Diploma Programme

Nature of science
Pilot guide

First assessment 2017

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The International Baccalaureate Organization (known as the IB) offers four high-quality and challenging educational programmes for a worldwide community of schools, aiming to create a better, more peaceful world. This publication is one of a range of materials produced to support these programmes.

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Contents

Purpose of this document

This publication is intended to guide the planning, teaching and assessment of the subject in schools. Subject teachers are the primary audience, although it is expected that teachers will use the guide to inform students and parents about the subject.

This guide is available for pilot schools only.

Additional resources

Pilot school teachers are encouraged to share resources during the pilot phase. Teachers can provide details of useful resources, for example: websites, books, videos, journals or teaching ideas. Past examination papers as well as markschemes and internal assessment guidance will be made available following each examination session.

Acknowledgment

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First assessment 2017

The Diploma Programme

The Diploma Programme is a rigorous pre-university course of study designed for students in the 16 to 19 age range. It is a broad-based two-year course that aims to encourage students to be knowledgeable and inquiring, but also caring and compassionate. There is a strong emphasis on encouraging students to develop intercultural understanding, open-mindedness, and the attitudes necessary for them to respect and evaluate a range of points of view.

The Diploma Programme model

The course is presented as six academic areas enclosing a central core (see figure 1). It encourages the concurrent study of a broad range of academic areas. Students study: two modern languages (or a modern language and a classical language); a humanities or social science subject; an experimental science; mathematics; one of the creative arts. It is this comprehensive range of subjects that makes the Diploma Programme a demanding course of study designed to prepare students effectively for university entrance. In each of the academic areas students have flexibility in making their choices, which means they can choose subjects that particularly interest them and that they may wish to study further at university.

Figure 1

Diploma Programme model

Choosing the right combination

Students are required to choose one subject from each of the six academic areas, although they can, instead of an arts subject, choose two subjects from another area**.** Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IB recommends 240 teaching hours for HL subjects and 150 hours for SL. Subjects at HL are studied in greater depth and breadth than at SL.

At both levels, many skills are developed, especially those of critical thinking and analysis. At the end of the course, students' abilities are measured by means of external assessment. Many subjects contain some element of coursework assessed by teachers.

The core of the Diploma Programme model

All Diploma Programme students participate in the three course elements that make up the core of the model.

Theory of knowledge (TOK) is a course that is fundamentally about critical thinking and inquiry into the process of knowing rather than about learning a specific body of knowledge. The TOK course examines the nature of knowledge and how we know what we claim to know. It does this by encouraging students to analyse knowledge claims and explore questions about the construction of knowledge. The task of TOK is to emphasize connections between areas of shared knowledge and link them to personal knowledge in such a way that an individual becomes more aware of his or her own perspectives and how they might differ from others.

Creativity, activity, service (CAS) is at the heart of the Diploma Programme. The emphasis in CAS is on helping students to develop their own identities, in accordance with the ethical principles embodied in the IB mission statement and the IB learner profile. It involves students in a range of activities alongside their academic studies throughout the Diploma Programme. The three strands of CAS are creativity (arts, and other experiences that involve creative thinking), activity (physical exertion contributing to a healthy lifestyle) and service (an unpaid and voluntary exchange that has a learning benefit for the student). Possibly, more than any other component in the Diploma Programme, CAS contributes to the IB's mission to create a better and more peaceful world through intercultural understanding and respect.

The extended essay, including the world studies extended essay, offers the opportunity for IB students to investigate a topic of special interest, in the form of a 4,000-word piece of independent research. The area of research undertaken is chosen from one of the Diploma Programme subjects, or in the case of the inter-disciplinary world studies essay, two subjects, and acquaints them with the independent research and writing skills expected at university. This leads to a major piece of formally presented, structured writing, in which ideas and findings are communicated in a reasoned and coherent manner, appropriate to the subject or subjects chosen. It is intended to promote high-level research and writing skills, intellectual discovery and creativity. As an authentic learning experience it provides students with an opportunity to engage in personal research on a topic of choice, under the guidance of a supervisor.

Approaches to teaching and approaches to learning

Approaches to teaching and learning across the Diploma Programme refers to deliberate strategies, skills and attitudes which permeate the teaching and learning environment. These approaches and tools, intrinsically linked with the learner profile attributes, enhance student learning and assist student preparation for the Diploma Programme assessment and beyond. The aims of approaches to teaching and learning in the Diploma Programme are to:

- empower teachers as teachers of learners as well as teachers of content
- empower teachers to create clearer strategies for facilitating learning experiences in which students are more meaningfully engaged in structured inquiry and greater critical and creative thinking

- promote both the aims of individual subjects (making them more than course aspirations) and linking previously isolated knowledge (concurrency of learning)

- encourage students to develop an explicit variety of skills that will equip them to continue to be actively engaged in learning after they leave school, and to help them not only obtain university admission through better grades but also prepare for success during tertiary education and beyond

- enhance further the coherence and relevance of the students' Diploma Programme experience

- allow schools to identify the distinctive nature of an IB Diploma Programme education, with its blend of idealism and practicality.

The five approaches to learning (developing thinking skills, social skills, communication skills, self-management skills and research skills) along with the six approaches to teaching (teaching that is inquiry-based, conceptually focused, contextualized, collaborative, differentiated and informed by assessment) encompass the key values and principles that underpin IB pedagogy.

The IB mission statement and the IB learner profile

The Diploma Programme aims to develop in students the knowledge, skills and attitudes they will need to fulfill the aims of the IB, as expressed in the organization's mission statement and the learner profile. Teaching and learning in the Diploma Programme represent the reality in daily practice of the organization's educational philosophy.

Academic honesty

Academic honesty in the Diploma Programme is a set of values and behaviours informed by the attributes of the learner profile. In teaching, learning and assessment, academic honesty serves to promote personal integrity, engender respect for the integrity of others and their work, and ensure that all students have an equal opportunity to demonstrate the knowledge and skills they acquire during their studies.

All coursework—including work submitted for assessment—is to be authentic, based on the student's individual and original ideas with the ideas and work of others fully acknowledged. Assessment tasks that require teachers to provide guidance to students or that require students to work collaboratively must be completed in full compliance with the detailed guidelines provided by the IB for the relevant subjects.

For further information on academic honesty in the IB and the Diploma Programme, please consult the IB publications *Academic honesty*, *The Diploma Programme: From principles into practice* and *General regulations: Diploma Programme*. Specific information regarding academic honesty as it pertains to external and internal assessment components of this Diploma Programme subject can be found in this guide.

Acknowledging the ideas or work of another person

Coordinators and teachers are reminded that candidates must acknowledge all sources used in work submitted for assessment. The following is intended as a clarification of this requirement.

Diploma Programme candidates submit work for assessment in a variety of media that may include audio-visual material, text, graphs, images and/or data published in print or electronic sources. If a candidate uses the work or ideas of another person, the candidate must acknowledge the source using a standard style of referencing in a consistent manner. A candidate's failure to acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB final award committee.

The IB does not prescribe which style(s) of referencing or in-text citation should be used by candidates; this is left to the discretion of appropriate faculty/staff in the candidate's school. The wide range of subjects, three response languages and the diversity of referencing styles make it impractical and restrictive to insist on particular styles. In practice, certain styles may prove most commonly used, but schools are free to choose a style that is appropriate for the subject concerned and the language in which candidates' work is written. Regardless of the reference style adopted by the school for a given subject, it is expected that the minimum information given includes: name of author, date of publication, title of source, and page numbers as applicable.

Candidates are expected to use a standard style and use it consistently so that credit is given to all sources used, including sources that have been paraphrased or summarized. When writing text a candidate must clearly distinguish between their words and those of others by the use of quotation marks (or other method, such as indentation) followed by an appropriate citation that denotes an entry in the bibliography. If an electronic source is cited, the date of access must be indicated. Candidates are not expected to show faultless expertise in referencing, but are expected to demonstrate that all sources have been acknowledged. Candidates must be advised that audio-visual material, text, graphs, images and/or data published in print or in electronic sources that is not their own must also attribute the source. Again, an appropriate style of referencing/citation must be used.

Learning diversity and learning support requirements

Schools must ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Candidates with assessment access requirements* and *Learning diversity within the International Baccalaureate programmes/Special educational needs within the International Baccalaureate programmes*.

Teaching approach

There are a variety of approaches to the teaching of the nature of science course. By its very nature, it lends itself to an experimental approach, and it is expected that this will be reflected throughout the course. The order in which the syllabus is arranged is **not** necessarily the order in which it should be taught, and it is up to individual teachers to decide on an arrangement that suits their circumstances. However it is recommended to begin teaching with part A which includes some of the main concepts which will be used throughout the course. Aspects of part D can be incorporated throughout the teaching of the course and then looked at holistically at the end of the course. The guiding questions should be considered throughout and especially at the end of each sub-topic.

Science and the international dimension

Science itself is an international endeavour—the exchange of information and ideas across national boundaries has been essential to the progress of science. This exchange is not a new phenomenon but it has accelerated in recent times with the development of information and communication technologies. Indeed, the idea that science is a Western invention is a myth—many of the foundations of modern-day science were laid many centuries before by Arabic, Indian and Chinese civilizations, among others. Teachers are encouraged to emphasize this contribution in their teaching of various topics, perhaps through the use of timeline websites. The scientific method in its widest sense, with its emphasis on peer review, open-mindedness and freedom of thought, transcends politics, religion, gender and nationality. Where appropriate within certain topics, the syllabus details sections in the group 4 guides contain links illustrating the international aspects of science.

On an organizational level, many international bodies now exist to promote science. United Nations bodies such as UNESCO, UNEP and WMO, where science plays a prominent part, are well known, but in addition there are hundreds of international bodies representing every branch of science. The facilities for large-scale research in, for example, particle physics and the Human Genome Project are expensive, and only joint ventures involving funding from many countries allow this to take place. The data from such research is shared by scientists worldwide. Group 4 teachers and students are encouraged to access the extensive websites and databases of these international scientific organizations to enhance their appreciation of the international dimension.

Increasingly there is a recognition that many scientific problems are international in nature and this has led to a global approach to research in many areas. The reports of the Intergovernmental Panel on Climate Change are a prime example of this. On a practical level, the group 4 project (which all science students must undertake) mirrors the work of real scientists by encouraging collaboration between schools across the regions.

Alongside the growth in our understanding of the natural world, perhaps the more obvious and relevant result of science to most of our students is our ability to change the world. This is the technological side of science, in which scientific principles have been applied to construct and alter the material world to suit our needs, and have had a profound influence on the daily lives of all human beings. This raises the issue of the impact of science on society, the moral and ethical dilemmas, and the social, economic and environmental implications of the work of scientists. These concerns have become more prominent as our power over the environment has grown, particularly among young people, for whom the importance of the responsibility of scientists for their own actions is self-evident.

The power of scientific knowledge to transform societies is unparalleled. It has the potential to produce great universal benefits, or to reinforce inequalities and cause harm to people and the environment. In line with the IB mission statement, group 4 students need to be aware of the moral responsibility of scientists to ensure that scientific knowledge and data are available to all countries on an equitable basis and that they have the scientific capacity to use this for developing sustainable societies.

There are no specific links to international-mindedness in this course as the whole course is addressed from this viewpoint. Many of the resources provided in the guide are global in nature and teachers could also use resources found on the Global Engage website (http://globalengage.ibo.org).

Prior learning

Past experience shows that students will be able to study a group 4 science subject at SL successfully with no background in, or previous knowledge of, science. Their approach to learning, characterized by the IB learner profile attributes, will be significant here.

However, while there is no intention to restrict access to group 4 subjects, some previous exposure to formal science education would be desirable. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an equivalent national science qualification or a school-based science course would be well prepared.

Links to the Middle Years Programme

Students who have undertaken the MYP science, design and mathematics courses will be well prepared for group 4 subjects. The alignment between MYP science and Diploma Programme group 4 courses allows for a smooth transition for students between programmes. The concurrent planning of the new group 4 courses and MYP: Next chapter (both launched in 2014) has helped develop a closer alignment.

Scientific inquiry is central to teaching and learning science in the MYP. It enables students to develop a way of thinking and a set of skills and processes that, while allowing them to acquire and use knowledge, equip them with the capabilities to tackle, with confidence, the internal assessment component of group 4 subjects. The vision of MYP sciences is to contribute to the development of students as 21st-century learners. A holistic sciences programme allows students to develop and utilize a mixture of cognitive abilities, social skills, personal motivation, conceptual knowledge and problem-solving competencies within an inquiry-based learning environment (Rhoton 2010). Inquiry aims to support students' understanding by providing them with opportunities to independently and collaboratively investigate relevant issues through both research and experimentation. This forms a firm base of scientific understanding with deep conceptual roots for students entering group 4 courses.

In the MYP, teachers make decisions about student achievement using their professional judgment, guided by criteria that are public, precise and known in advance, ensuring that assessment is transparent. The IB describes this approach as "criterion-related"—a philosophy of assessment that is neither "norm-referenced" (where students must be compared to each other and to an expected distribution of achievement) nor "criterion-referenced" (where students must master all strands of specific criteria at lower achievement levels before they can be considered to have achieved the next level). It is important to emphasize that the single most important aim of MYP assessment (consistent with the PYP and DP) is to support curricular goals and encourage appropriate student learning. Assessments are based upon evaluating course aims and objectives and, therefore, effective teaching to the course requirements also ensures effective teaching for formal assessment requirements. Students need to understand what the assessment expectations, standards and practices are and these should all be introduced early and naturally in teaching, as well as in class and homework activities. Experience with criterion-related assessment greatly assists students entering group 4 courses with understanding internal assessment requirements.

MYP science is a concept-driven curriculum, aimed at helping the learner construct meaning through improved critical thinking and the transfer of knowledge. At the top level are key concepts which are broad, organizing, powerful ideas that have relevance within the science course but also transcend it, having relevance in other subject groups. These key concepts facilitate both disciplinary and interdisciplinary learning as well as making connections with other subjects. While the key concepts provide breadth, the related concepts in MYP science add depth to the programme. The related concept can be considered to be the big idea of the unit which brings focus and depth and leads students towards the conceptual understanding.

Across the MYP there are 16 key concepts with the three highlighted below the focus for MYP science.

The key concepts across the MYP curriculum			
Aesthetics	**Change**	Communication	Communities
Connections	Creativity	Culture	Development
Form	Global interactions	Identity	Logic
Perspective	**Relationships**	**Systems**	Time, place and space

MYP students may in addition undertake an optional on-screen concept-based assessment as further preparation for Diploma Programme science courses.

Science and theory of knowledge

The theory of knowledge (TOK) course (first assessment 2015) engages students in reflection on the nature of knowledge and on how we know what we claim to know. The course identifies eight ways of knowing: reason, emotion, language, sense perception, intuition, imagination, faith and memory. Students explore these means of producing knowledge within the context of various areas of knowledge: the natural sciences, the social sciences, the arts, ethics, history, mathematics, religious knowledge systems and indigenous knowledge systems. The course also requires students to make comparisons between the different areas of knowledge, reflecting on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

TOK lessons can support students in their study of science, just as the study of science can support students in their TOK course. TOK provides a space for students to engage in stimulating wider discussions about questions such as what it means for a discipline to be a science, or whether there should be ethical constraints on the pursuit of scientific knowledge. It also provides an opportunity for students to reflect on the methodologies of science, and how these compare to the methodologies of other areas of knowledge. It is now widely accepted that there is no one scientific method, in the strict Popperian sense. Instead, the sciences utilize a variety of approaches in order to produce explanations for the behaviour of the natural world. The different scientific disciplines share a common focus on utilizing inductive and deductive reasoning, on the importance of evidence, and so on. Students are encouraged to compare and contrast these methods with the methods found in, for example, the arts or in history.

In this way there are rich opportunities for students to make links between their science and TOK courses. One way in which science teachers can help students to make these links to TOK is by drawing students' attention to knowledge questions which arise from their subject content. Knowledge questions are open-ended questions about knowledge, and include questions such as:

- How do we distinguish science from pseudoscience?
- When performing experiments, what is the relationship between a scientist’s expectation and their perception?
- How does scientific knowledge progress?
- What is the role of imagination and intuition in the sciences?
- What are the similarities and differences in methods in the natural sciences and the human sciences?

Examples of relevant knowledge questions are provided throughout this guide within the sub-topics in the syllabus content. Teachers can also find suggestions of interesting knowledge questions for discussion in the "Areas of knowledge” and "Knowledge frameworks" sections of the *Theory of knowledge guide*. Students should be encouraged to raise and discuss such knowledge questions in both their science and TOK classes.

Aims

Group 4 aims

Through studying group 4 subjects, students should become aware of how scientists work and communicate with each other. While the scientific method may take on a wide variety of forms, it is the emphasis on a practical approach through experimental work that characterizes these subjects.

The aims enable students, through the overarching theme of the nature of science, to:

1. appreciate scientific study and creativity within a global context through stimulating and challenging opportunities
2. acquire a body of knowledge, methods and techniques that characterize science and technology
3. apply and use a body of knowledge, methods and techniques that characterize science and technology
4. develop an ability to analyse, evaluate and synthesize scientific information
5. develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills including the use of current technologies
7. develop and apply 21st-century communication skills in the study of science
8. become critically aware, as global citizens, of the ethical implications of using science and technology
9. develop an appreciation of the possibilities and limitations of science and technology
10. develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge.

Assessment objectives

The assessment objectives for the group 4 subjects reflect those parts of the aims that will be formally assessed either internally or externally. These assessments will centre upon the nature of science. It is the intention of these courses that students are able to fulfill the following assessment objectives.

1. Demonstrate knowledge and understanding of:
    a. facts, concepts, and terminology
    b. methodologies and techniques
    c. communicating scientific information.
2. Apply:
    a. facts, concepts, and terminology
    b. methodologies and techniques
    c. methods of communicating scientific information.
3. Formulate, analyse and evaluate:
    a. hypotheses, research questions and predictions
    b. methodologies and techniques
    c. primary and secondary data
    d. scientific explanations.
4. Demonstrate the appropriate research, experimental and personal skills necessary to carry out insightful and ethical investigations.

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).

Format of the syllabus

The format of the syllabus section of this guide gives prominence and focus to the teaching and learning aspects. It is designed to support all aspects of the course, and provides detailed resources for practical work and other teaching activities.

Parts and topics

The four parts are labelled with a letter and topics are numbered, for example, “part A”, “topic B.2”.

Sub-topics

The numbering for subtopics follows the above, for example, “sub topic B.2.3” or “subtopic C.3.5”.

There are no separate references to international-mindedness as this subject by its very nature has this aspect fully integrated into the syllabus content and many of the resources are international and transnational in nature. Similarly there are no separate references to TOK as the course itself is about science as an area of knowledge and encompasses seven of the eight ways of knowing in the *Theory of knowledge guide*.

Format of the guide

Topic A.1 <title> 12 hours

Subtopic A.1.1 <title>			
Essential idea: This shows the main nature of science theme(s) dealt with in the sub-topic.			
Understanding the nature of science	**Practical activities**	**Research activities**	**Human impact on the planet**
This column contains the NOS aspects covered and the contextual subject matter that is used to illustrate them. This is followed by numbered links to the specific aspects in the “Nature of science” section. * **Guidance** This gives information about the limits and constraints and the depth of treatment required for teachers and examiners.	This column contains suggestions for practical activities with hyperlinks to specific resources. Practical activities include hands-on experiments, using simulations, modelling etc.	This column suggests research activities with hyperlinks to specific resources. Research activities are activities that can be done in school or at home.	This column is used for part C only and illustrates the issues arising that could also be used in the culminating activity of the course, part D, challenges and the future.

*Move the cursor above a numbered link and press **Ctrl + Click** to take you to the NOS aspect in the Nature of science document. To return to the original numbered link, press **ALT +** ⟸ keys.

Group 4 experimental skills

“I hear and I forget. I see and I remember. I do and I understand.”

Confucius

Integral to the experience of students in any of the group 4 courses is their experience in the classroom laboratory or in the field. Practical activities allow students to interact directly with natural phenomena and secondary data sources. These experiences provide the students with the opportunity to design investigations, collect data, develop manipulative skills, analyse results, collaborate with peers and evaluate and communicate their findings. Experiments can be used to introduce a topic, investigate a phenomenon or allow students to consider and examine questions and curiosities.

By providing students with the opportunity for hands-on experimentation, they are carrying out some of the same processes that scientists undertake. Experimentation allows students to experience the nature of scientific thought and investigation. All scientific theories and laws begin with observations.

It is important that students are involved in an inquiry-based practical programme that allows for the development of scientific inquiry. It is not enough for students just to be able follow directions and to simply replicate a given experimental procedure; they must be provided with the opportunities for genuine inquiry. Developing scientific inquiry skills will give students the ability to construct an explanation based on reliable evidence and logical reasoning. Once developed, these higher order thinking skills will enable students to be lifelong learners and scientifically literate.

A school’s practical scheme of work should allow students to experience the full breadth and depth of the course. This practical scheme of work must also prepare students to undertake the independent investigation that is required for the internal assessment. The development of students’ manipulative skills should involve them being able to follow instructions accurately and demonstrate the safe, competent and methodical use of a range of techniques and equipment.

At the school level both theory and experiments should be undertaken by all students. They should complement one another naturally, as they do in the wider scientific community. The Diploma Programme nature of science course allows students to develop traditional practical skills and techniques. It also allows students to develop interpersonal and digital communication skills which are essential in modern scientific endeavour and are important life-enhancing, transferable skills in their own right.

Mathematical requirements

All Diploma Programme nature of science students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- carry out calculations involving means, decimals, fractions, percentages, ratios, approximations and reciprocals
- use standard notation (for example, 3.6×10^6)
- use direct and inverse proportion
- solve simple algebraic equations
- plot graphs (with suitable scales and axes) including two variables that show linear and non-linear relationships
- interpret graphs, including the significance of gradients, changes in gradients, intercepts and areas, and uncertainty bars
- draw lines (either curves or linear) of best fit on a scatter plot graph
- interpret data presented in various forms (for example, bar charts, histograms and pie charts)
- represent arithmetic mean using x-bar notation (for example, $\bar{x}$)
- express uncertainties to one or two significant figures, with justification
- represent and interpret frequency data in the form of bar charts, graphs and histograms, including direct and inverse proportion
- plot and interpret scattergraphs to identify a correlation between two variables, and appreciate that the existence of a correlation does not establish a causal relationship
- determine the mode and median of a set of data, calculate and analyse standard deviation
- select statistical tests appropriate for the analysis of particular data and interpret the results.

Use of information communication technology

The use of information communication technology (ICT) is encouraged throughout all aspects of the course in relation to both the practical programme and day-to-day classroom activities.

Planning your course

The syllabus as provided in the subject guide is not intended to be a teaching order. Instead it provides detail of what must be covered by the end of the course. A school should develop a scheme of work that best works for its students. For example, the scheme of work could be developed to match available resources, to take into account student prior learning and experience, or in conjunction with other local requirements.

However the course is planned, adequate time must be provided for examination revision. Time must also be given for students to reflect on their learning experience and their growth as learners.

Although the topics can be approached in any order, it is suggested that the course begins with an introductory activity which is designed to challenge the students to think like scientists. An open-ended exercise should not result in any conclusion or explanation at this stage. Then a series of questions are posed to elicit the initial understanding of the students about the nature of science. These questions should be looked at again after every topic to build up gradually a more sophisticated understanding through practice. After all the topics have been studied these should be looked at one final time and the understanding compared to the “Nature of science” section in this guide, For students this should be the first time they see this text as the philosophy of the course is to construct their own understanding through studying the course itself. The culminating activity in part D, challenges and the future, is an opportunity for students to think critically about the impact of science and to suggest ways forward to create a sustainable planet.

The IB learner profile

The nature of science course contributes to the development of the IB learner profile. By following the course, students will have addressed the attributes of the IB learner profile. For example, the requirements of the internal assessment provide opportunities for students to develop every aspect of the profile. For each attribute of the learner profile, a number of references from the group 4 courses are given below.

Learner profile attribute	Nature of Science course
Inquirers	Aims 2 and 6 Practical work and internal assessment
Knowledgeable	Aims 1 and 10, international-mindedness links Practical work and internal assessment
Thinkers	Aims 3 and 4, theory of knowledge links Practical work and internal assessment
Communicators	Aims 5 and 7, external assessment Practical work and internal assessment, the group 4 project
Principled	Aims 8 and 9 Practical work and internal assessment: ethical behaviour/practice (*Ethical practice* poster, *IB animal experimentation policy*), academic honesty
Open-minded	Aims 8 and 9, international-mindedness links Practical work and internal assessment, the group 4 project
Caring	Aims 8 and 9 Practical work, internal assessment, the group 4 project, ethical behaviour/practice (*Ethical practice* poster, *IB animal experimentation policy*)
Risk-takers	Aims 1 and 6 Practical work, internal assessment, the group 4 project
Balanced	Aims 8 and 10 Practical work, internal assessment, the group 4 project, fieldwork
Reflective	Aims 5 and 9 Practical work, internal assessment analysis, the group 4 project

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=Δv/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=L2ZrMXNzL05TU19jb21wL05TU19EVkQvTlNTUEFXX1BEVkQyIChEKS9kb3dubG9hZC9wd2IvUFdCXzIwMmIucGRm 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	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

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.		

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	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	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

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. 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	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 Measuring distances using parallax. http://cse.ssl.berkeley.edu/astro48bcc/pdf_files/Parallax.pdf	http://www.universeadventure.org/fundamentals/cosmol-beginning.htm

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	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	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/

water vapour to the atmosphere. Aquatic living organisms also affect the levels of dissolved gases and the levels of dissolved solids. 1.10	http://www.planetseed.com/sciencearticle/cybergeologist	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	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.

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		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/

<table>
<tr><th colspan="3">B.2.3 Equilibrium</th></tr>
<tr><td colspan="3">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.</td></tr>
<tr><th>Understanding the nature of science</th><th>Practical activities</th><th>Research activities</th></tr>
<tr><td>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</td><td>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.</td><td>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.</td></tr>
</table>

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 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.nuffieldfoundation.org/practical-chemistry/greenhouse-effect Building a barometer. http://www.rmets.org/weather-and-climate/observing/make-barometer Creating a Foucault's pendulum. http://www.calacademy.org/products/pendulum/index.html Demonstrating the Coriolis effect.	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 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	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.

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		

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	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.

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.		

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**	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.

Include the different types of evidence required, an example of selective breeding (for example, dogs) and an example of a molecular clock.		

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	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.	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)

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 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.		Research the Barlow–Ohm dispute in terms of evidence-based science and the development of a law.	

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	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.

electrochemical cell. The series will be limited to Mg, Zn, Fe, Sn, Ag. Details of the chemical reactions occurring will not be expected.			

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	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.	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.	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.

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. 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.	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	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 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	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.

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**	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	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.

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, wind, solar (thermal and photovoltaic), geothermal and biomass.		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 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	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.	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.

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 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**		Investigate enrichment of fuels and the physics of nuclear weapons.	Nuclear testing has an effect on the environment.

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.	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.

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.			

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.	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.

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 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	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	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.

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 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		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.	

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	Practical investigation of electromagnetic induction and the	Investigate other devices that can be used to convert between audio signals and electrical signals.	The installation of telephone lines to allow the transmission of the electrical signals involved has consumed a great

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.	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.	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 Investigate evidence that using mobile phones poses health risks.	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.

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	Investigation of refraction, critical angle and total internal reflection using ray boxes or by simulations. Refraction interactive simulations (including total internal reflection)	Calculations of the effect of transmission speed, through both electrical wires and optical fibres, on the time lag over long distances.	Reduced dependence on metallic conductors should reduce mining of copper and its associated environmental consequences.

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	http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Refraction/Refraction-Interactive http://phet.colorado.edu/en/simulation/bending-light	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.	

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. 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	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 Information on satellite transmission http://www.sqa.org.uk/e-learning/NetTechDC01CCD/page_33.htm#SatelliteTransmission	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.

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.		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	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.	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	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

There is a debate about the best way to assess a healthy body. 3.5 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.	Comparing methods of food preservation.	voyages led to an understanding of scurvy and how to treat it. 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.	inability to live a productive life and a low life expectancy. Legislation on food labelling and public campaigns for healthy eating are 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 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**	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. 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.	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 wetlands, animal habitats, palm oil plantations. Aquaculture is an interesting growth area to discuss.

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.		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_scientific_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	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	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.

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 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.		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. 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	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	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?

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 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		manufacture, through trials, testing and marketing.	

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

Assessment in the Diploma Programme

General

Assessment is an integral part of teaching and learning. The most important aims of assessment in the Diploma Programme are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the Diploma Programme. IB examiners mark work produced for external assessment, while work produced for internal assessment is marked by teachers and externally moderated by the IB.

There are two types of assessment identified by the IB.

- Formative assessment informs both teaching and learning. It is concerned with providing accurate and helpful feedback to students and teachers on the kind of learning taking place and the nature of students' strengths and weaknesses in order to help develop students' understanding and capabilities. Formative assessment can also help to improve teaching quality, as it can provide information to monitor progress towards meeting the course aims and objectives.

- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement.

The Diploma Programme primarily focuses on summative assessment designed to record student achievement at, or towards the end of, the course of study. However, many of the assessment instruments can also be used formatively during the course of teaching and learning, and teachers are encouraged to do this. A comprehensive assessment plan is viewed as being integral with teaching, learning and course organization. For further information, see the IB *Programme standards and practices* document.

The approach to assessment used by the IB is criterion-related, not norm-referenced. This approach to assessment judges students' work by their performance in relation to identified levels of attainment, and not in relation to the work of other students. For further information on assessment within the Diploma Programme please refer to the publication *Diploma Programme assessment: principles and practice*.

To support teachers in the planning, delivery and assessment of the Diploma Programme courses, a variety of resources can be found on the OCC or purchased from the IB store (http://store.ibo.org). Pilot schools will be provided with specimen examination papers and markschemes, past examination papers and markschemes, and subject reports.

Methods of assessment

The IB uses several methods to assess work produced by students.

Assessment criteria

Assessment criteria are used when the assessment task is open-ended. Each criterion concentrates on a particular skill that students are expected to demonstrate. An assessment objective describes what students should be able to do, and assessment criteria describe how well they should be able to do it. Using assessment criteria allows discrimination between different answers and encourages a variety of responses. Each criterion comprises a set of hierarchically ordered level descriptors. Each level descriptor is worth one or more marks. Each criterion is applied independently using a best-fit model. The maximum marks for each criterion may differ according to the criterion's importance. The marks awarded for each criterion are added together to give the total mark for the piece of work.

Markbands

Markbands are a comprehensive statement of expected performance against which responses are judged. They represent a single holistic criterion divided into level descriptors. Each level descriptor corresponds to a range of marks to differentiate student performance. A best-fit approach is used to ascertain which particular mark to use from the possible range for each level descriptor.

Analytic markschemes

Analytic markschemes are prepared for those examination questions that expect a particular kind of response and/or a given final answer from students. They give detailed instructions to examiners on how to break down the total mark for each question for different parts of the response.

Marking notes

For some assessment components marked using assessment criteria, marking notes are provided. Marking notes give guidance on how to apply assessment criteria to the particular requirements of a question.

Inclusive assessment arrangements

Inclusive assessment arrangements are available for candidates with assessment access requirement. These arrangements enable candidates with diverse needs to access the examinations and demonstrate their knowledge and understanding of the constructs being assessed.

The IB document *Candidates with assessment access requirements* provides details on all the inclusive assessment arrangements available to candidates with learning support requirements. The IB document *Learning diversity within the International Baccalaureate programmes/Special educational needs within the International Baccalaureate programmes* outlines the position of the IB with regard to candidates with diverse learning needs in the IB programmes. For candidates affected by adverse circumstances, the IB documents *General regulations: Diploma Programme* and the *Handbook of procedures for the Diploma Programme* provide details on special consideration.

Responsibilities of the school

The school is required to ensure that equal access arrangements and reasonable adjustments are provided to candidates with special educational needs that are in line with the IB documents *Candidates with assessment access requirements* and *Learning diversity within the International Baccalaureate programmes/Special educational needs within the International Baccalaureate programmes*.

Assessment outline

First assessment 2017

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	40	20	20	1½
Paper 2	30	15	15	1
Internal assessment	30	Covers objectives 1, 2, 3 and 4		15

External assessment

The method used to assess students is the use of detailed markschemes specific to each examination paper.

External assessment details

Paper 1

Duration: 1½ hours

Weighting: 40%

Marks: 60

- Students are required to demonstrate an understanding of the nature of science through contextual examples drawn from the topics in the syllabus guide.
- About half the marks are for the nature of science and about half for subject knowledge.
- Section A: 20 marks are available from 8 to 10 questions, some of which are multiple choice questions. Short answers are required, each worth between 1 and 5 marks.
- Section B: 40 marks are available from around three questions. Longer answers are required, each worth an average of 15 marks with no question worth more than 18 marks.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See the calculator section of the OCC.)
- No marks are deducted for incorrect answers.

Paper 2

Duration: 1 hour

Weighting: 30%

Marks: 45

- Students are required to demonstrate an understanding of the nature of science through contextual examples drawn from the topics in the syllabus guide or from other scientific material.
- This paper has one section with 4 or 5 questions, each worth up to 12 marks.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See the calculator section of the OCC.)
- No marks are deducted for incorrect answers.

Purpose of internal assessment

Internal assessment is an integral part of the course and is compulsory for both SL and HL students. It enables students to demonstrate the application of their skills and knowledge, and to pursue their personal interests, without the time limitations and other constraints that are associated with written examinations. The internal assessment should, as far as possible, be woven into normal classroom teaching and not be a separate activity conducted after a course has been taught.

This internal assessment section of the guide should be read in conjunction with the internal assessment section of the teacher support materials.

Guidance and authenticity

The work submitted for internal assessment must be the student's own work. However, it is not the intention that students should decide upon a title or topic and be left to work on the internal assessment component without any further support from the teacher. The teacher should play an important role during both the planning stage and the period when the student is working on the internally assessed work. It is the responsibility of the teacher to ensure that students are familiar with:

- the requirements of the type of work to be internally assessed
- the *IB animal experimentation policy*
- the assessment criteria—students must understand that the work submitted for assessment must address these criteria effectively.

Teachers and students must discuss the internally assessed work. Students should be encouraged to initiate discussions with the teacher to obtain advice and information, and students must not be penalized for seeking guidance. As part of the learning process, teachers should read and give advice to students on one draft of the work. The teacher should provide oral or written advice on how the work could be improved, but not edit the draft. The next version handed to the teacher must be the final version for submission.

It is the responsibility of teachers to ensure that all students understand the basic meaning and significance of concepts that relate to academic honesty, especially authenticity and intellectual property. Teachers must ensure that all student work for assessment is prepared according to the requirements and must explain clearly to students that the internally assessed work must be entirely their own. Where collaboration between students is permitted, it must be clear to all students what the difference is between collaboration and collusion.

All work submitted to the IB for moderation or assessment must be authenticated by a teacher, and must not include any known instances of suspected or confirmed academic misconduct. Each student must confirm that the work is his or her authentic work and constitutes the final version of that work. Once a student has officially submitted the final version of the work it cannot be retracted. The requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that will be submitted to the IB for the purpose of moderation. For further details refer to the two IB publications on academic honesty: *Diploma Programme: From principles into practice* (2009) and the relevant articles in *General regulations: Diploma Programme* (2012).

Authenticity may be checked by discussion with the student on the content of the work, and scrutiny of one or more of the following.

- The student's initial proposal
- The first draft of the written work

- The references cited
- The style of writing compared with work known to be that of the student
- The analysis of the work by a web-based plagiarism detection service such as www.turnitin.com

The same piece of work cannot be submitted to meet the requirements of both the internal assessment and the extended essay.

Group work

Each investigation is an individual piece of work based on different data collected or measurements generated. Ideally, students should work on their own when collecting data. In some cases, data collected or measurements made can be from a group experiment provided each student collected his or her own data or made his or her own measurements. In this course, in some cases, group data or measurements may be combined to provide enough for individual analysis. Even in this case, students should have collected and recorded their own data and they should clearly indicate which data are theirs.

It should be made clear to students that all work connected with the investigation should be their own. It is therefore helpful if teachers try to encourage in students a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work.

Time allocation

Internal assessment is an integral part of the nature of science course, contributing 30% to the final assessment. This weighting should be reflected in the time that is allocated to teaching the knowledge, skills and understanding required to undertake the work, as well as the total time allocated to carry out the work.

It is recommended that a total of approximately 15 hours of teaching time should be allocated to the work. This should include:

- time for the teacher to explain to students the requirements of the internal assessment
- class time for students to work on the internal assessment component and ask questions
- time for consultation between the teacher and each student
- time to review and monitor progress, and to check authenticity.

Safety requirements and recommendations

While teachers are responsible for following national or local guidelines, which may differ from country to country, attention should be given to the guidelines below, which were developed for the International Council of Associations for Science Education (ICASE) Safety Committee by The Laboratory Safety Institute (LSI).

It is a basic responsibility of everyone involved to make safety and health an ongoing commitment. Any advice given will acknowledge the need to respect the local context, the varying educational and cultural traditions, the financial constraints and the legal systems of differing countries.

The Laboratory Safety Institute's

Laboratory Safety Guidelines...

40 suggestions for a safer lab

Steps Requiring Minimal Expense

1. Have a written health, safety and environmental affairs (HS&E) policy statement.

2. Organize a departmental HS&E committee of employees, management, faculty, staff and students that will meet regularly to discuss HS&E issues.

3. Develop an HS&E orientation for all new employees and students.

4. Encourage employees and students to care about their health and safety and that of others.

5. Involve every employee and student in some aspect of the safety program and give each specific responsibilities.

6. Provide incentives to employees and students for safety performance.

7. Require all employees to read the appropriate safety manual. Require students to read the institution's laboratory safety rules. Have both groups sign a statement that they have done so, understand the contents, and agree to follow the procedures and practices. Keep these statements on file in the department office

8. Conduct periodic, unannounced laboratory inspections to identify and correct hazardous conditions and unsafe practices. Involve students and employees in simulated OSHA inspections.

9. Make learning how to be safe an integral and important part of science education, your work, and your life.

10. 1Schedule regular departmental safety meetings for all students and employees to discuss the results of inspections and aspects of laboratory safety.

11. When conducting experiments with hazards or potential hazards, ask yourself these questions:

    – What are the hazards?

    – What are the worst possible things that could go wrong?

    – How will I deal with them?

    – What are the prudent practices, protective facilities and equipment necessary to minimize the risk of exposure to the hazards?

12. Require that all accidents (incidents) be reported, evaluated by the departmental safety committee, and discussed at departmental safety meetings.

13. Require every pre-lab/pre-experiment discussion to include consideration of the health and safety aspects.

14. Don't allow experiments to run unattended unless they are failsafe.

15. Forbid working alone in any laboratory and working without prior knowledge of a staff member.

16. Extend the safety program beyond the laboratory to the automobile and the home.

17. Allow only minimum amounts of flammable liquids in each laboratory.

18. Forbid smoking, eating and drinking in the laboratory.

19. Do not allow food to be stored in chemical refrigerators.

20. Develop plans and conduct drills for dealing with emergencies such as fire, explosion, poisoning, chemical spill or vapour release, electric shock, bleeding and personal contamination.

21. Require good housekeeping practices in all work areas.

22. Display the phone numbers of the fire department, police department, and local ambulance either on or immediately next to every phone.

23. Store acids and bases separately. Store fuels and oxidizers separately.

24. Maintain a chemical inventory to avoid purchasing unnecessary quantities of chemicals.

25. Use warning signs to designate particular hazards.

26. Develop specific work practices for individual experiments, such as those that should be conducted only in a ventilated hood or involve particularly hazardous materials. When possible most hazardous experiments should be done in a hood.

Steps Requiring Moderate Expense

27. Allocate a portion of the departmental budget to safety.

28. Require the use of appropriate eye protection at all times in laboratories and areas where chemicals are transported.

29. Provide adequate supplies of personal protective equipment—safety glasses, goggles, face shields, gloves, lab coats and bench top shields.

30. Provide fire extinguishers, safety showers, eye wash fountains, first aid kits, fire blankets and fume hoods in each laboratory and test or check monthly.

31. Provide guards on all vacuum pumps and secure all compressed gas cylinders.

32. Provide an appropriate supply of first aid equipment and instruction on its proper use.

33. Provide fireproof cabinets for storage of flammable chemicals.

34. Maintain a centrally located departmental safety library:

    - "Safety in School Science Labs", Clair
    - Wood, 1994, Kaufman & Associates, 101
    - Oak Street, Wellesley, MA 02482
    - "The Laboratory Safety Pocket Guide", 1996, Genium Publisher, One Genium Plaza, Schnectady, NY
    - "Safety in Academic Chemistry Laboratories", ACS, 1155 Sixteenth Street NW, Washington, DC 20036
    - "Manual of Safety and Health Hazards in The School Science Laboratory", "Safety in the School Science Laboratory", "School Science Laboratories: A guide to Some Hazardous Substances" Council of State Science Supervisors (now available only from LSI.)
    - "Handbook of Laboratory Safety", 4th Edition, CRC Press, 2000 Corporate Boulevard NW, Boca Raton, FL 33431
    - "Fire Protection Guide on Hazardous Materials", National Fire Protection Association, Batterymarch Park, Quincy, MA 02269
    - "Prudent Practices in the Laboratory: Handling and Disposal of Hazardous Chemicals", 2nd Edition, 1995
    - "Biosafety in the Laboratory", National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418
    - "Learning By Accident", Volumes 1-3, 1997-2000, The Laboratory Safety Institute, Natick, MA 01760

    (All are available from **LSI**.)

35. Remove all electrical connections from inside chemical refrigerators and require magnetic closures.

36. Require grounded plugs on all electrical equipment and install ground fault interrupters (GFIs) where appropriate.

37. Label all chemicals to show the name of the material, the nature and degree of hazard, the appropriate precautions, and the name of the person responsible for the container.

38. Develop a program for dating stored chemicals and for recertifying or discarding them after predetermined maximum periods of storage.

39. Develop a system for the legal, safe and ecologically acceptable disposal of chemical wastes.

40. Provide secure, adequately spaced, well-ventilated storage of chemicals.

Using assessment criteria for internal assessment

For internal assessment, a number of assessment criteria have been identified. Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work against the criteria using the level descriptors.

- The aim is to find, for each criterion, the descriptor that conveys most accurately the level attained by the student, using the best-fit model. A best-fit approach means that compensation should be made when a piece of work matches different aspects of a criterion at different levels. The mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded.

- When assessing a student's work, teachers should read the level descriptors for each criterion until they reach a descriptor that most appropriately describes the level of the work being assessed. If a piece of work seems to fall between two descriptors, both descriptors should be read again and the one that more appropriately describes the student's work should be chosen.

- Where there are two or more marks available within a level, teachers should award the upper marks if the student's work demonstrates the qualities described to a great extent; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.

- Only whole numbers should be recorded; partial marks (fractions and decimals) are not acceptable.

- Teachers should not think in terms of a pass or fail boundary, but should concentrate on identifying the appropriate descriptor for each assessment criterion.

- The highest level descriptors do not imply faultless performance but should be achievable by a student. Teachers should not hesitate to use the extremes if they are appropriate descriptions of the work being assessed.

- A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.

- It is recommended that the assessment criteria be made available to students.

Practical work and internal assessment

General introduction

There is one single internal assessment task worth 30% of the total assessment. It should take about 15 hours and the report produced should be 10 to 15 pages long. There should be no appendices. An abstract is not required and a title page will not be counted as part of the document.

The task should examine aspects of the nature of science through a particular context chosen by the student. Explicit reference to, and explanation of, nature of science aspects is required. Practical work is possible in many contexts.

Examples of contexts could include an investigation of:

- a particular case of scientific achievement or discovery

- a claim or claims regarded as pseudoscience
- two different cases, one accepted by scientific opinion and one not accepted
- a topical issue of scientific interest
- the development of scientific ideas in different civilizations and over time

Many other contexts may also be appropriate.

Investigations exceeding the specified length will be penalized in the scientific communication and engagement criterion as lacking in conciseness.

The investigation addresses many of the learner profile attributes. See the section on “Approaches to teaching and learning” for further details.

The work produced should be complex and commensurate with the level of the course. The marked exemplar material in the teacher support material demonstrates that the assessment is rigorous and of the same standard as the assessment of other group 4 subjects.

Student work is internally assessed by the teacher and externally moderated by the IB.

The five assessment criteria are: context; strategy; analysis; evaluation and conclusion; and scientific communication and engagement.

Note: Any investigation that is to be used to assess students should be specifically designed to match the relevant assessment criteria.

Internal assessment details

Internal assessment component

Duration: 15 hours

Weighting: 30%

- This is an individual investigation.
- This investigation covers assessment objectives 1, 2, 3 and 4.

Internal assessment criteria

The new assessment model uses five criteria to assess the final report of the individual investigation with the following raw marks assigned:

Context	Strategy	Analysis	Evaluation and conclusion	Scientific communication and engagement	Total
6	6	6	6	4	28

Levels of performance are described using multiple indicators per level. In many cases the indicators occur together in a specific level, but not always. Also, not all indicators are always present. This means that a candidate can demonstrate performances that fit into different levels. To accommodate this, the IB assessment models use mark bands and advise examiners and teachers to use a best-fit approach in deciding the appropriate mark for a particular criterion.

Teachers should read the guidance on using markbands in the section “Using assessment criteria for internal assessment” before starting to mark. It is also essential to be fully acquainted with the marking of the exemplars in the teacher support material. The precise meaning of the command terms used in the criteria can be found in the glossary of this guide.

Context

This criterion assesses the extent to which the student develops a research topic and establishes a context for their investigation into the nature of science.

Mark	Descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	**States** a research topic but it is not focused. **Lists** some background NOS information.
3–4	**Outlines** a research topic but does not fully focus on the NOS aspects. **Describes** the relevant background NOS information to provide context to the inquiry.
5–6	**Constructs** a relevant and coherent research topic and focuses it on the NOS aspects**.** **Discusses** the relevant background NOS information to provide context to the inquiry.

Strategy

This criterion assesses the extent to which the student makes the appropriate nature of science connections to the research topic and uses the **appropriate resources and/or methodology**.

Mark	Descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	**States** the connection to the relevant NOS aspects. **Lists** a limited range of resources*. **Describes** an inappropriate methodology**.
3–4	**Outlines** the connection to the relevant NOS aspects. **Lists** a wide range of different resources*. **Describes** an appropriate methodology**.
5–6	**Explains** the connection to the relevant NOS aspects. **Justifies** the appropriate resources*. **Justifies** the methodology** chosen.

Note that either the second or third point would apply, but not both usually.

* For resources we include published literature, interviews, primary or secondary data collection and so on.

**By methodology we mean the published scientific methods or those designed by the student.

Analysis

This criterion assesses the extent to which the student analyses the resources and the connection between their results and the nature of science aspects.

Mark	Descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	**States** the evidence. **Lists** the results of their investigation.
3–4	**Outlines** the evidence. **Describes** the results of their investigation and their connection to the NOS aspects.
5–6	**Analyses** the evidence. **Discusses** the results of their investigation and their connection to the NOS aspects.

Evaluation and conclusion

This criterion assesses the extent to which the student addresses the nature of science appropriately, evaluates the investigation and suggests further extensions.

Mark	Descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	**States** a conclusion that is not valid or too simplistic. **Lists** strengths, weaknesses and limitations of resources and/or methodology. **States** simplistic and superficial modifications and/or further areas for research/investigation.
3–4	**Demonstrates** a conclusion that has limited validity. **Describes** strengths, weaknesses and limitations of resources and/or methodology. **Describes** some modifications and further areas for research and/or investigation.
5–6	**Demonstrates** a valid conclusion. **Discusses** strengths, weaknesses and limitations of resources and/or methodology. **Suggests** appropriate related modifications and further areas of research and/or investigation.

Scientific communication and engagement

This criterion assesses whether the report has been presented in a way that supports effective communication in terms of structure, coherence and clarity. The focus, process and outcomes of the report should all be well presented.

Mark	Descriptor
0	The report does not reach a standard described by any of the descriptors given below.

1–2	The investigation has limited structure and organization. The report makes limited use of appropriate terminology The report is not concise. There is little evidence of personal input and initiative in the designing, implementation or presentation of the investigation.
3–4	The report is well structured and coherent. The report makes consistent use of appropriate terminology. The report is concise. There is evidence of personal input and initiative in the designing, implementation or presentation of the investigation.

Please note that, while it is expected that the report will be correctly referenced, students will not be penalized under this criterion for a lack of bibliography or other means of citation. It is likely that such an omission would be considered under the IB's academic honesty policy.

Note: In addition to the assessment criteria, the section in this guide called "Nature of science" and the definitions of the command terms found in the appendix must both be used in assessing the internal assessment task.

Rationale for practical work

Although the requirements for internal assessment are centred on the investigation, the different types of practical activities that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of much scientific work
- developing an appreciation of scientists' use of secondary data from databases
- developing an appreciation of scientists' use of modelling
- developing an appreciation of the benefits and limitations of scientific methodology.

Practical scheme of work

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student.

Syllabus coverage

The range of practical work carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all students must participate in the group 4 project and the internal assessment investigation.

Planning your practical scheme of work

Teachers are free to formulate their own practical schemes of work by choosing practical activities according to the requirements outlined. Their choices should be based on:

- the needs of their students
- available resources
- teaching styles.

Each scheme must include some complex experiments that make greater conceptual demands on students. A scheme made up entirely of simple experiments, such as ticking boxes or exercises involving filling in tables, will not provide an adequate range of experience for students.

Pilot course teachers are encouraged to use the Basecamp group to share ideas about possible practical activities by joining in the discussion forum and adding resources.

Flexibility

The practical programme is flexible enough to allow a wide variety of practical activities to be carried out. These could include:

- short labs
- projects extending over several weeks
- computer simulations
- using databases for secondary data
- developing and using models
- data-gathering exercises such as questionnaires, user trials and surveys
- data-analysis exercises
- fieldwork.

Practical work documentation

Details of the practical scheme of work are recorded on Form 4/PSOW/NOS provided in the *Handbook of procedures for the Diploma Programme*. A copy of Form 4/PSOW/NOS for the class must be included with any sample set sent for moderation.

Time allocation for practical work

The recommended teaching times for all Diploma Programme SL courses is 150 hours. Students undertaking the nature of science SL course are required to spend 50 hours on practical activities (excluding time spent writing up work). This time includes 10 hours for the group 4 project and 15 hours for realizing the internal assessment investigation. (Only two to three hours of investigative work can be carried out after the deadline for submitting work to the moderator and still be counted in the total number of hours for the practical scheme of work.)

The group 4 project

The group 4 project is an interdisciplinary activity in which all students studying a Diploma Programme group 4 subject (that is, biology, chemistry, physics, design technology, sports, exercise and health science, and computer science) must participate. The intention is that students from the different group 4 subjects analyse a common topic or problem. The exercise should be a collaborative experience where the emphasis is on the processes involved in, rather than the products of, such an activity.

In most cases students in a school would be involved in the investigation of the same topic. Where there are large numbers of students, it is possible to divide them into several smaller groups containing representatives from each of the science subjects. Each group may investigate the same topic or different topics—that is, there may be several group 4 projects in the same school.

Students studying the transdisciplinary groups 3 and 4 subject environmental systems and societies are not required to undertake the group 4 project.

Summary of the group 4 project

The group 4 project is a collaborative activity where students from different group 4 subjects work together on a scientific or technological topic, allowing for concepts and perceptions from across the disciplines to be shared in line with aim 10—that is, to “develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge”. The project can be practically or theoretically based. Collaboration between schools in different regions is encouraged.

The group 4 project allows students to appreciate the environmental, social and ethical implications of science and technology. It may also allow them to understand the limitations of scientific study, for example, the shortage of appropriate data and/or the lack of resources. The emphasis is on interdisciplinary cooperation and the processes involved in scientific investigation, rather than the products of such investigation.

The choice of scientific or technological topic is open but the project should clearly address aims 7, 8 and 10 of the group 4 subject guides.

Ideally, the project should involve students collaborating with those from other group 4 subjects at all stages. To this end, it is not necessary for the topic chosen to have clearly identifiable separate subject components. However, for logistical reasons, some schools may prefer a separate subject “action” phase (see the following “Project stages” section).

Project stages

The 10 hours allocated to the group 4 project, which are part of the teaching time set aside for developing the practical scheme of work, can be divided into three stages: planning, action and evaluation.

Planning

This stage is crucial to the whole exercise and should last about two hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all group 4 students meeting to “brainstorm” and discuss the central topic, sharing ideas and information.
- The topic can be chosen by the students themselves or selected by the teachers.
- Where large numbers of students are involved, it may be advisable to have more than one mixed subject group.

After selecting a topic or issue, the activities to be carried out must be clearly defined before moving from the planning stage to the action and evaluation stages.

A possible strategy is that students define specific tasks for themselves, either individually or as members of groups, and investigate various aspects of the chosen topic. At this stage, if the project is to be experimentally based, apparatus should be specified so that there is no delay in carrying out the action stage. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

Action

This stage should last around six hours and may be carried out over one or two weeks in normal scheduled class time. Alternatively, a whole day could be set aside if, for example, the project involves fieldwork.

- Students should investigate the topic in mixed subject groups or single subject groups.
- There should be collaboration during the action stage; findings of investigations should be shared with other students within the mixed/single subject group. During this stage, in any practically based activity, it is important to pay attention to safety, ethical and environmental considerations.

Note: Students studying two group 4 subjects are not required to do two separate action phases.

Evaluation

The emphasis during this stage, for which two hours are probably necessary, is on students sharing their findings, both successes and failures, with other students. How this is achieved can be decided by the teachers, the students or jointly.

- One solution is to devote a morning, afternoon or evening to a symposium where all the students, as individuals or as groups, give brief presentations.
- Alternatively, the presentation could be more informal and take the form of a science fair where students circulate around displays summarizing the activities of each group.

The symposium or science fair could also be attended by parents, members of the school board and the press. This would be especially pertinent if some issue of local importance has been researched. Some of the findings might influence the way the school interacts with its environment or local community.

Addressing aims 7 and 8

Aim 7: “develop and apply 21st century communication skills in the study of science.”

Aim 7 may be partly addressed at the planning stage by using electronic communication within and between schools. It may be that technology (for example, data logging, spreadsheets, databases and so on) will be used in the action phase and certainly in the presentation/evaluation stage (for example, use of digital images, presentation software, websites, digital video and so on).

Aim 8: “become critically aware, as global citizens, of the ethical implications of using science and technology.”

Addressing the international dimension

There are also possibilities in the choice of topic to illustrate the international nature of the scientific endeavour and the increasing cooperation required to tackle global issues involving science and technology. An alternative way to bring an international dimension to the project is to collaborate with a school in another region.

Types of project

While addressing aims 7, 8 and 10 the project must be based on science or its applications. The project may have a hands-on practical action phase or one involving purely theoretical aspects. It could be undertaken in a wide range of ways:

- designing and carrying out a laboratory investigation or fieldwork
- carrying out a comparative study (experimental or otherwise) in collaboration with another school
- collating, manipulating and analysing data from other sources, such as scientific journals, environmental organizations, science and technology industries and government reports
- designing and using a model or simulation
- contributing to a long-term project organized by the school.

Logistical strategies

The logistical organization of the group 4 project is often a challenge to schools. The following models illustrate possible ways in which the project may be implemented.

Models A, B and C apply within a single school, while model D relates to a project involving collaboration between schools.

Model A: mixed subject groups and one topic

Schools may use mixed subject groups and choose one common topic. The number of groups will depend on the number of students.

Model B: mixed subject groups adopting more than one topic

Schools with large numbers of students may choose to do more than one topic.

Model C: single subject groups

For logistical reasons some schools may opt for single subject groups, with one or more topics in the action phase. This model is less desirable as it does not show the mixed subject collaboration in which many scientists are involved.

Model D: collaboration with another school

The collaborative model is open to any school. To this end, the IB provides an electronic collaboration board on the OCC where schools can post their project ideas and invite collaboration from other schools. This could range from merely sharing evaluations for a common topic to a full-scale collaborative venture at all stages.

For schools with few Diploma Programme students or schools with Diploma Programme course students, it is possible to work with non- Diploma Programme or non-group 4 students or undertake the project once every two years. However, these schools are encouraged to collaborate with another school. This strategy is also recommended for individual students who may not have participated in the project, for example, through illness or because they have transferred to a new school where the project has already taken place.

Timing

The 10 hours that the IB recommends for the project may be spread over a number of weeks. The distribution of these hours needs to be taken into account when selecting the optimum time to carry out the project. However, it is possible for a group to dedicate a period of time exclusively to project work if all/most other school work is suspended.

Year 1

In the first year, students' experience and skills may be limited and it would be inadvisable to start the project too soon in the course. However, doing the project in the final part of the first year may have the advantage of reducing pressure on students later on. This strategy provides time for solving unexpected problems.

Year 1-Year 2

The planning stage could start, the topic could be decided upon, and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation time to think about how they are going to tackle the project and would be ready to start work early in the second year.

Year 2

Delaying the start of the project until some point in the second year, particularly if left too late, increases pressure on students in many ways: the schedule for finishing the work is much tighter than for the other options; the illness of any student or unexpected problems will present extra difficulties. Nevertheless, this choice does mean students know one another and their teachers by this time, have probably become accustomed to working in a team and will be more experienced in the relevant fields than in the first year.

Combined SL and HL

Where circumstances dictate that the project is only carried out every two years, HL beginners and more experienced SL students can be combined into one group.

Selecting a topic

Students may choose the topic or they can propose possible topics and have the teacher decide which one is the most viable based on resources, staff availability and so on. Alternatively, the teacher selects the topic or proposes several topics from which students make a choice.

Student selection

Students are likely to display more enthusiasm and feel a greater sense of ownership for a topic that they have chosen themselves. A possible strategy for student selection of a topic, which also includes part of the planning stage, is outlined here. At this point, subject teachers may provide advice on the viability of proposed topics.

- Identify possible topics by using a questionnaire or a survey of students.
- Conduct an initial "brainstorming" session of potential topics or issues.
- Discuss, briefly, two or three topics that seem interesting.
- Select one topic by consensus.
- Students make a list of potential investigations that could be carried out. All students then discuss issues such as possible overlap and collaborative investigations.

A reflective statement written by each student on their involvement in the group 4 project must be included on the coversheet for each internal assessment investigation. See the *Handbook of procedures for the Diploma Programme* for more details.

Glossary of command terms

Command terms for nature of science

Students should be familiar with the following key terms and phrases used in examination questions, which are to be understood as described below. Although these terms will be used frequently in examination questions, other terms may be used to direct students to present an argument in a specific way.

These command terms indicate the depth of treatment required.

Assessment objective 1

Command term	Definition
Define	Give the precise meaning of a word, phrase, concept or physical quantity.
Draw	Represent by means of a labelled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve.
Label	Add labels to a diagram.
List	Give a sequence of brief answers with no explanation.
Measure	Obtain a value for a quantity.
State	Give a specific name, value or other brief answer without explanation or calculation.
Write down	Obtain the answer(s), usually by extracting information. Little or no calculation is required. Working does not need to be shown.

Assessment objective 2

Command term	Definition
Annotate	Add brief notes to a diagram or graph.
Apply	Use an idea, equation, principle, theory or law in relation to a given problem or issue.
Calculate	Obtain a numerical answer showing the relevant stages in the working.

Describe	Give a detailed account.
Distinguish	Make clear the differences between two or more concepts or items.
Estimate	Obtain an approximate value.
Formulate	Express precisely and systematically the relevant concept(s) or argument(s).
Identify	Provide an answer from a number of possibilities.
Outline	Give a brief account or summary.
Plot	Mark the position of points on a diagram.

Assessment objective 3

Command term	**Definition**
Analyse	Break down in order to bring out the essential elements or structure.
Comment	Give a judgment based on a given statement or result of a calculation.
Compare	Give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout.
Compare and contrast	Give an account of similarities and differences between two (or more) items or situations, referring to both (all) of them throughout.
Construct	Display information in a diagrammatic or logical form.
Deduce	Reach a conclusion from the information given.
Demonstrate	Make clear by reasoning or evidence, illustrating with examples or practical application.
Derive	Manipulate a mathematical relationship to give a new equation or relationship.
Design	Produce a plan, simulation or model.
Determine	Obtain the only possible answer.

Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Explain	Give a detailed account including reasons or causes.
Hence	Use the preceding work to obtain the required result.
Hence or otherwise	It is suggested that the preceding work is used, but other methods could also receive credit.
Justify	Give valid reasons or evidence to support an answer or conclusion.
Predict	Give an expected result.
Show	Give the steps in a calculation or derivation.
Show that	Obtain the required result (possibly using information given) without the formality of proof. “Show that” questions do not generally require the use of a calculator.
Sketch	Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Solve	Obtain the answer(s) using algebraic and/or numerical and/or graphical methods.
Suggest	Propose a solution, hypothesis or other possible answer.

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This bibliography lists the principal works used to inform the curriculum review. It is not an exhaustive list and does not include all the literature available: judicious selection was made in order to better advise and guide teachers. This bibliography is not a list of recommended textbooks.

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