artefacts long before there was an understanding of why materials had different properties that could be used for different purposes. In the modern world the reverse is the case: an understanding of the underlying science is the basis for technological developments. These new technologies in their turn drive developments in science.

Despite their mutual dependence they are based on different values: science on evidence, rationality and the quest for deeper understanding; technology on the practical, the appropriate and the useful with an increasingly important emphasis on sustainability.

1. What is science and what is the scientific endeavour?

1.1. The underlying assumption of science is that the universe has an independent, external reality accessible to human senses and amenable to human reason.

1.2. Pure science aims to come to a common understanding of this external universe; applied science and engineering develop technologies that result in new processes and products. However, the boundaries between these fields are fuzzy.

1.3. Scientists use a wide variety of methodologies which, taken together, make up the process of science. There is no single “scientific method”. Scientists have used, and do use, different methods at different times to build up their knowledge and ideas but they have a common understanding about what makes them all scientifically valid.

1.4. This is an exciting and challenging adventure involving much creativity and imagination as well as exacting and detailed thinking and application. Scientists also have to be ready for unplanned, surprising, accidental discoveries. The history of science shows this is a very common occurrence.

1.5. Many scientific discoveries have involved flashes of intuition and many have come from speculation or simple curiosity about particular phenomena.

1.6. Scientists have a common terminology and a common reasoning process, which involves using deductive and inductive logic through analogies and generalizations. They share mathematics, the language of science, as a powerful tool. Indeed, some scientific explanations only exist in mathematical form.

1.7. Scientists must adopt a skeptical attitude to claims. This does not mean that they disbelieve everything, but rather that they suspend judgment until they have a good reason to believe a claim to be true or false. Such reasons are based on evidence and argument.

1.8. The importance of evidence is a fundamental common understanding. Evidence can be obtained by observation or experiment. It can be gathered by human senses, primarily sight, but much modern science is carried out using instrumentation and sensors that can gather information remotely and automatically in areas that are too small, or too far away, or otherwise beyond human sense perception. Improved instrumentation and new technology have often been the drivers for new discoveries. Observations followed by analysis and deduction led to the Big Bang theory of the origin of the universe and to the theory of evolution by natural selection. In these cases, no controlled experiments were possible. Disciplines such as geology and astronomy rely strongly on collecting data in the field, but all disciplines use observation to collect evidence to some extent. Experimentation in a controlled environment, generally in laboratories, is the other way

of obtaining evidence in the form of data, and there are many conventions and understandings as to how this is to be achieved.

1.9. This evidence is used to develop theories, generalize from data to form laws and propose hypotheses. These theories and hypotheses are used to make predictions that can be tested. In this way theories can be supported or opposed and can be modified or replaced by new theories.

1.10. Models, some simple, some very complex, based on theoretical understanding, are developed to explain processes that may not be observable. Computer-based mathematical models are used to make testable predictions, which can be especially useful when experimentation is not possible. Models tested against experiments or data from observations may prove inadequate, in which case they may be modified or replaced by new models.

1.11. The outcomes of experiments, the insights provided by modelling and observations of the natural world may be used as further evidence for a claim.

1.12. The growth in computing power has made modelling a much more powerful. Models, usually mathematical, are now used to derive new understandings when no experiments are possible (and sometimes when they are). This dynamic modelling of complex situations involving large amounts of data, a large number of variables and complex and lengthy calculations is only possible as a result of increased computing power. Modelling of the Earth's climate, for example, is used to predict or make a range of projections of future climatic conditions. A range of different models have been developed in this field and results from different models have been compared to see which models are most accurate. Models can sometimes be tested by using data from the past and used to see if they can predict the present situation. If a model passes this test, we gain confidence in its accuracy.

1.13. Both the ideas and the processes of science can only occur in a human context. Science is carried out by a community of people from a wide variety of backgrounds and traditions, and this has clearly influenced the way science has proceeded at different times. It is important to understand, however, that to do science is to be involved in a community of inquiry with certain common principles, methodologies, understandings and processes.

2. The understanding of science

2.1. Theories, laws and hypotheses are concepts used by scientists. Though these concepts are connected, there is no progression from one to the other. These words have a special meaning in science and it is important to distinguish these from their everyday use.

2.2. Theories are themselves integrated, comprehensive models of how the universe, or parts of it, work. A theory can incorporate facts and laws and tested hypotheses. Predictions can be made from the theories and these can be tested in experiments or by careful observations. Examples are the germ theory of disease or atomic theory.

2.3. Theories generally accommodate the assumptions and premises of other theories, creating a consistent understanding across a range of phenomena and disciplines. Occasionally, however, a new theory will radically change how essential concepts are understood or framed, impacting other theories and causing what is sometimes called a "paradigm shift" in science. One of the most famous paradigm shifts in science occurred when our idea of time changed from an absolute frame of reference to an observer-dependent frame of reference within Einstein's theory of relativity. Darwin's theory of evolution by natural selection also changed our understanding of life on Earth.

2.4. Laws are descriptive, normative statements derived from observations of regular patterns of behaviour. They are generally mathematical in form and can be used to calculate outcomes and to make predictions. Like theories and hypotheses, laws cannot be proven. Scientific laws may have exceptions and may be modified or rejected based on new evidence. Laws do not necessarily explain a phenomenon. For example, Newton's law of universal gravitation tells us that the force between two masses is inversely proportional to the square of the distance between them, and allows us to calculate the force between masses at any distance apart, but it does not explain why masses attract each other. Also, note that the term law has been used in different ways in science, and whether a particular idea is called a law may be partly a result of the discipline and time period at which it was developed.

2.5. Scientists sometimes form hypotheses—explanatory statements about the world that could be true or false, and which often suggest a causal relationship or a correlation between factors. Hypotheses can be tested by both experiments and observations of the natural world and can be supported or opposed.

2.6. To be scientific, an idea (for example, a theory or hypothesis) must focus on the natural world and natural explanations and must be testable. Scientists strive to develop hypotheses and theories that are compatible with accepted principles and that simplify and unify existing ideas.

2.7. The principle of Occam's razor is used as a guide to developing a theory. The theory should be as simple as possible while maximizing explanatory power.

2.8. The ideas of correlation and cause are very important in science. A correlation is a statistical link or association between one variable and another. A correlation can be positive or negative and a correlation coefficient can be calculated that will have a value between +1, 0 and -1. A strong correlation (positive or negative) between one factor and another suggests some sort of causal relationship between the two factors but more evidence is usually required before scientists accept the idea of a causal relationship. To establish a causal relationship, ie one factor causing another, scientists need to have a plausible scientific mechanism linking the factors. This strengthens the case that one causes the other, for example smoking and lung cancer. This mechanism can be tested in experiments.

2.9. The ideal situation is to investigate the relationship between one factor and another while controlling all other factors in an experimental setting; however this is often impossible and scientists, especially in biology and medicine, use sampling, cohort studies and case control studies to strengthen their understanding of causation when experiments (such as double blind tests and clinical trials) are not possible. Epidemiology in the field of medicine involves the statistical analysis of data to discover possible correlations when little established scientific knowledge is available or the circumstances are too difficult to control entirely. Here, as in other fields, mathematical analysis of probability also plays a role.

3. The objectivity of science

3.1. Data is the lifeblood of scientists and may be qualitative or quantitative. It can be obtained purely from observations or from specifically designed experiments, remotely using electronic sensors or by direct measurement. The best data for making accurate and precise descriptions and predictions is often quantitative and amenable to mathematical analysis. Scientists analyse data and look for patterns, trends and discrepancies, attempting to discover relationships and establish causal links. This is not always possible, so identifying and classifying observations and artefacts (eg types of galaxies or fossils) is still an important aspect of scientific work.

3.2. Taking repeated measurements and large numbers of readings can improve reliability in data collection. Data can be presented in a variety of formats such as linear and logarithmic graphs that can be analysed for, say, direct or inverse proportion or for power relationships.

3.3. Scientists need to be aware of random errors and systematic errors, and use techniques such as error bars and lines of best fit on graphs to portray the data as realistically and honestly as possible. There is a need to consider whether outlying data points should be discarded or not.

3.4. Scientists need to understand the difference between errors and uncertainties, accuracy and precision, and need to understand and use the mathematical ideas of average, mean, mode, median, etc. Statistical methods such as standard deviation and chi-squared tests are often used. It is important to be able to assess how accurate a result is. A key part of the training and skill of scientists is in being able to decide which technique is appropriate in different circumstances.

3.5. It is also very important for scientists to be aware of the cognitive biases that may impact experimental design and interpretation. The confirmation bias, for example, is a well-documented cognitive bias that urges us to find reasons to reject data that is unexpected or does not conform to our expectations or desires, and to perhaps too readily accept data that agrees with these expectations or desires. The processes and methodologies of science are largely designed to account for these biases. However care must always be taken to avoid succumbing to them.

3.6. Although scientists cannot ever be certain that a result or finding is correct, we know that some scientific results are very close to certainty. Scientists often speak of "levels of confidence" when discussing outcomes. The discovery of the existence of a Higgs boson is such an example of a "level of confidence". This particle may never be directly observable,

but to establish its “existence” particle physicists had to pass the self-imposed definition of what can be regarded as a discovery—the 5-sigma “level of certainty”—or about a 0.00003% chance that the effect is not real based on experimental evidence.

3.7. In recent decades, the growth in computing power, sensor technology and networks has allowed scientists to collect large amounts of data. Streams of data are downloaded continuously from many sources such as remote sensing satellites and space probes and large amounts of data are generated in gene sequencing machines. Experiments in CERN’s Large Hadron Collider regularly produce 23 petabytes of data per second, which is equivalent to 13.3 years of high definition TV content per second.

3.8. Research involves analysing large amounts of this data, stored in databases, looking for patterns and unique events. This has to be done using software which is generally written by the scientists involved. The data and the software may not be published with the scientific results but would be made generally available to other researchers.

4. The human face of science

4.1. Science is highly collaborative and the scientific community is composed of people working in science, engineering and technology. It is common to work in teams from many disciplines so that different areas of expertise and specializations can contribute to a common goal that is beyond one scientific field. It is also the case that how a problem is framed in the paradigm of one discipline might limit possible solutions, so framing problems using a variety of perspectives, in which new solutions are possible, can be extremely useful.

4.2. Teamwork of this sort takes place with the common understanding that science should be open-minded and independent of religion, culture, politics, nationality, age and gender. Science involves the free global interchange of information and ideas. Of course, individual scientists are human and may have biases and prejudices, but the institutions, practices and methodologies of science help keep the scientific endeavour as a whole unbiased.

4.3. As well as collaborating on the exchange of results, scientists work on a daily basis in collaborative groups on a small and large scale within and between disciplines, laboratories, organizations and countries, facilitated even more by virtual communication. Examples of large-scale collaboration include:

- The Manhattan project, the aim of which was to build and test an atomic bomb. It eventually employed more than 130,000 people and resulted in the creation of multiple production and research sites that operated in secret, culminating in the dropping of two atomic bombs on Hiroshima and Nagasaki.

- The Human Genome Project (HGP), which was an international scientific research project set up to map the human genome. The $3-billion project beginning in 1990 produced a draft of the genome in 2000.The sequence of the DNA is stored in databases available to anyone on the internet.

- The IPCC (Intergovernmental Panel on Climate Change), organized under the auspices of The United Nations, is officially composed of about 2,500 scientists. They produce reports summarizing the work of many more scientists from all around the world.

- CERN, the European Organization for Nuclear Research, an international organization set up in 1954, is the world's largest particle physics laboratory. The laboratory, situated in Geneva, employs about 2,400 people and shares results with 10,000 scientists and engineers covering over 100 nationalities from 600 or more universities and research facilities.

All the above examples are controversial to some degree and have aroused emotions among scientists and the public.

4.4. Scientists spend a considerable amount of time reading the published results of other scientists. They publish their own results in scientific journals after a process called peer review. This is when the work of a scientist or, more usually, a team of scientists is anonymously and independently reviewed by several scientists working in the same field who decide if the research methodologies are sound and if the work represents a new contribution to knowledge in that field. They also attend conferences to make presentations and display posters of their work. Publication of peer-reviewed journals on the internet has increased the efficiency with which the scientific literature can be searched and accessed. There are a large number of national and international organizations for scientists working in specialized areas within subjects.

4.5. Scientists often work in areas, or produce findings, that have significant ethical and political implications. These areas include cloning, genetic engineering of food and organisms, stem cell and reproductive technologies, nuclear power, weapons development (nuclear, chemical and biological), transplantation of tissue and organs and in areas that involve testing on animals (see IB animal experimentation policy). There are also questions involving intellectual property rights and the free exchange of information that may impact significantly on a society. Science is undertaken in universities, commercial companies, government organizations, defence agencies and international organizations. Questions of patents and intellectual property rights arise when work is done in a protected environment.

4.6. The integrity and honest representation of data is paramount in science—results should not be fixed or manipulated or doctored. To help ensure academic honesty and guard against plagiarism, all sources are quoted and appropriate acknowledgement made of help or support. Peer review and the scrutiny and skepticism of the scientific community also help achieve these goals.

4.7. All science has to be funded and the source of the funding is crucial in decisions regarding the type of research to be conducted. Funding from governments and charitable foundations is sometimes for pure research with no obvious direct benefit to anyone whereas funding from private companies is often for applied research to produce a particular product or technology. Political and economic factors often determine the nature and extent of the funding. Scientists often have to spend time applying for research grants and have to make a case for what they want to research.

4.8. Science has been used to solve many problems and improve man's lot, but it has also been used in morally questionable ways and in ways that inadvertently caused problems. Advances in sanitation, clean water supplies and hygiene led to significant decreases in death rates but without compensating decreases in birth rates this led to huge population increases with all the problems of resources, energy and food supplies that entails. Ethical discussions, risk-benefit analyses, risk assessment and the precautionary principle are all parts of the scientific way of addressing the common good.

5. Scientific literacy and the public understanding of science

5.1. An understanding of the nature of science is vital when society needs to make decisions involving scientific findings and issues. How does the public judge? It may not be possible to make judgments based on the public's direct understanding of a science, but important questions can be asked about whether scientific processes were followed and scientists have a role in answering such questions.

5.2. As experts in their particular fields, scientists are well placed to explain to the public their issues and findings. Outside their specializations, they may be no more qualified than ordinary citizens to advise others on scientific issues, although their understanding of the processes of science can help them to make personal decisions and to educate the public as to whether claims are scientifically credible.

5.3. As well as comprising knowledge of how scientists work and think, scientific literacy involves being aware of faulty reasoning. There are many cognitive biases/fallacies of reasoning to which people are susceptible (including scientists) and these need to be corrected whenever possible. Examples of these are the confirmation bias, hasty generalizations, *post hoc ergo propter hoc* (false cause), the straw man fallacy, redefinition (moving the goal posts), the appeal to tradition, false authority and the accumulation of anecdotes being regarded as evidence.

5.4. When such biases and fallacies are not properly managed or corrected, or when the processes and checks and balances of science are ignored or misapplied, the result is pseudoscience. Pseudoscience is the term applied to those beliefs and practices which claim to be scientific but do not meet or follow the standards of proper scientific methodologies, ie they lack supporting evidence or a theoretical framework, are not always testable and hence falsifiable, are expressed in a non-rigorous or unclear manner and often fail to be supported by scientific testing.

5.5. Another key issue is the use of appropriate terminology. Words that scientists agree on as being scientific terms will often have a different meaning in everyday life and scientific discourse with the public needs to take this into account. For example, a theory in everyday use means a hunch or speculation, but in science an accepted theory is a scientific idea that has produced predictions that have been thoroughly tested in many different ways. An aerosol is just a spray can to the general public, but in science it is a suspension of solid or liquid particles in a gas.

5.6. Whatever the field of science—whether it is in pure research, applied research or in engineering new technology—there is boundless scope for creative and imaginative thinking. Science has achieved a great deal but there are many, many unanswered questions to challenge future scientists.

The link below leads to an interactive flow chart showing the scientific process of inquiry in practice. It is part of a website "How science works" *Understanding Science*. University of California Museum of Paleontology. 1 February 2013.

http://undsci.berkeley.edu/article/scienceflowchart

Introduction (5 hours)

What is the nature of science?

1. Black box experiment (Time 2 hours)

Students are given a box that is taped up and contains a variety of items (usually more than one) inaccessible to sight or touch. Their task is to determine what the contents may be. By shaking, tilting, lifting and listening to the box they may form hypotheses about what they think the items inside are, or at least their general shape. They have access to a range of materials and spare boxes. They may place objects within this spare box and see if they behave in a similar manner to their black box. They have no way of knowing if the test materials provided are actually samples of the ones inside the black boxes. In this manner hypotheses can be tested and models made of the contents of the black box. Communication with other students can allow models to be compared and ideas to be exchanged. Students can observe their tendencies to support their own hypotheses above those of others.

Critically the box may never be opened to determine its actual contents, showing that in the real world science operates without complete certainty and is always open to models that may better explain experimental findings.

2. Discussion questions (Time 3 hours split over more than one session to allow time for reflection)

The black box experiment should be followed by a series of discussion questions

The aim is to establish the extent of prior knowledge and understanding. The remainder of the course will help remove misconceptions and build a fuller understanding of the nature of science.

Questions/tasks

The following big picture questions should be raised in the introductory exercise and students should be given the opportunity to reflect on them.

- What is science?
- Are there different types of science?
- What is the difference between pure science, applied science and technology?
- Is science good or bad?
- Do scientists work together and collaborate?
- How is science disseminated? How do scientists communicate and publish their work?
- Where do scientists work?
- Who provides funding for the scientists?
- Do those providing the funding decide what scientists should do? How do those providing funds make their decisions? Do scientists have a role in obtaining funding?
- How do scientists work?

Part A: Concepts

A.1 Energy and particles — 12 hours

A.1.1 What are fields?

Essential idea

The concept of fields was developed to help explain the "action at a distance" observed in the motion of masses, charges and magnetic materials in the presence of each other.

Understanding the nature of science	Practical activities	Research activities
Fields are a convenient concept for the quantitative interpretation of the phenomena of forces acting over a distance. 1.2, 1.6 Visualizations of fields are helpful to our understanding of a range of phenomena. 1.10 Electromagnetic radiation is understood as the interaction of electric and magnetic fields. 1.6 Moving within fields may involve transfer of energy and work being done. 2.4 **Guidance** Electric fields are associated with charged particles and changing magnetic fields. Magnetic fields are associated with permanent magnets, moving charges and a changing electric field. Gravitational fields are associated with masses. An understanding of what fields represent is required and not the reproduction of different field patterns.	Use of modelling software such as *Modellus.* http://modellus.co/index.php/en/ Simulations to visualize field patterns. http://www.falstad.com/emstatic/index.html Explore field patterns around charge—semolina experiment. http://www.nuffieldfoundation.org/practical-physics/electric-fields?topic_id=8&collection_id=39 Plotting magnetic field patterns. http://www.nuffieldfoundation.org/practical-physics/magnetic-fields-due-arrangements-magnets	Examine the evidence of the use of fields in the natural world (for example, navigation in animals). Salmon use magnetic field for navigation. http://www.natureworldnews.com/articles/5915/20140206/salmon-use-magnetic-field-navigation-study-confirms.htm Geotropism http://www.biologie.uni-hamburg.de/b-online/e32/32c.htm Plotting the variation on gravitational field strength *g* with distance from the surface of a planet and/or its mass. The value of *g* http://www.physicsclassroom.com/Class/circles/u6l3e.cfm Problem-based learning http://pbl.ccdmd.qc.ca/resultat.php?action=clicFiche&he=1050&afficheRecherche=-1&IDFiche=158&endroitRetour=0

A.1.2 What is energy?		
Essential idea Often in science abstract concepts are useful and the concept of “energy” has been developed to help explain observations and measurements of causally linked phenomena.		
Understanding the nature of science	**Practical activities**	**Research activities**
Energy has intrigued scientists from the earliest times. It is a concept common to all sciences.1.1, 1.13 Energy is the ability to do work. Work done equates to the energy transferred. 5.5 Energy is a concept that is best understood by exploring the underlying mechanisms (both microscopic and macroscopic) in a process. 1.2 In developing the concept of energy, models have been built to help explain the different ways in which energy exists. 5.5 Einstein’s equation $E=mc^2$ shows that mass and energy are interchangeable. This applies to all energy transfers. 1.2, 1.5 **Guidance** The understanding of energy should focus on the underlying mechanisms and not on descriptions in terms of energy changes.	Students can revisit some energy topics from earlier studies in terms of the underlying mechanisms. Carry out a simple science experiment that can be understood in terms of the underlying mechanisms, for example, use a calorimeter to measure the energy content of food. http://www.nuffieldfoundation.org/practical-biology/how-much-energy-there-food http://www.rsc.org/learn-chemistry/resource/res00000397/energy-values-of-food?cmpid=CMP00000467 Perform step ups and measure temperature rise. Heat up different fuels and calculate their energy density. http://www.nuffieldfoundation.org/practical-chemistry/measuring-heat-energy-fuels Energy transfers in bouncing balls. https://www.asee.org/conferences-and-events/conferences/kworkshop/2012/Ball_Drop_activity.pdf Using a battery operated torch. Energy skate park simulation. http://phet.colorado.edu/en/simulation/energy-skate-park	What types of energy have students met before? Consider different types, everyday examples, where energy is used and energy transformations. Group discussion of how the terms “energy” and “work” are understood by students. Work in groups to find out the history of a particular form of energy. Students should pay particular attention to the nature of the concepts employed (for example, the caloric theory) and how they think they compare to present-day ideas. Energy density of fuels. http://www.eia.gov/todayinenergy/detail.cfm?id=9991
A.1.3 Newton’s laws of motion		

Essential idea

Newton was able to explain motion through developing a set of laws that can be expressed mathematically. The laws are obeyed by all objects, regardless of the nature of the force or the situation of the objects. Through his laws, Newton was able to create an explanation of motion that clarified thinking, explained observations and made successful predictions.

Understanding the nature of science	Practical activities	Research activities
Newton's laws are independent of the types of force experienced by the object. 2.4 Newton's second law can be expressed mathematically as $F=ma$, where acceleration is a vector quantity that has the same direction as the force that caused it. 1.6 Newton's laws can be used to make predictions about the motion of objects. 2.4 Circular motion involves a force acting towards the centre of rotation. 1.6 **Guidance** Students will need to calculate acceleration using $F=ma$ and $a=\Delta v/t$.	Students build model rockets. http://sctritonscience.com/Wilson/physics/worksheets/lab%20baloon%20rockets%20newtons%20laws.pdf Graphing of velocity and time from experimental data to determine acceleration (for example, trolley). http://fk1ss.fungkai.school.hk/system/readfile.php?charset=big5&netroom_id=894&tool_id=8709&filename=L2ZrMXNzL05TU19jb21wL05TU19EVkQvTlNTUEFXX1BEVkQyIChEKS9kb3dubG9hZC9wd2lvUFdCXzIwMmIucGRm http://www.animatedscience.co.uk/blog/wp-content/uploads/2011/04/8_2_Practical_Acceleration.docx http://www.schoolphysics.co.uk/age1619/Mechanics/Kinematics/experiments/Speed_and_acceleration.doc	Students predict the behaviour of bodies given initial conditions. Identify exceptions to Newton's laws found in movies and cartoons. http://violatingthelawsofphysics.weebly.com/index.html Explain the orbital motion of objects in the solar system. http://www.universetoday.com/61202/earths-orbit-around-the-sun/ Relate graphs of displacement versus time, speed versus time and acceleration versus time. http://hyperphysics.phy-astr.gsu.edu/hbase/mechanics/motgraph.html Explore the implications of Newton's laws for space travel and exploration. http://quest.nasa.gov/space/teachers/liftoff/newton.html Use secondary data to determine acceleration in a variety of novel circumstances (for example, space shuttle, particle accelerators, and so on) Investigate forces and the operation of Newton's laws in amusement park rides. http://www.funderstanding.com/educators/coaster/

A.1.4 Fundamental particles		
Essential idea Various models have been proposed to explain the underlying structure of the material universe. Particle models supported by evidence that match our observations provide useful unifying concepts and enable accurate predictions to be made.		
Understanding the nature of science	**Practical activities**	**Research activities**
Over time humans have postulated a variety of models to explain the structure of matter. Some models were based on speculation and logic (for example, early Greek theories of the four "elements": fire, earth, air and water). Later models were based on experimental findings and the need to explain these. Dalton and other chemists in the 19th century interpreted the world in terms of atoms, molecules and ions. Substances with different numbers of protons in their atoms are called elements. There are only 98 long-lasting elements in the universe. Mendeleev was able to produce a periodic table of the elements when he observed properties and patterns in their behaviour and was able to predict the existence of missing elements that were subsequently discovered. In the 20th century the work of Thompson, Millikan, Rutherford and Chadwick led to an understanding of the structure of atoms and the existence of subatomic particles. More recently large multinational teams of scientists working in high budget research centres, such as CERN, have produced evidence that these subatomic particles are in turn comprised of fundamental particles and at a deeper level even more basic units such as quarks. 1.10, 2.2, 2.5 **Guidance** A qualitative, descriptive understanding is sufficient.	Students can explore various ways of understanding the sub-microscopic nature of matter including the following. The oil film experiment http://www.schoolphysics.co.uk/age16-19/Thermal%20physics/Kinetic%20theory%20of%20matter/text/Molecular_size_oil_drop/index.html Models of different types of solids http://www.chem1.com/acad/webtext/states/crystals-cubic.html X-ray crystallography photographs of different materials Students can perform virtual kinetic theory experiments in which changes to parameters affect the pressure of a gas, along with visualizations of colliding particles. Gas simulation http://www.falstad.com/gas/ http://phet.colorado.edu/en/simulation/gas-properties	Research: • the existence of atoms, molecules and ions • the work of Dalton and the evidence for his atomic theory • the work of the pioneers of subatomic physics • the investigations that are currently in progress at high energy research centres. The Higgs boson http://home.web.cern.ch/topics/higgs-boson

Part B: The quest for understanding

B.1 The universe — 12 hours

B.1.1: Origin of the universe

Essential idea

Observations, initially through the naked eye and then using advancing technologies such as optical telescopes, X-ray telescopes, radio telescopes and so on, together with theoretical developments of a mathematical nature have led to our present knowledge of the universe.

Understanding the nature of science	Practical activities	Research activities
Some explanations for the origin of the universe cannot be tested scientifically; scientific claims must focus on the observational evidence and must be testable. 1.7, 2.6 Different cultures have contributed to our scientific understanding of the universe. 1.13 Developments in theoretical knowledge such as relativity have led to refinements in our model of the universe. 1.10, 1.11 Newton's work on gravitation advanced the quantitative analysis of the universe. 2.3, 2.4, 2.5, 3.1 Olber realised that the night sky being dark in certain directions did not fit with an infinite universe model (Olbers paradox). 1.4, 1.6 Einstein's theory of general relativity provides an explanation of Newton's law of gravitation. 2.2, 2.3 Acceptance of a steady-state theory avoids questions about the origin of the universe. 1.9, 2.7 The concept of the light year as a measurement of large distances is important. 1.6 Cosmic background radiation (CMBR) signals were serendipitously detected in 1964 by Penzias and Wilson and this refuted the steady-state theory by providing evidence of the Big Bang. 1.4, 1.5 The present theory of the origin of the universe is that there was a Big Bang about 13.8 billion years ago, which resulted in a spontaneous release of energy from which the universe was created.	Exploring the universe using virtual observatory resources. http://tdc-www.harvard.edu/astro.image.html http://www3.gettysburg.edu/~marschal/clea/CLEAhome.html http://www.stellarium.org http://astro.unl.edu/naap/distance/distance.html http://astro.unl.edu/naap/ http://www.cfa.harvard.edu/seuforum/einstein/resource_journeyexpanding.htm http://www.illustris-project.org/ Images of astronomical objects http://csep10.phys.utk.edu/astr162/lect/galaxies/ http://hubblesite.org/gallery/ http://apod.nasa.gov/apod/archivepix.html http://www.noao.edu/image_gallery/ Constructing a timeline of the origin of the universe (contrast very short timeframe of initial events with the unimaginable eons since then and/or the evolution of humankind's concept of the universe including critical events). Chronozoom can be used to create timelines. http://eps.berkeley.edu/~saekow/chronozoom/ www.youtube.com/watch?v=0fKBhvDjuy0 http://images.cryhavok.org/d/1151-1/Big+Bang+Timeline.jpg	Explorations of scale in the universe. www.powersof10.com/ http://htwins.net/scale2/ Size comparison of astronomical units http://www.quantrek.org/size_comparison/size_comparison.htm Research dark matter and dark energy. http://vimeo.com/22956103 http://hubblesite.org/hubble_discoveries/dark_energy/ http://map.gsfc.nasa.gov/resources/camb_tool/index.html Methods for estimating the age of the universe http://stardate.org/astroguide/btss/cosmology/age_of_the_universe Concepts of the universe held by different cultures and religions Steady-state models of the universe First few seconds of the universe http://www.universeadventure.org/fundamentals/cosmol-beginning.htm

Computer modelling of galaxy formation from the initial fluctuations in the density of the early universe as shown by COBE and WMAP satellite data help explain the appearance of the universe. 1.8, 1.12 Present-day astronomical observations generate vast amounts of data and rely on rapid computer processing to convert it into useful information. 1.10, 3.7 Current models of the universe require the presence of large quantities of “dark matter” and “dark energy”. 1.7, 2.3	Measuring distances using parallax. http://cse.ssl.berkeley.edu/astro48bcc/pdf_files/Parallax.pdf	

B.1.2 Galaxies		
Essential idea Initially most of the visible objects in the sky were thought of as being similar, but as a result of improved observational technology, gradually different groups, including non-visible objects, have been identified and their origins deduced, showing the value of pattern recognition and classification in science.		
Understanding the nature of science	**Practical activities**	**Research activities**
Improvements in observational technology have enabled more detailed information to be obtained regarding the large-scale structure of the universe. 1.8 Stars are clustered together in galaxies and these galaxies are clustered into groups. 1.8 Hubble found evidence, through the “red shift”, for the recession of galaxies. This implied the universe might have had its origin at a singularity. Measuring the rate of expansion allowed the age of the universe to be estimated. 1.8, 1.9, 3.2 There is great uncertainty in the value of the current rate of expansion and this may also be changing over time. Recent measurements suggest that the rate of expansion is increasing. 2.3, 3.3, 3.4	Compare naked eye observations of stars, planets, nebulas (Orion nebula) and galaxies (Andromeda) with those possible using early telescopes, current terrestrial telescopes and Hubble images. Investigate the Doppler effect using sound. http://www.physicsclassroom.com/getattachment/lab/sound/s1tg.pdf https://cms.qut.edu.au/__data/assets/pdf_file/0012/24501/investigating_doppler_effect_teacher_worksheet.pdf Carry out virtual experiments, such as correlating the red shift with distance. Show spiral galaxy formation by spinning a wet ball. https://stratplan.basecamphq.com/projects/6782540/file/190279736/why_galaxies_are_spirals.jpg	Types of telescopes (all em range) and their development. Contributions of different types of telescopes to our understanding. Types of nebulas and galaxies. Colliding and interacting galaxies. Evidence of changes in rate of expansion. Use of the Drake equation to look at possible existence of intelligent life beyond Earth. http://www.activemind.com/Mysterious/Topics/SETI/drake_equation.html Size comparison of astronomical units. http://www.quantrek.org/size_comparison/size_comparison.htm

B.1.3 Stars		
Essential idea Application of the basic laws of physics has enabled scientists to deduce the origin and evolution of stars.		
Understanding the nature of science	**Practical activities**	**Research activities**
Current models postulate that stars are created when massive clouds of dust and gas coalesce under gravitational attraction, when the resulting extreme temperatures and pressures initiate the nuclear fusion of hydrogen. 1.8, 1.9, 1.10, 1.1 Stars can be classified into different groups according to their appearance, and interpreted more quantitatively in graphs of luminosity against temperature called Hertzsprung-Russell (HR) diagrams. 2.8, 3.1 Most stars evolve from "main sequence" through red giants, white dwarves and neutron stars to form black holes when their supply of hydrogen runs out, although very massive stars undergo a catastrophic collapse known as a supernova. 1.3, 3.1 Main sequence stars, similar to our Sun, use nuclear fusion to convert hydrogen to helium. Other types of stars convert helium into other light elements. 1.3, 1.8, 1.10 As their formation would be endothermic, elements heavier than iron could not have been produced in this manner and they are currently thought to result from extreme events such as supernovas. 1.9 Observations of the spectra of stars can be used to deduce their composition. 1.8, 3.1, 3.8	Use luminosity and temperature data on stars to construct HR diagrams. http://hubblesite.org/pubinfo/ppt/2010/28/ppt.ppt Identify different classes of stars, both by direct observation and by accessing images online. Deduce the presence of particular elements by analysing stellar spectra. http://dev.physicslab.org/Document.aspx?doctype=3&filename=AtomicNuclear_AtomicModelsSpectra.xml Use of a spectrometer to look at spectra of white light and some elements. http://umanitoba.ca/outreach/crystal/resources%20for%20teachers/Flame%20Tests,%20Atomic%20Spectra%20&%20Applications%20Activity%20C12-2-02%20&%2003.doc	Nuclear stability and nuclear fusion. Stellar evolution on an interactive HR diagram. Origin of the elements http://www.sciencelearn.org.nz/Contexts/Just-Elemental/Sci-Media/Animations-and-Interactives/Universal-element-formation Stellar evolution http://lcogt.net/files/flash/hr-diagram/main.html) Solar magnetic field and global warming http://wattsupwiththat.com/2013/10/09/a-link-between-the-solar-magnetic-field-and-weather-patterns-on-earth-may-explain-our-lower-than-normal-severe-weather-in-2013/

B.1.4 The solar system		
Essential idea The movement of the bodies that comprise the solar system has been systematically measured and recorded by many civilizations. The interpretation of detailed observations proving it to be heliocentric rather than geocentric was one of the major triumphs of scientific method.		
Understanding the nature of science	**Practical activities**	**Research activities**
Our basic understanding of the solar system, its components and their motion was dependent on new technological developments that improved our observational capacity and mathematical modelling. 1.10, 3.2 The changes in position of the planets over time compared to the stars was a challenge to the geocentric model. 2.3, 4.4, 4.6 Recent observations show that stars other than the Sun are also surrounded by planets. 1.8 **Guidance** A detailed knowledge and the underlying mathematical treatments of the physics involved, such as relativity and planetary motion, will not be expected. The emphasis will be on general concepts and on critical observations and their significance.	Observing images of the planets and their motions relative to the stars. Ptolemaic system simulator http://astro.unl.edu/naap/ssm/animations/ptolemaic.html Using planetary orbit practicals to investigate Kepler's laws. Planetary orbit simulator http://astro.unl.edu/naap/pos/animations/kepler.html http://phet.colorado.edu/en/simulation/gravity-and-orbits	Ptolomeic and Copernican models. The influence of the observations of Tycho Brahe, Galileo and the invention of the telescope. The nature of comets and meteors. The search for planets outside our solar system. Search for Exoplanets http://planetquest.jpl.nasa.gov/ Planetary motion and Kepler's laws http://astro.unl.edu/naap/pos/pos.html http://www.1728.org/kepler3a.htm http://earthobservatory.nasa.gov/Features/OrbitsHistory/ First rock dating experiment performed on Mars http://www.caltech.edu/content/first-rock-dating-experiment-performed-mars

B.2 Nature of our planet — 12 hours

B.2.1 The origin of the Earth

Essential idea

The origin of the Earth and the way it has metamorphosed into its current state are not open to experimental investigation. Scientists have had to base their ideas on detailed studies of the Earth as it now exists, and rely on inferences and models that can explain their findings.

Understanding the nature of science	Practical activities	Research activities
1. The age of the Earth Models of the Earth's formation are part of broader models that explain how the solar system was formed. 1.10, 1.12 Quantitative data derived from radioactive emissions from meteorites found on the Earth and the Moon leads us to infer that the Earth formed at least 4.6 billion years ago. 2.1, 2.2 **2. The structure of the Earth** The interior of the Earth is inaccessible to direct study. Advanced techniques in analysing seismic waves, the Earth's magnetic field, and geomagnetic and gravity measurements made at the surface have helped scientists gather information about the composition and thickness of the Earth's internal structure. 1.6,1.8, 1.9, 3.1 **3. Rocks that compose the Earth** Rocks can be dated by both absolute and relative techniques and the study of rocks provides scientists with important information about the Earth, including evidence of the Earth's origin and changes that the Earth has undergone over time. 1.10, 3.1 Living organisms significantly affect these processes by taking in liquid water and releasing water vapour to the atmosphere. Aquatic living organisms also affect the levels of dissolved gases and the levels of dissolved solids. 1.10	Create an effective means of conveying the magnitude of the geological timescale. Construct a model of the Earth's structure. Analyse seismic waves. http://www.iris.edu/hq/programs/education_and_outreach/animations Half-life/decay curve practical. http://sciencenetlinks.com/student-teaher-sheets/case-melting-ice/ Investigating rock samples. Animations of the shaping of the Earth. https://solarsystem.nasa.gov/scitech/display.cfm?ST_ID=446 http://solidearth.jpl.nasa.gov/rp.html Mapping below the surface. http://www.planetseed.com/laboratory-activities/underground-mapping http://www.planetseed.com/laboratory/exploring-petroleum http://www.planetseed.com/laboratory/experiment-personal-seismographs http://www.planetseed.com/sciencearticle/cybergeologist	Research theories of the origin of the Earth, including the currently accepted solar nebula theory. Research attempts to determine the age of the Earth: • religious/cultural beliefs such as that of Archbishop Ussher • Lord Kelvin's logical, but now discredited, hypothesis • modern radioactive dating • the known structure of the Earth and evidence on which it is based • the Big Burp theory. http://www.sciencedaily.com/releases/2010/05/100527141959.htm Compare the Earth's structure with those of the other planets. Explore how models of the Earth's formation account for the presence of the Moon. How understanding the age of the Earth allowed the theory of evolution by natural selection to be properly developed. Geobiodiversity database http://www.geobiodiversity.com/ Access animations on the formation of the Earth and the shaping of its surface. https://www.youtube.com/watch?v=_mcC8kFacrk#t=276

B.2.2 Plate tectonics		
Essential idea Sometimes support for a theory does not come just from a single piece of evidence, or field of research, but from the way in which the theory explains observations over a range of different sciences.		
Understanding the nature of science	**Practical activities**	**Research activities**
1 Origins of the theory Evidence for the concept of plate tectonics gradually built up over the years based on the complementary shape of parts of the present continents as well as similarities in rock formations and plant species, though much of the scientific community was initially sceptical. 1.5, 1.6, 1.7, 1.8, 2.7, 4.1 The results of studies involving paleomagnetism in the 1960s, especially critical evidence concerning the magnetic orientation of rocks from either side of the mid-Atlantic ridge, lead to a widespread acceptance that continental plates move over time. 2.2, 2.3 As a result of new technologies to measure distance and position very precisely, nowadays the movements of the tectonic plates can be directly observed. 3.7 2 The nature of continental masses The Earth's crust is comprised of a number of separate plates that gradually move relative to each other. 1.10 Over geological time the number and shape of the plates, as well as the positions of these, have undergone many changes. 1.10 Interactions of the plates are responsible for earthquakes and physical features such as volcanoes and mountain ranges. 2.5, 2.8	Cutting out bits of card into the shape of the present continents and trying to reform them into the supercontinent Pangaea and later Laurasia and Gondwana. https://imaxmelbourne.com.au/images/uploads/PDF/Study_Guides/Gondwanaland.pdf http://volcanoes.usgs.gov/about/edu/dynamicplanet/wegener/ Continental drift animation. http://www.planetseed.com/files/uploadedfiles/Science/Features/Earth_Science/The_Earth_A_Living_Planet/anim/index.html?width=570&height=465&popup=true	Pangaea. Similar rock formations exist in now separated land masses. Similar plant and animal species exist in now separated land masses. Magnetism of rocks around mid-ocean ridges. http://www.divediscover.whoi.edu/ridge/magnet-polar.html Direct measurements of the change in heights of mountains and positions of land masses. Theories regarding the forces driving the movement of the plates. Patterns of seismic and volcanic activity and their relation to the interaction of plates. The influence of continental drift on evolution. The work of Alfred Wegener in mapping the oceans. http://www.theguardian.com/science/2014/oct/03/uncharted-mountains-underwater-scars-revealed-satellite-map Earth's magnetic field. http://www.scientificamerican.com/article/earth-s-magnetic-field-flip-could-happen-sooner-than-expected/ Incorporated Research Institutions for Seismology http://www.iris.edu/hq/ USGS National Earthquake Information Center http://earthquake.usgs.gov/regional/neic/ The Dynamic Earth http://pubs.usgs.gov/gip/dynamic/dynamic.html

		Smithsonian Institution National Museum of Natural History Global Volcanism Program http://www.volcano.si.edu/

B.2.3 Equilibrium

Essential idea

The Earth's atmospheric composition is in a dynamic equilibrium and such complex systems are very difficult to model but changes to it have occurred in the past and will occur in the future. The extent to which humans contribute to this change is under scientific examination.

Understanding the nature of science	Practical activities	Research activities
The Earth is surrounded by an atmosphere, the composition of which has changed and continues to change. 1.9 Radiation from the Sun, especially UV light, causes chemical reactions between components of the atmosphere, giving rise to an important ozone layer in the upper atmosphere. 1.8, 4.3 Equilibrium exists between gases in the atmosphere and gases dissolved in water on the surface of the Earth, which hence acts as a reservoir of gases. 3.1 A detailed study of the atmosphere has enabled us to develop models that can predict the effects of changes in gas composition that may occur in the future. 1.10, 4.3 Direct evidence of more recent changes in the Earth's atmosphere (about the last half million years) come from ice core samples, especially from the Antarctic, which contain trapped air. 1.8 The total amount of water, and the ratio of water to ice, has caused sea levels to change over geological time. As these variations continue, and affect humankind, an understanding of the factors controlling this is important. 5.1 Most of the energy on Earth originates from the Sun. Solar radiation is absorbed by the Earth's surface and transferred to the atmosphere. The Earth emits infrared radiation, some of which is absorbed and re-radiated by some gases in the atmosphere, creating a greenhouse effect. The balance between absorbed and emitted radiation results in a surface temperature that makes life possible. 1.10 Variations in solar activity are hypothesized to affect global climate by 5% 1.6, 1.8	Measuring the concentration of various gases in the atmosphere. Measuring the uptake and production of gases by living organisms. http://www.nuffieldfoundation.org/practical-biology/measuring-rate-metabolism Measuring the solubilities of different atmospheric gases. Studying the uptake and release of water and dissolved salts by living organisms. Investigating how the presence of aquatic plant and animal life affects the levels of dissolved oxygen and carbon dioxide. Measuring the effect of temperature on the solubility of gases. https://www.youtube.com/watch?v=K3j9HAsoV5Q Measuring the effect of temperature and freezing on the density of water. http://virtuallaboratory.colorado.edu/BioFun-Support/labs/WaterDiffusionMembranes/section_04.html Burning various fossil fuels and measuring their energy content. Generating a greenhouse effect. http://www.nuffieldfoundation.org/practical-chemistry/greenhouse-effect Building a barometer. http://www.rmets.org/weather-and-climate/observing/make-barometer Creating a Foucault's pendulum.	Layer structure of the atmosphere and reasons for this. The nature of the atmosphere at different ages of the Earth, the reasons for this and the way the rocks produced reflect this. Quantitative estimates of the effect of living organisms on atmospheric gases and the assumptions these are based on. The amounts of gases produced as a result of radioactive decay and volcanic activity. The amounts of atmospheric gases dissolved in the oceans. The photochemical changes occurring in the atmosphere. Atmospheres of other planets. Evidence from ice cores about changes in the atmosphere and the uncertainties surrounding this. http://www.antarctica.ac.uk/bas_research/science_briefings/icecorebriefing.php the composition of sea water, its variations and reasons for these. The materials obtained from dissolved solids in sea water. The number of atoms of gold present in a glass of sea water. Ocean productivity http://www.science.oregonstate.edu/ocean.productivity/index.php Measuring gas concentrations http://www.sciencelearn.org.nz/Contexts/Icy-Ecosystems/Sci-Media/Video/Measuring-gas-concentrations

Fossils and sediments also provide information on how the Earth's climate has changed over time. Changes to the atmosphere that result from human activity have a significant effect on the climate. 4.3 There are several greenhouse gases, each with a different contribution to global warming	http://www.calacademy.org/products/pendulum/index.html Demonstrating the Coriolis effect.	The climates of different parts of the Earth and the reasons for these. Torricelli's barometer and compare it with current barometers. Sun spots, the solar wind and variations in these. Why weather patterns tend to drift from West to East. Why pressure zones rotate in different directions on either side of the equator. Access data from the NASA Earth Observatory. http://earthobservatory.nasa.gov/GlobalMaps/?eocn=topnav&eoci=globalmaps El Niño and La Niña. Volcanic eruptions (Tambora, Krakatau, Agung and Pinatubo). Meteorite impacts, such as in the Chicxulub region of Mexico. The "snowball Earth" hypothesis. The relative contribution of different gases to global warming.

B.3 Evolution — 12 hours

B.3.1 Ideas on the origin of life		
Essential idea Scientists have proposed hypotheses, models and theories to explain the diversity of life on Earth which has ontological and chronological characteristics. Evolution is a unifying principle of the life sciences with great explanatory power.		
Understanding the nature of science	**Practical activities**	**Research activities**
The changes that have occurred over the 4 billion year history of life on Earth are thought to be the result of natural processes. 1.1, 1.5 The origin of life on Earth is still unknown. A number of models and theories exist but the scientific community requires verifiable evidence. 1.8, 1.9, 5.1 Scientists developed a testable hypothesis to determine if the organic molecules necessary for life could be synthesized through the interactions of inorganic molecules. 1.11, 2.1, 2.2, 2.5, 2.6 Evidence supports the presence of organic molecules in space, based on examination of comets/meteorites. 1.7, 1.8 Observations of primitive life forms near volcanoes and deep ocean hydrothermal vents suggest a possible location for the origin of single-celled organisms 1.8, 1.9 Scientists studying the composition of ancient rocks have deduced that there was no oxygen in the early Earth's atmosphere. 1.8, 1.9 Analysis and understanding of photosynthesis helped identify cyanobacteria as the source of oxygen. 1.6, 2.6 A unifying hypothesis in the life sciences is the connection between these primitive prokaryotic cells and all of the diverse forms of life that followed. 2.6, 1.10	Make microspheres from amino acids. http://old.analytical.chem.itb.ac.id/coursesdata/19/moddata/forum/138/978/PLGA1.pdf Carry out an investigation to measure oxygen production in photosynthetic organisms under different environmental conditions. http://www.nuffieldfoundation.org/practical-biology/investigating-factors-affecting-rate-photosynthesis	Research different cultural creation myths from a nature of science perspective. Investigate the concept of emergent properties (for example, the computer game *Game of Life*). Review Stephen Hawking on Conway's Game of Life. https://www.youtube.com/watch?v=CgOcEZinQ2I&feature=share&list=FLwikA_t8e6TSJW-L-IAHkKw Research Panspermia (and directed Panspermia). Exploring deep sea vents. http://www.youtube.com/watch?v=HGT8HKvEH1Q&noredirect=1 Research the occurrence of iron oxide minerals as a marker for the rise in oxygen on the surface of the Earth. Research Stromatolites.

B.3.2 Evolution and the theory of natural selection		
Essential idea Observations of the natural world have revealed verifiable broad concepts and general principles that explain the diversity and complexity of life on Earth.		
Understanding the nature of science	**Practical activities**	**Research activities**
Darwin developed a theory in which natural selection provided a possible and verifiable mechanism for evolution. A similar theory was also independently developed by Alfred Wallace. 2.3 Charles Darwin's publication *On the origin of the species by means of natural selection* connected previously unrelated ideas into a coherent view of life.1.8, 1.9, 2.6 The theory of natural selection is built on inferences based on observations. The theory explains how increased reproductive success of individuals with favourable heritable characteristics can lead to change in the genetic composition of a population. 1.6, 2.2 Although natural selection involves interactions between organisms and their environment evolution is measured by the changes in populations. Examples of natural selection, including multiple antibiotic resistances in bacteria and pesticide resistance in rodents, have been studied to increase understanding of the relationship between selective environmental pressures and survival of different organisms. 2.8, 1.11 Darwin's ideas were not well accepted as they challenged the prevailing scientific thinking and tested longstanding theological beliefs. However, within a short time he had convinced many scientists that biological diversity resulted from evolution because of his logical sequence of ideas based on verifiable evidence.	Manipulate variables in a natural selection simulation. Simulations http://phet.colorado.edu/en/simulation/natural-selection http://phet.colorado.edu/en/simulation/natural-selection#software-requirements	Create a timeline of the development of evolutionary ideas including the early Greek philosophers Linnaeus, Cuvier, Hutton, Lyell and Lamarck. Chronozoom can be used to create timelines. http://eps.berkeley.edu/~saekow/chronozoom/ Research what is polymorphism? Superbugs: origin and evolution. http://www.ourprg.com/?p=17415 Investigate the various forms of evidence Darwin used to support his theory.

B.3.3 Evidence for evolution		
Essential idea Scientists rely on observations and evidence in many forms, from fossils to biochemical analysis of nucleic acids. Increased powers of instrumentation and advances in available techniques, combined with multidisciplinary cooperation have yielded an extensive body of evidence supporting evolution.		
Understanding the nature of science	**Practical activities**	**Research activities**
Darwin's evidence for evolution was based on geographical distribution of species and the fossil record. His observations of the homologous anatomical structures of different mammals supported his reasoning that all mammals descended from a common ancestor. 1.8, 1.9 Continuing research and the development of improved technologies has led to new interpretations of the fossil record and a more complete picture of early animal evolution. 1.8, 1.9, 2.3 Although artificial selection does not apply to natural ecosystems, it does provide evidence that species can change over time with selective breeding.1.8. 1.9 Modern molecular biology supports evolution by comparing the DNA and proteins of current and ancestral species. 1.8, 1.11, 2.3 **Guidance** Include the different types of evidence required, an example of selective breeding (for example, dogs) and an example of a molecular clock.	Comparing DNA. http://xylian.igh.cnrs.fr/bin/align-guess.cgi http://fasta.bioch.virginia.edu/fasta_www2/fasta_www.cgi?rm=compare	Compare the pentadactyl limbs of different mammals. Take a virtual tour of fossil collections. The Smithsonian Collection http://www.mnh.si.edu/vtp/2-mobile/#fossils Explore the Burgess Shale. http://www.geo.ucalgary.ca/~macrae/Burgess_Shale/ Discuss the underlying reasons for the original misinterpretation of the fossils.

B.3.4 Human evolution		
Essential idea Molecular data provided by advances in technology has increased the clarity of the evolutionary lineage of *Homo sapiens* deduced from incomplete fossil records.		
Understanding the nature of science	**Practical activities**	**Research activities**
There is uncertainty about the ancestry of humans due, in part, to an incomplete fossil record and misinterpretation of existing remains. 2.3, 2.6 Radioactive dating has established the existence of a bipedal ape in Africa 4.4 million years ago. 1.8, 3.1 Development of tool making, hunting skills and language have contributed to survival and natural selection. 1.6, 1.8, 3.1 There are several models of early human migration, but evidence from mitochondrial DNA (mtDNA) and Y chromosome indicates the original source as the Rift valley of Central Africa. 1.8 A newly mapped Neanderthal genome provided evidence of some interbreeding between modern man and Neanderthal man leading to a reclassification of Neanderthal man as *Homo sapiens neanderthalensis* 1.6, 3.1, 3.6, 3.7 Modern humans have demonstrated rapid cultural evolution with minimal biological evolution. 1.6, 4.3	Compare hominid skulls. http://www.nhm.ac.uk/nature-online/life/human-origins/hominid-skulls/index.html	Piltdown man. Research conflicting theories of human evolution: single or multiple origins, aquatic versus savannah apes, etc Research persistent myths, including a linear evolution from modern ape to *Homo sapiens.* The discovery of *Australopithecus afarensis and Homo floresiensis.* Participate in National Geographic's Genographic project. https://genographic.nationalgeographic.com/genographic/journey.html

Part C: The impact of science

C.1 Energy and physical resources

18 hours

C.1.1 Electrical energy

Essential idea

Models of electrical energy have developed with time as our understanding of the science has developed. With this man has created a multitude of devices to harness the power and flexibility of electricity.

Understanding the nature of science	Practical activities	Research activities	Man's impact on the planet
A brief qualitative overview of the historical development of electricity through individual scientists should be undertaken specifically with regard to the NOS links. Early forms of electricity studied included lightning and static electricity. 1.2 Hauksbee strived to understand the natural phenomena by asking questions and looking for explanations; this is thematic investigation. 1.2, 1.8 Franklin was crucial in identifying effects and proposing causes. 1.2, 1.4, 1.8, 2.5 Luigi Galvani considered electricity to be a property of living things. 1.5, 1.8, 2.5 Alessandro Volta disproved Galvani's ideas by producing a continuous flow of electricity from a battery which was made from different metals. 1.2, 1.3, 1.8 Hans Christian Ørsted and Andre-Marie Ampere were the first to investigate the connection between electricity and magnetism. This resulted in the invention of the electric generator and the electric motor by Michael Faraday. 1.2, 1.3, 1.8, 1.9 By employing quantitative thinking, Volta established the concept of	Investigate static electricity (using different rods and fabrics, van de Graaff generator). Electromagnetic induction (hands-on or simulation). Building simple electrochemical cells using different pairs of metals.	Chart the discoveries of key scientists who investigated electricity and the success of the models they proposed compared to current understanding. Consider electricity in nature in relation to lightning, electric eels/rays and static electricity, living cells, nerve impulses. Consider Hauksbee's experiments with static electricity resulting in his "electric machine" and how the use of the machine as entertainment stimulated public interest in the new phenomena called "electricity". We would not have regarded Franklin's work as truly scientific in our present-day terms. But as a figure of the Enlightenment he exemplified the "thinking man" of his time. Discuss. Compare the work (and rivalry) of Galvani and Volta in relation to electrical current and why Volta became an international celebrity. Research the Barlow–Ohm dispute in terms of evidence-based science and the development of a law.	Prior to the development of electric lighting, artificial light was in the form of candle or gas light. Electricity was considered a cleaner source of power but the subsequent impact of burning fossil fuels to create electricity in power stations was not a consideration. Knowledge of magnetism has allowed us to develop sophisticated motors that move people and goods. Such motors require a source of energy which may cause damage to the environment. This has helped to draw attention to the need for the development of alternative energy sources (see A.1.6)

electrical current, that is, the amount of electricity **flowing** out of a source. 1.6, 1.8 Quantitative observations allowed a more mathematical approach and formulation of laws by Coulomb, Faraday and Ohm among many others. 1.3, 1.6, 1.8, 1.9, 2.4, 3.2 **Guidance** Electrical current involves the movement of charged particles in an electric or magnetic field. This flow of charge can do work on other systems. Scientists describe electrical phenomena in terms of: • electric charge • electric current • potential difference/voltage. This is a hybrid description of energy where the work done is calculated but is described per unit of charge that has flowed.			

C.1.2 Using electrical energy I—portable electricity			
Essential idea Improvements in the understanding of science have enabled the development of a range of devices to enhance the quality of life that are independent of fixed sources of energy.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Both batteries and fuel cells convert chemical energy into electrical energy. 1.6 Primary cells are batteries that employ non-reversible chemical reactions and therefore cannot be recharged. 1.6 The variation of the voltage produced in relation to the reactivity of the metals used in an electrochemical cell illustrates the recognition of patterns in science. 1.3, 1.6, 1.9, 3.1 Secondary cells are batteries that employ reversible chemical reactions that allow them to be recharged. 1.6 Fuel cells use chemical reactions that continuously consume a fuel to produce electricity. 1.6 The challenge for scientists is to produce devices that can produce a high current for a long period but also have a low mass and high efficiency. This has lead to the research into and the development of new materials for electrodes and electrolytes. 1.2, 5.6 **Guidance** Relate the activity series to the voltage which can be produced in an electrochemical cell. The series will be limited to Mg, Zn, Fe, Sn, Ag. Details of the chemical reactions occurring will not be expected.	Experiment with lead plates and sulphuric acid. Construction of electrochemical cells to investigate how various parameters affect the potential difference and current.	Compare and contrast different types of batteries. Factors could include cost, energy storage, environmental issues, efficiency, portability, total energy available related to the weight. Analysis of quantitative data regarding the power and amount of stored energy in relation to the requirements of the device. Electrochemical energy storage and conversion. http://www.chem1.com/acad/webtext/elchem/ec6.html Life cycle of batteries and the chemicals involved in their production. The benefits of recycling old batteries on a local, national and global scale.	With an increased understanding of chemical reactions and cell design, portable supplies of electrical energy have been made increasingly smaller and more efficient to meet the increase in number of portable electrical devices and the demands for smaller, lighter, longer lasting energy sources. But the increased volumes produced cause other problems. Cost issues led to the development of rechargeable batteries which results in a large reduction of primary cells. Disposal of batteries and the effect on the environment is a global issue giving rise to legislation and recycling schemes in different parts of the world. There are issues with the safe use of batteries in situations such as on planes.

C.1.3 Using electrical energy II—centralized electricity production

Essential idea

The production of electricity through the movement of electrical coils in magnetic fields is most efficient when it takes place in large centralized facilities linked to a distribution network. A rise in the global demand for electricity was met by using cheap fossil fuels that emit carbon dioxide, causing the enhanced greenhouse effect, that is, manmade global warming.

Understanding the nature of science	Practical activities	Research activities	Man's impact on the planet
The movement of a conductor through a magnetic field produces an electric current. This discovery by Faraday lead to a greater understanding of fields and an application of more mathematical language 1.2, 1.3, 1.6 Electricity is a secondary energy source as it is generated by non-renewable and renewable primary sources of energy. 1.6 In a power station, the primary energy source drives a turbine (either directly as with wind, or indirectly as with steam from the combustion of fuels) which rotates the generator coils to produce a current. Coal-powered steam engines were the initial sources of energy for generators but more recently there has been a shift to oil, gas and nuclear power. 1.8 The use of computer modelling has allowed for the development of even more efficient power generation using a wider variety of primary energy sources to cater for differing locations and access to natural resources. 1.12 Electric current can be direct (DC) in which electrons move in one direction or alternating (AC) in which the electrons oscillate rapidly back and forth. A generator can be designed to produce either AC or DC. AC has been used for large-scale distribution for domestic and industrial use owing to the need for high voltages for efficient distribution.	Electromagnetic induction using a length of wire and a strong magnet. Electromagnetic induction simulation http://www.walterfendt.de/ph14e/generator_e.htm Build an electric motor and then see a motor working in "reverse" to generate energy. Focus on energy conversion ideas and relate back to the mechanism. Building an electric motor http://www.msichicago.org/onlinescience/activities/activity-detail/activities/build-an-electric-motor/browseactivities/0/ Compete to build an electric generator and produce the largest electric current. Compare the efficiency of power transmission lines with and without transformers. Model AC power transmission http://www.nuffieldfoundation.org/practical-physics/ac-power-line-high-voltage	Develop an electricity timeline. Compare the motivation of Edison and Tesla. Nikola Tesla and Thomas Edison feuded over which was the preferable system. This led to "the war of currents". Evaluate the contribution of Tesla to the provision of a safe distribution network of electricity over large distances. Compare the work of Edison with Swann in the incremental development of the incandescent light bulb and why they decided to become partners in the first electricity supply company Evaluate how the invention of the light bulb provided the impetus for the technological development of a large-scale electricity supply network and how the key challenge was the storage and distribution of electricity. Investigate recent developments to produce a more energy efficient bulb. Identify a range of products in the home which utilize electric motors. Investigate the use of electricity in industry, for example, aluminium production. Household supplies—120 V or 240? Why? Investigating the differences in the domestic and industrial use of electricity on a global scale. Possible effects of high voltage electrical power transmission lines	The establishment of a reliable and affordable electricity supply allowed for the transformation of mass production free from the limitations of steam power. This resulted in cheaper products and the concept of mass consumption with consequences for the use of natural resources and waste/pollution on a global scale. Consider the visual impact the use of electricity has on the built environment in relation to safety, aesthetics and pollution. Edison established a Research and Development establishment in New Jersey in the USA from which many inventions would emerge causing a significant impact on people's lives and the environment. The public were very concerned about how electricity could be used safely. Injuries and fires related to electricity still remain a major factor for public safety. Power plants for converting fossil fuels to electricity were subsequently established in all industrialized countries and have become synonymous with environmental pollution and global warming. The development of computer technology further enhanced mass production via automation, a cleaner form of manufacturing. But it has dramatically increased electricity consumption.

Energy is distributed at high voltage through a supply network and the voltage reduced by transformers before delivery to the end user. **Guidance** A detailed knowledge of the generator is not required but any understanding should relate to A.1.1, fields.		http://www.independent.co.uk/environment/powerlines-disturb-animal-habitats-by-appearing-as-disturbing-flashes-of-uv-light-invisible-to-the-human-eye-9187631.html	

C.1.4 Renewable and non-renewable energy

Essential idea

Our increasing dependence on reliable and affordable energy supplies is a challenge for developed and developing countries alike. Industrialization, economic growth and increasing population are stressing the finite energy resources of the Earth. As a result of environmental issues caused by burning fossil fuels scientists have needed to consider how we can most effectively harness natural sources of energy for the good of all. Our quest should be for a sustainable pattern of energy consumption.

Understanding the nature of science	Practical activities	Research activities	Man's impact on the planet
Some carbon-based materials found in the Earth's crust, known collectively as fossil fuels, are a potent, though finite, source of energy. 4.8 Recent research in renewable energy sources has been brought about due to increased industrialization and increased population, yet some countries support the use of fossil fuels for their energy needs. 1.2, 4,7, 5.6 There are basic operating principles for a variety of energy sources (renewable and non-renewable). The focus should be on the efficiencies and relative advantages and disadvantages of each. 4.8 The choice of primary energy source depends on availability of resources, capital costs and running costs, as well as potential environmental impact. 4.8 The development of more efficient turbines depends on the increased power of instrumentation and computer simulations. 1.2, 3.7, 5.6 **Guidance** Only a brief overview of the mechanisms for each energy source is required. Non-renewable sources to be considered are fossil fuels (oil, natural gas, coal) and nuclear fission. Renewable sources to be considered are wave, hydroelectric power, tidal,	Experiment on the efficiency of a wind turbine (school kits are available). Investigate the output from a solar cell. Vary wavelength of light, light intensity, angle of light incident on the surface. http://www.usc.edu/org/edisonchallenge/2008/ws1/SolarCellExperiments.pdf Produce biodiesel from waste vegetable oil. Energy density comparisons using different fuels.	Access and analyse data on relative efficiency of energy sources in your local area. Include the influence of government schemes to introduce more non-renewable sources of energy. Investigate traditional/historical use of renewable sources of power. Investigate use of windmills (pumping water, milling grain) and wind turbines (electrical generation). Alternative wind turbine design. http://www.washingtonpost.com/blogs/innovations/wp/2014/06/10/is-this-odd-looking-wind-turbine-the-most-efficient-you-can-buy/ Investigate waterwheel use (under-shot, over-shot) and wheel efficiencies. Small groups of students work on producing a poster summarizing one energy source for a plenary session. http://www.businessinsider.com/new-method-for-hybrid-solar-cells-2014-10 Consider the social, ethical and environmental issues in the choice and use of different energy sources on a local, national and global scale. Health effects of breathing wood smoke. http://www.epa.gov/burnwise/pdfs/woodsmoke_health_effects_jan07.pdf	There is strong evidence to suggest that the huge increases in the burning of fossil fuels since the Industrial Revolution has had a detrimental effect on the environment. Global warming article http://www.theguardian.com/environment/planet-oz/2014/oct/03/scientists-find-human-fingerprints-all-over-australias-hottest-year-on-record The increased demand for fuels has lead to a change in land use and the increase of plant material in the production of fuel. Both have potential effects on the environment. Pollution is caused by wood-burning stoves.

wind, solar (thermal and photovoltaic), geothermal and biomass.		Comparisons of energy use and sources of energy in developed and developing countries.	

C.1.5 Nuclear power			
Essential idea The most surprising energy change of all: mass to (nuclear) energy and the consideration of mass as a form of energy. This is an excellent indication of how unanticipated discoveries can totally transform particular fields of human endeavour.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
The aim here is not to give an exhaustive account of the physics of nuclear energy production but rather to emphasize the paradigm shift that Einstein instigated. 2.3 Nuclear power is commonplace throughout the world, generating a significant proportion of the total energy output of many countries. Nuclear fission is the process where the nucleus of an atom splits into several smaller fragments. The final total mass is less than the initial mass; the difference in mass (mass deficit) appears as energy. 2.4 Controlled fission is used for nuclear power and uncontrolled fission for nuclear weapons. The converted mass appears as kinetic energies of the fragments and as excited energy states of the products. Sustained nuclear fission provides the nuclear power used to generate electrical energy by means of conventional steam turbines and generators. The ability to do work in nuclear reactions is much greater than from the burning of fossil fuels because of the	Calculate the expected mass changes for some common energy processes, for example, boil 1kg of water, charge a secondary cell, the fission of 1kg of uranium 235 etc. Investigate simulations of the workings of a nuclear power station. http://www.nuclearinst.com/Nuclear-Reactor-Simulator	Evaluate the typical life span of a nuclear reactor and the total amount of radioactive waste produced. Research issues surrounding uranium mining, enrichment (including the responsibilities of the International Atomic Energy Agency and weapon grade uranium), safety of power stations, decommissioning of power stations, waste products and their long-term storage. Research other nuclear fuel options such as thorium and breeder-reactor-based plutonium cycles. Investigate nuclear accidents. Investigate enrichment of fuels and the physics of nuclear weapons.	Man's increasing need for power, an ever diminishing supply of fossil fuels and the relatively high costs of renewable energy technologies has seen an increasing reliance on nuclear fission reactors in many countries. The carbon footprint is low but not zero. Although the probability of a disaster is low, when it does happen the effects can be long lasting (for example, Chernobyl, Fukushima). The long-term effects of such accidents on the local environment are still unknown. Highly enriched uranium can be used for the production of nuclear weapons. Nuclear testing has an effect on the environment.

extremely high energy density of uranium-235. The development and effective, safe control of nuclear reactors depends on the advances in technology and the power of instrumentation. 3.1 Although accidents at nuclear power stations are rare, when they occur they can be catastrophic. Risk assessments are required. 4.5 Natural uranium requires enriching in one particular isotope, uranium-235, to be used as a reactor fuel and even greater enrichment is required for weapons use. Uranium is only mined in a few countries and its trade has obvious ethical and political implications. 4.5 **Guidance** Details of the nuclear reactions involved in a nuclear power plant are not required.			

C.1.6 Forces and physical properties			
Essential idea One of the strengths of scientific thinking is that a limited number of fundamental concepts can be used to explain a wide range of phenomena. In this reductionist approach four fundamental forces (strong nuclear, weak nuclear, electromagnetic and gravitational) can be used to explain the way in which fundamental particles interact to produce the amazing variety of properties that we observe in the matter that comprises the universe.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Experimental evidence shows the properties of materials depend on the particles present and the forces between them. In general, metallic, ionic and covalent bonds are strong, whereas forces between molecules are much weaker. A consequence is that almost all liquids and gases have molecular structures. Ionic and covalent bonds depend on the relative position of the particles, giving rise to brittle structures, whereas others, such as metallic bonding and most intermolecular forces, are much less dependent on their positions and hence produce malleable materials. 1.11, 2.4 **Guidance** The topic focuses on the links between material properties and chemical structure and the uses made by humans of these material properties. It does not explore subatomic structures.	Students can compare the physical properties of a range of solids (aluminium foil, salt crystals, quartz crystals, wax, and so on). Students can compare the attraction between two pieces of metal glued together and between two pieces held together by magnetism. Students can perform various experiments in which the physical properties of materials are explained in terms of the forces between their component particles.	Students perform a comparison of physical properties of a number of substances and discuss what the reasons for these might be in terms of the forces between the particles they are made of. Students can explore the extent to which melting point and boiling point are measures of the same property. Students can research the relationship between properties of materials and their suitability for particular uses.	Materials technologies have also influenced the nature of much of what is around us in our daily lives, from the presence of large structures based on concrete and steel to the many polymers we interact with each day. In the case of plastics, many are non-biodegradable and can persist in the environment for many years as rubbish.

C.1.7 Uses of physical resources			
Essential idea The key challenge is how to maintain environmental quality for future generations while at the same time providing for the needs of current generations.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
1. An understanding of scientific processes is the basis for the development and use of basic raw materials and the invention and production of new materials. Population growth and economic growth results in a high demand for large quantities of raw materials (steel, industrial wood, fuel wood, cement) and materials such as aluminium and plastics. Some very rare, important materials are required for some high technology products such as computers. 2. The concept of the World Reserves Index is important. 3. Every material/product has an energy cost in its exploration, extraction production, use, reuse and disposal. Calculating the energy cost requires a knowledge of scientific processes and is the work of scientists. The carbon footprint is an important consideration. 4. Production of every material and every product has environmental impacts including recycling. Use of Life Cycle Analysis (LCA) is the only way to determine environmental impacts with any certainty. It can only be conducted on a scientific basis by trained scientists.	Investigate world demand and world reserve index for one material. Investigate energy cost for a chosen material. Energy costs in producing various materials. http://wwwmaterials.eng.cam.ac.uk/mpsite/interactive_charts/energy-cost/basic.html Investigate LCA for a simple product (two parts only such as a knife).	http://www.forestinfo.org/teaching_unit/materials-and-the-env This site has five Powerpoint presentations or PDFs on population, economic growth, materials availability, consumption and environmental impact. What are "rare earths" used for? http://www.bbc.com/news/world-17357863 British Geological Survey report on "Rare Earth Metals" http://www.bgs.ac.uk/downloads/start.cfm?id=1638 Research world demand and world reserve index for important materials. Research energy costs for important materials. Research LCA for a complex product	Global population is growing, with the most rapid growth in the developing nations. World economic growth is much more rapid than population growth and the highest economic growth rates are in the developing nations. The extraction, refining and manufacturing of resources has a significant effect on the environment. This has been a result of directly accessing the resources (for example, mining) and of the chemical pathways and waste products involved in the stages of production, use, reuse and disposal. What responsibility do consumers have for the negative environmental and social impacts of their consumption? What could be done to limit or reduce the negative environmental and social impacts of consumption? The major environment impact is global warming leading to climate change.

C.2 Transport — 6 hours

C.2.1 Unbalanced forces			
Essential idea Among other things, the history of human progress can be marked by an increasing ability to create and control forces through technology, in particular the forces needed for translational motion.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
All motion is the result of external unbalanced forces acting on a body. 1.6, 2.5, 2.6 The science of motion is characterized by a common terminology that includes displacement, speed, velocity, and acceleration. 1.6 **Guidance** Simple calculations for resultant forces are only required for linear situations.	Students can investigate the chaotic motion of party balloons as they are released. A tethered rocket moving horizontally (bottle rocket)—video capture and data analysis. Measure forces in various situations.	Identify examples of balanced and unbalanced forces acting on objects at rest and in motion. http://www.physicsclassroom.com/Class/newtlaws/U2L2c.cfm#Questions Label diagrams with forces. Match physical situations of unbalanced forces with graphical representations. Understanding graphs of motion. http://www.physicsclassroom.com/class/1DKin/Lesson-4/Meaning-of-Shape-for-a-v-t-Graph Research the scales of various forces, from forces between charges to gravitational forces on a large scale.	The waste from engine fuels has been shown to have significant environmental impacts. Clean energy research is an increasing focus of governments and scientists. The development of clean, cheap energy would have an enormous economic and social impact as well as relieving environmental pressures.

C.2.2 Transportation systems			
Essential idea Science and technology have produced mass transportation of people and goods around the globe that has changed our way of life. However, this mass movement has a major impact on the environment and is not sustainable.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
An understanding of energy transfer, in combination with advances in materials technology and fuel extraction and refinement, have allowed humans to create engines able to generate very large forces that can be used to power transportation. Oil-based fuels are used in the internal combustion engine. A controlled explosion is used to drive a piston up and down in a cylinder. 1.2 Jet engines are subject to very large tensile forces and special materials have been developed to cope with these. 1.2, 1.10 Electric cars use stored electric energy to produce motion. Some modern cars have a hybrid petrol-electric engine: Both these technologies require a battery of cells to be carried in the vehicle. 1.2 Hydrogen-cell transport: hydrogen gas is used in a fuel cell to produce electric current with water as its waste product. 1.2 Engines use a variety of fuels, and the means of extracting the energy from the fuels produces waste products. Some waste products are damaging to the environment. 4.8 **Guidance** Students will require sufficient prior knowledge to enable them to understand the underlying concepts of the electric motor (for example, a flow of charge is known as an electric	Energy transfer from chemical to heat can be observed through the calculation of the energy density of a fuel. Work with models of the internal combustion engine. Locate magnetic field lines and determine the direction of magnetic force when current and field are perpendicular to each other. http://www.bbc.co.uk/schools/gcsebitesize/science/triple_aqa/keeping_things_moving/the_motor_effect/revision/1/ Production of circular continuous motion using a commutator (electric motor). https://www.edumedia-sciences.com/en/a182-dc-motor Build a hydrogen fuel cell. http://scitoys.com/scitoys/scitoys/echem/fuel_cell/fuel_cell.html	Compare the energy density of a variety of transport fuels. Describe the technological limitations and possible solutions for the development of electric cars. All-electric vehicles http://www.fueleconomy.gov/feg/evtech.shtml Compare the waste products of various engines/fuels in terms of their environmental impact. Compare the efficiency of the internal combustion engine, electric cars and hybrids. Compare the relative contributions of land, sea and air transportation to environmental degradation.	Pollution of land, sea, rivers and air by the emissions from cars, ships and aircraft has had a huge impact on the environment and people, resulting in serious health conditions and deaths. National and international agreements on the reduction of emissions, developments in catalytic converters, and new, more efficient engines and fuels have helped but the growth in the numbers of cars and ships and in air travel due to higher living standards has worsened the problems.

current, in a conductor the charge carrier is an electron, simple direction rules for the direction of magnetic force). Only the dc electric motor is required. The choice of engines is related to their environmental impact.			

C.3 Communications — 12 hours

C.3.1 Introduction to communication			
Essential idea Modern developments in science have allowed continuous communication and information exchange at large volumes and high speeds, over long distances. This has transformed our everyday lives.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
The historical development of communications was dependent on the technology. 1.8 A revolution in communications was brought about by the ability to interconvert audio signals and electrical signals using a microphone and reverse this at the opposite end using a loudspeaker. 1.5, 1.8 Oscillations of current in an electrical conductor emit electromagnetic waves that mirror the oscillations. These waves may be detected by a conductor at some distance from the source, without there being any physical connection between the two. Broadcasting techniques using electromagnetic waves allow a signal to be received at many stations. This has brought nations into closer contact and helped to overcome cultural differences. 4.2 The application of the principle of electromagnetic induction to the transmission of audio signals is a	Students can experiment with a variety of means of communicating (Morse, semaphore) and consider the advantages and disadvantages of these. Factors such as rate of information transfer, cost and privacy could be included.	Investigate the advances in communications (men running, horses, smoke signals, drumming, telegraph, radio, telephony, television, internet) and the ways in which progress has reflected increased scientific understanding and technological development (copper wires, microwaves, optical fibres, satellites). Mobile phone technology http://en.wikipedia.org/wiki/Coltan Explore how these advances have impacted on the speed of communications and the audience that can be reached.	Improved communication has reduced the need to travel and this could decrease environmental impact. However a growing standard of living may have the opposite effect. This is a social issue transcending science involving cultural, economic and other aspects of globalization.

wonderful example of the creative, imaginative way that scientists have adapted basic discoveries to make possible things that had previously been considered impossible. 1.4, 1.5			

C.3.2 Electromagnetic induction and electromagnetic waves			
Essential idea The unifying concept of electromagnetic waves and the imagination to use them for transmitting information in many forms together form the basis for developments in global communications.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Electromagnetic induction The motion of an electrical conductor in a magnetic field generates a current in the conductor. If this motion is linked to the vibrations caused by sound waves, the electrical current will oscillate in a similar manner and this can be transmitted along a conductor. At the other end of the conductor, the changes in the electrical current can cause the movement of the conductor, which can be converted back to sound waves that, ideally, are identical to the original ones. **Electromagnetic waves** Electromagnetic waves are of frequencies well above audio frequencies so the audio signal has to be superimposed on the wave. This can be done by amplitude modulation or frequency modulation.	Practical investigation of electromagnetic induction and the principles of the electromagnetic microphone and loudspeaker. Use of an oscilloscope, or a simulation, to demonstrate the modulation of an audio wave on to a carrier wave.	Investigate other devices that can be used to convert between audio signals and electrical signals. Loudspeakers and microphones http://www.explainthatstuff.com/microphones.html Electromagnetic waves/radio https://kicp.uchicago.edu/education/explorers/2002summer-YERKES/pdfs-sum02/background.pdf How radio works http://electronics.howstuffworks.com/radio.htm Investigate the reflection of radio waves by the atmosphere and factors, such as sunlight and frequency, that affect this. Explore the link of AM and FM to particular frequency bands and the advantages and disadvantages of each. Differences between AM and FM http://www.engineersgarage.com/contribution/difference-between-am-and-fm-modulation	The installation of telephone lines to allow the transmission of the electrical signals involved has consumed a great deal of copper, the mining and smelting of which has significant environmental impacts. There are issues surrounding the disposal of mobile phones. Rare materials are used in the manufacture of mobile phones.

		Investigate evidence that using mobile phones poses health risks.	

C.3.3 Digital signals			
Essential idea The binary counting system using only 0s and 1s is the basis of all modern electronic communication.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
The electronic circuits involved operate according to Boolean logic using electronic gates. 1.6, 1.12 The use of digital conversion has only become possible in recent decades because of the increased speed of computers carrying out analogue to digital conversion. Noise from many sources can affect the quality of an analogue signal, but digital transmission has no loss of quality. A wave may be converted to a digital signal by successively sampling the amplitude of the wave and the process reversed to recreate the wave.	Investigate the input and output of analogue to digital converters. Logic gates. http://www.neuroproductions.be/logic-lab/ Analogue to digital convertor simulation. http://www.vias.org/simulations/simusoft_adconversion.html	Familiarization exercises with binary code. Demonstration of conversion and the concept of bit rate using analogue to digital conversion applets. Research issues surrounding digital conversion and audio quality.	Converters consume energy and have to run at high speed. The extra power required for this has to be balanced against that required for serial amplification of analogue signals down transmission lines.

C.3.4 Optical fibres			
Essential idea The technology of optical fibres and the simple physics involved in transmitting light along them has led to a global system of information transfer and communication.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Total internal reflection allows light signals to be transmitted down glass fibres as an alternative to electrons moving in conductors. 2.4 The introduction of optical fibres has been totally dependent on the ability of manufacturers to produce very thin fibres of highly transparent glass. Optical fibres are highly transparent, but regular amplification of the signal is still required. 4.7 Many signals can be transmitted simultaneously in an optical fibre using light without interference resulting in a high bandwidth. 1.5	Investigation of refraction, critical angle and total internal reflection using ray boxes or by simulations. Refraction interactive simulations (including total internal reflection) http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Refraction/Refraction-Interactive http://phet.colorado.edu/en/simulation/bending-light	Calculations of the effect of transmission speed, through both electrical wires and optical fibres, on the time lag over long distances. Investigation of different fibre types, their manufacture, transmission losses and amplification implications. Fibre optics http://hyperphysics.phy-astr.gsu.edu/hbase/optmod/fibopt.html http://computer.howstuffworks.com/fiber-optic.htm Research global optical fibre networks.	Reduced dependence on metallic conductors should reduce mining of copper and its associated environmental consequences.

C.3.5 Communication networks			
Essential idea The imaginative leap to use orbiting satellites for the transfer of information has allowed for global communications on a large scale. More recent developments in computing power and cell phone networks have led to another revolution in communications.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Broadcast coverage requires the siting of transmitters that will deliver appropriate signal strength to the desired audience. Microwave frequency signals can be transmitted through the atmosphere to geostationary or polar orbiting satellites, which re-transmit the signal back to Earth.	Receive educational satellite transmissions through FUNcube. http://funcube.org.uk/	Use a database to investigate communications satellites: how many, their location, who runs them, what they are used for, international control. Satellite database http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html#.VDzuuGeSyuI	The proliferation of satellites, particularly geosynchronous ones, has given rise to "space junk", and there are some risks when these crash to Earth. As well as the safety aspects, the launching of satellites consumes enormous amounts of fuel. Large amounts of specialized materials, with their extraction issues, are used in the construction of satellites.

Transmission of signals from satellites is particularly efficient because of the wide area they cover and reduced interference from geographical features because of the high angle of incidence. Person-to-person communications, in addition, require routing from the sender to a particular recipient. Telephone conversations, whether mobile or landline, require directing from a particular caller to a specific recipient.		Information on satellite transmission http://www.sqa.org.uk/e-learning/NetTechDC01CCD/page_33.htm#SatelliteTransmission Build a model telephone exchange. Investigation of how public switched telephone networks (PSTNs) and cellular network coverage operate. Research reasons for mobile phone "black spots". Research the legal implications of the use of space for telecommunications. http://www.itu.int/en/history/Pages/ITUsHistory-page-5.aspx Research the origin of the idea of geostationary orbits. Article about Arthur C. Clarke and geostationary orbits http://lakdiva.org/clarke/1945ww/	

C.4 Food security — 12 hours

C.4.1 Nutritional requirements			
Essential idea Epidemiology and scientific experiments have established a causal relationship between diet and health.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Nutrients are the chemicals found in food that are essential for life. 2.6 Malnutrition can result from insufficient or excess intake of any nutrients; this varies significantly between populations. 2.8 There is a debate about the best way to assess a healthy body. 3.5	Food testing to identify nutrients. http://www.scienceteacherprogram.org/biology/Lillien02.html Measuring the caloric value of food. Analysing a daily intake of nutrients. Calculating BMI. Comparing methods of food preservation.	Debate the ethical issues of human and animal dietary experimentation. Research how the experimentation on prisoners by Joseph Goldberger led to an understanding of pellagra. Research how James Lind's experimentation on sailors on long sea voyages led to an understanding of scurvy and how to treat it.	In developed countries poor diets and lack of exercise due to modern lifestyles have led to health problems and increased demand on medical services. In other countries, poor diet has led to deficiency diseases, disabilities, an inability to live a productive life and a low life expectancy. Legislation on food labelling and public campaigns for healthy eating are

Reliable nutritional information can only be obtained from verifiable scientific evidence. 1.8 Methods of preservation and cooking may affect the nutritional content of food and cause adverse effects on health. 4.8 Food additives extend the shelf life of food products, and can improve the appearance or nutritional content. 4.8 **Guidance** Causes of malnutrition include: protein deficiency, vitamin and mineral deficiencies, obesity, anorexia, geographical location, economic status and lack of education. Methods of preservation include: drying, salting, freezing, smoking, pickling, fermentation and using synthetic preservatives.		Analyse nutritional databases (for example, World Health Organization or United Nations databases). Research current and historical fad diets. Compare the benefits and risks of introducing food additives into the diet. Research mandatory labelling of food products.	countered by advertising and the food industries' mass production of ready-made meals.

C.4.2 Agricultural science			
Essential idea Agriculture has improved food yields through the domestication of animals and plant cultivation, contributing to the quality of modern life and an increase in life expectancy but at some detriment to the environment.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
There are many challenges in providing sufficient food to a growing global population. 4.8 Scientific innovation in agrochemicals (pesticides, synthetic fertilizers, hormones and other chemical growth agents) and in land use has led to increased food yield that has helped to support the growing population. 4.8 A rise in monocultures has led to an increased vulnerability to disease and	Test the effects of altering one nutrient variable on plant growth. Produce fertilizer in the laboratory. Test the result of fertilizer on plant growth.	Investigate the carrying capacity of the Earth (ecological footprint), including whether the current issue is one of a food-producing capacity or a socio-economic issue. Research the historical development of artificial fertilizers, for example, the Haber-Bosch process. Research the role of Norman Borlaug in the Green Revolution. Research the nature of animal food additives.	Increasing population has led to an increase in cultivation and development of land. There are issues surrounding equitable distribution of food. Poor agricultural practices and overgrazing may result in soil depletion, desertification, and an increased demand for water leading to increasing salinity of soil. There has been a loss of biodiversity. Possible examples include loss of

pests, promoting the use of pesticides and selective herbicides. 4.7 Animals are frequently treated with antibiotics and hormones to increase food yields and profitability. 4.5 The use of agrochemicals has a negative impact on the environment. 4.5 The term “organic” when used to describe foods that have been grown without agrochemicals is not a scientific term. 5.5 “Food miles” describes the impact that changing patterns of food production has had on the seasonal availability of food. There needs to be a balance between growing crops in the optimum climate and transportation to markets. 4.2 Pressures on food distribution are increasing. 4.1 **Guidance** The difference between past and current practices of biotechnology should be discussed. Pressures on food distribution may include changing global weather patterns, political instability, unreliable food supply patterns, consumer demand and economic gain. The difficulties in providing sufficient food could include availability of arable land, accessible water, population pressures, climate change, economic factors, transport and storage. Agrochemicals include fertilizers, herbicides, pesticides and fungicides. Biological controls should also be considered.		Research diseases arising from monoculture. Examine a possible correlation between antibiotic resistance and the use of antibiotics in livestock. Research case studies relating to herbicide or pesticide use and/or biological solutions and the environmental consequences (for example, Australian Cane toad). Research the role of international agribusinesses such as Dow AgroSciences, DuPont, Monsanto, Syngenta and China Shenghua and so on. Research alternative food sources Calculate the food miles in available food. Analyse food distribution data that illustrates the influence that money has on food security. Discuss the balance between an equitable distribution of food and an insufficient food supply. Agrochemicals http://agrochemicals.iupac.org/index.php?option=com_sobi2&catid=3&Itemid=19 Food and Agriculture Organization http://www.fao.org/home/en/ Aquaculture http://www.fao.org/aquaculture/en/ Food miles calculator http://www.foodmiles.com/ GM food and peer-reviewed research http://www.researchgate.net/post/GMO_crops_Is_there_any_peer_reviewed_s	wetlands, animal habitats, palm oil plantations. Aquaculture is an interesting growth area to discuss.

		cientific evidence that questions their safety Food distribution https://foodhub.org/files/resources/Food%20Miles.pdf	

C.4.3 Biotechnology			
Essential idea Genetic modification has both positive and negative implications including ethical dimensions. Scientific literacy and the public understanding of science is vital for decision-making on the use of biotechnology.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
The development of genetically modified (GM) organisms and foods increase the rate and enhance the capability of changes resulting from selective breeding. 4.5 The safety of GM foods is still under debate and this has implications for public acceptance and regulation. 5.1 Differences in regional GMO regulations in combination with the globalization of trade leading to the increased import and export of food makes informed decision-making difficult. 5.1	Extraction of DNA from food (for example, strawberries, liver).	Debate the use of GM foods. Research gene bank programmes.	Biotechnology's modification of food stocks focuses on gains in food production. Long-term changes to the natural sequence of events remain untested.

C.5 Medicine — 12 hours

C.5.1 Science and health

Essential idea

Evidence-based medicine has resulted in major improvements in health, quality of life, increased life expectancy and population growth.

Understanding the nature of science	Practical activities	Research activities	Man's impact on the planet
Progress in the diagnosis and treatment of many diseases and disorders has been advanced by scientific research. 2.6, 3.1, 4.5 Increased life expectancy in some countries will have negative consequences on resources and medical care. 4.8 Epidemiologists study the incidence, distribution and control of diseases. 1.8, 2.9 Causal relationships have been established between some pathogens and infectious diseases. 2.8 Some health practices are not evidence based. 5.4 Funding is required for continued research into infectious diseases, especially in the area of prevention. 4.7 New diseases are appearing due to pathogens crossing species barriers. 4.7 There is a correlation between poverty and the incidence of infectious diseases. 2.8 Public health policies promoting disease prevention have been developed by the scientific community and government agencies. 1.13, 4.1, 4.2 Vaccinations can prevent and eliminate some diseases. In some countries, public understanding has been	Microscopic work with prepared pathogens. Microorganism incubation experiments. Testing microbiology zones of inhibition (for example, antibiotics and wasabi).	Compare electron micrographs of viruses, bacteria, protists and fungi. Investigate the spread, prevention, treatment and symptoms of infectious diseases. Infectious disease http://www.who.int/topics/infectious_diseases/factsheets/en/ Analyse the occurrence of pandemics. Investigate the 10/90 gap in global health research. Research how the threshold for herd immunity varies according to the virulence of the disease. Use simulation software to show an example of successful herd immunity (for example, smallpox). Research the measles, mumps, and rubella (MMR) vaccine/autism controversy and the resulting negative effect on vaccination programmes. Research the increasing resistance in bacteria (for example, methicillin-resistant *Staphylococcus aureus).* Relevant areas could include global perspectives, the link between the developed world and threshold nations, links between national health policies/legislation and international impact. The following link to the Wellcome Trust is an excellent source of animation on a range of topics.	With an increasing life expectancy, there is upward pressure on population numbers and increasing demand for energy and associated resources, including food, water, medical care, arable land and other necessities.

influenced by non-scientific opinion. 2.9, 4.4, 4.6, 5.1, 5. **Guidance** Communicable diseases could include HIV/AIDS, malaria, cholera, tuberculosis, influenza (e.g. H5N1) and Ebola. Public health policies could include reduction in infant mortality, vaccination programmes and how to deal with an ageing population. Medical practices subject to discussion could include reflexology, homeopathy, magnetism, colonic hydrotherapy, acupuncture and chiropractic treatments.		http://www.wellcome.ac.uk/Education-resources/Education-and-learning/Resources/Animation/	

C.5.2 Modern medicine			
Essential idea Advances in technology and collaboration between the scientific community, pharmaceutical industry and governments have been instrumental in improving the diagnosis and treatment of many of the diseases and disorders that threaten health.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Man's impact on the planet**
Pharmaceutical drugs have been synthesized and derived from natural sources. 1.2, 1.8, 4.5, 4.8 Increasing resistance to current drug treatments is a threat to public health. 4.7 Drug treatments can be preventative or curative. 4.5, 4.8 Contraceptive drugs can be used as a means of controlling the birth rate. 4.5 The effectiveness of a drug is closely related to the chemical groups present and the three-dimensional shape of the molecule. 1.10 Computer software is used to design molecules as potential drugs. 1.10 Experimentation and clinical studies are needed to demonstrate the effectiveness, safety, and limitations of new drugs. 2.9, 3.2, 3.3, 4.8 Advances in biomedical diagnostic tests and technology have enabled quick and accurate analysis of medical conditions. 3.7 DNA profiling/sequencing has advanced medical diagnosis and treatment. 1.12, 3.7, 4.8 With health care costs, including use of expensive diagnostic equipment, there needs to be a balance between benefit and cost. 4.5, 4.6	Conduct serial dilutions. Test medical diagnostic kits (for example, blood pressure, glucose analysis). Investigate sensitivity of glucose testing (for example, taste, silver mirror test, commercial laboratory strips). Compare DNA profiles.	Research traditional medicine and medicinal botany. Analyse the effect of contraceptives on the birth rate. Investigate thalidomide. Debate the risks versus benefits of invasive medical diagnostic techniques. Research the history and developments in doping in sports and the World Anti-Doping Organization's role in monitoring and enforcing anti-doping regulations. Determine the reliability of medical/scientific information by comparing sources, for example, different websites. Research the history of the double-blind trial (including the placebo effect). Examine the connections between the pharmaceutical industry, politics and generic drugs. Research the history of a recently introduced drug, from concept to manufacture, through trials, testing and marketing.	The potential of pharmaceutical drugs from the Amazon rainforest has been recognized, but is still underdeveloped. Medicines known to the local population are being investigated. Destruction of the rainforest would lead to a loss of possible drug treatments. Who should pay for the cost of providing health care?

Some medical practices are subject to debate, including experimental cancer drugs and the use of performance enhancers in sports. 3.5, 5.1, 5.2, 5.4 **Guidance** Pathogens that can be treated by drugs could include bacteria, worms, prions and viruses. Preventative pharmaceutical drugs could include contraceptives and statins. Medical disorders treated by modern pharmaceutical drugs could include depression, diabetes, coronary heart disease, high blood pressure and Parkinson's disease. Drug experiments could include sampling, cohort studies, case control studies, double-blind tests and clinical trials. DNA profiling/sequencing is able to classify certain types of cancer and indicate risk factors for certain diseases. Medical imaging techniques could include radiography, magnetic resonance imaging (fMRI), nuclear medicine, ultrasound and computerized tomography (CT and PET) scans.			

Part D: Challenges and the future

Man's impact on the environment — 12 hours

Introduction to this part of the course

Revisit the nature of science questions from the introduction one last time. The purpose is to establish how the students' understanding of the nature of science has grown and become more sophisticated during the course.

This would also be a suitable time for the students to see the section "Nature of science" that underpins the whole course. The philosophy of the course is to develop the understanding of the nature of science through the contexts explored in parts A, B and C and to also see in that exploration the power of science and technology to transform the planet and challenge its sustainability. This then leads naturally to the final challenge to students.

Final exercise

The course culminates with a 12-hour exercise led by the students in which they explore some of the impacts discussed in the course topics or any other impact they may wish to explore. The format can be any that the teacher and students devise but it should focus on solutions to current problems resulting from man's actions and on approaches to sustainability. It should have a science focus although social aspects will also be relevant. It could be group work or individual work but there should be a whole-class presentation of the work. One or more impacts can be dealt with depending on class size and on the interests of the students. New techniques, tools and ideas that scientists use can be looked at in addition to those found in the "Nature of science" section. Such ideas include Life Cycle Analysis, complexity theory (Complex Adaptive Systems) and the circular economy.

A permanent product would be worthwhile. Here is a website produced by one individual interested in global affairs to show what is possible.
http://www.globalissues.org/issue/235/consumption-and-consumerism

The Wikipedia contents list for "human impact on the environment" below is provided purely as a reference for the teacher to show the range of possible issues. Much of the 12 hours devoted to this section should come from the students themselves.

- 1 Causes
  - 1.1 Technology
  - 1.2 Agriculture
    - 1.2.1 Fishing
    - 1.2.2 Irrigation
    - 1.2.3 Topsoil loss
    - 1.2.4 Meat production
    - 1.2.5 Palm oil
  - 1.3 Energy industry
    - 1.3.1 Biodiesel
    - 1.3.2 Coal mining and burning
    - 1.3.3 Electricity generation
    - 1.3.4 Nuclear power
    - 1.3.5 Oil shale industry
    - 1.3.6 Petroleum
    - 1.3.7 Reservoirs
    - 1.3.8 Wind power
  - 1.4 Manufactured products
    - 1.4.1 Cleaning agents
    - 1.4.2 Nanotechnology
    - 1.4.3 Paint
    - 1.4.4 Paper
    - 1.4.5 Pesticides
    - 1.4.6 Pharmaceuticals and personal care products

- 1.5 Mining
- 1.6 Transport
  - 1.6.1 Aviation
  - 1.6.2 Roads
  - 1.6.3 Shipping
- 1.7 War

2 Effects
- 2.1 Biodiversity
- 2.2 Coral reefs
- 2.3 Carbon cycle
- 2.4 Nitrogen cycle
- 2.5 Effects on human health

3 See also
- Anthropocene
- Attribution of recent climate change
- Biome
- Environmental issue
- Hemeroby
- Human–wildlife conflict
- Planetary boundaries
- Sustainability

4 References
- 4.1 Notes
- 4.2 Further reading

5 External links