INTERNATIONAL BACCALAUREATE ORGANIZATION

ENVIRONMENTAL SYSTEMS

Environmental Systems
February 2001

(*last updated May 2004*)

International Baccalaureate Organization
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CONTENTS

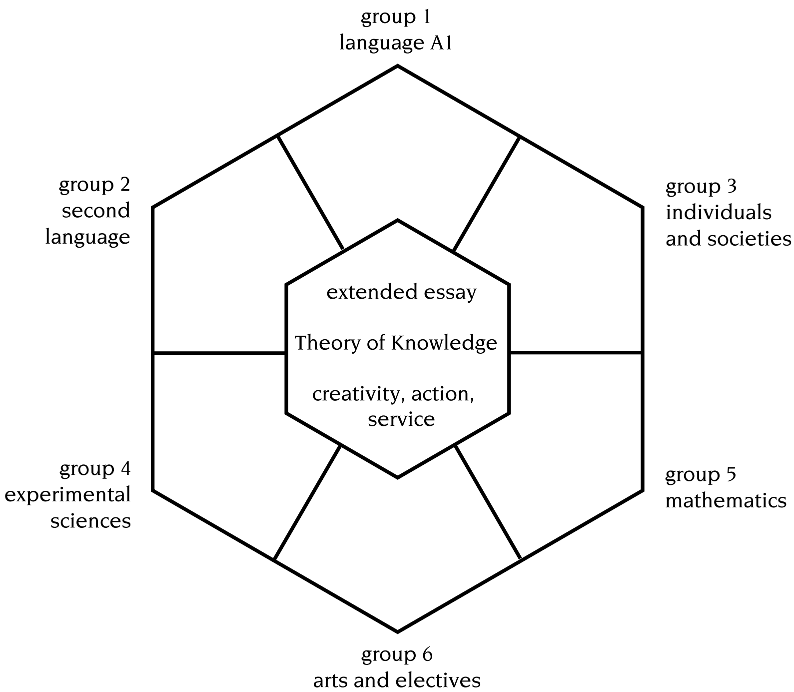
PART 1—GROUP 4

INTRODUCTION

The International Baccalaureate Diploma Programme is a rigorous pre-university course of studies, leading to examinations, that meets the needs of highly motivated secondary school students between the ages of 16 and 19 years. Designed as a comprehensive two-year curriculum that allows its graduates to fulfill requirements of various national education systems, the Diploma Programme model is based on the pattern of no single country but incorporates the best elements of many. The programme is available in English, French and Spanish.

The curriculum is displayed in the shape of a hexagon with six academic areas surrounding the core. Subjects are studied concurrently and students are exposed to the two great traditions of learning: the humanities and the sciences.

Diploma Pro



Diploma Programme candidates are required to select one subject from each of the six subject groups. At least three and not more than four are taken at higher level (HL), the others at standard level (SL). Higher level courses represent 240 teaching hours; standard level courses cover 150 hours. By arranging work in this fashion, students are able to explore some subjects in depth and some more broadly over the two-year period; this is a deliberate compromise between the early specialization preferred in some national systems and the breadth found in others.

Distribution requirements ensure that the science-orientated student is challenged to learn a foreign language and that the natural linguist becomes familiar with science laboratory procedures. While overall balance is maintained, flexibility in choosing higher level combinations allows the student to pursue areas of personal interest and to meet special requirements for university entrance.

Successful Diploma Programme candidates meet three requirements in addition to the six subjects. The interdisciplinary Theory of Knowledge (TOK) course is designed to develop a coherent approach to learning which transcends and unifies the academic areas and encourages appreciation of other cultural perspectives. The extended essay of some 4000 words offers the opportunity to investigate a topic of special interest and acquaints students with the independent research and writing skills expected at university. Participation in the creativity, action, service (CAS) requirement encourages students to be involved in artistic pursuits, sports and community service work.

For first examinations in 2003

CURRICULUM MODEL

A common curriculum model applies to all the Diploma Programme group 4 subjects: biology, chemistry, environmental systems, physics and design technology. (There are some differences in this model for design technology and these arise from the design project, a unique feature of this subject. A double asterisk (**) indicates where these differences occur.) A core of material is studied by both higher level and standard level students in all subjects, and this is supplemented by the study of options. Higher level students also study additional higher level (AHL) material. Higher level students and SL students both study two options. There are three kinds of options: those specific to SL students, those specific to HL students and those which can be taken by both SL and HL students. Schools wishing to develop their own school-based option should contact the IBCA office in the first instance.

This curriculum model is not designed to favour the teaching of SL and HL students together. The IBO does not support the joint teaching of students at different levels as this does not provide the greatest educational benefit for either level.

Higher level students are required to spend 60 hours, and SL students 40 hours, on practical/ investigative work**. This includes 10 to 15 hours for the group 4 project.

Group 4 Curriculum Model HL **

HL	Total teaching hours	240
Theory		**180**
	Core	80
	Additional higher level (AHL)	55
	Options	45
Internal assessment (IA)		**60**
	Investigations	45–50
	Group 4 project	10–15

Group 4 Curriculum Model SL **

SL	Total teaching hours	**150**
Theory		**110**
	Core	80
	Options	30
Internal assessment (IA)		**40**
	Investigations	25–30
	Group 4 project	10–15

Format of the Syllabus Details

Note: The order in which the syllabus content is presented is not intended to represent the order in which it should be taught.

The format of the syllabus details section of the group 4 guides is the same for each subject. The structure is as follows.

Topics or Options

Topics are numbered and options are indicated by a letter (eg Topic 6: Nucleic Acids and Proteins or Option C: Cells and Energy).

Sub-topics

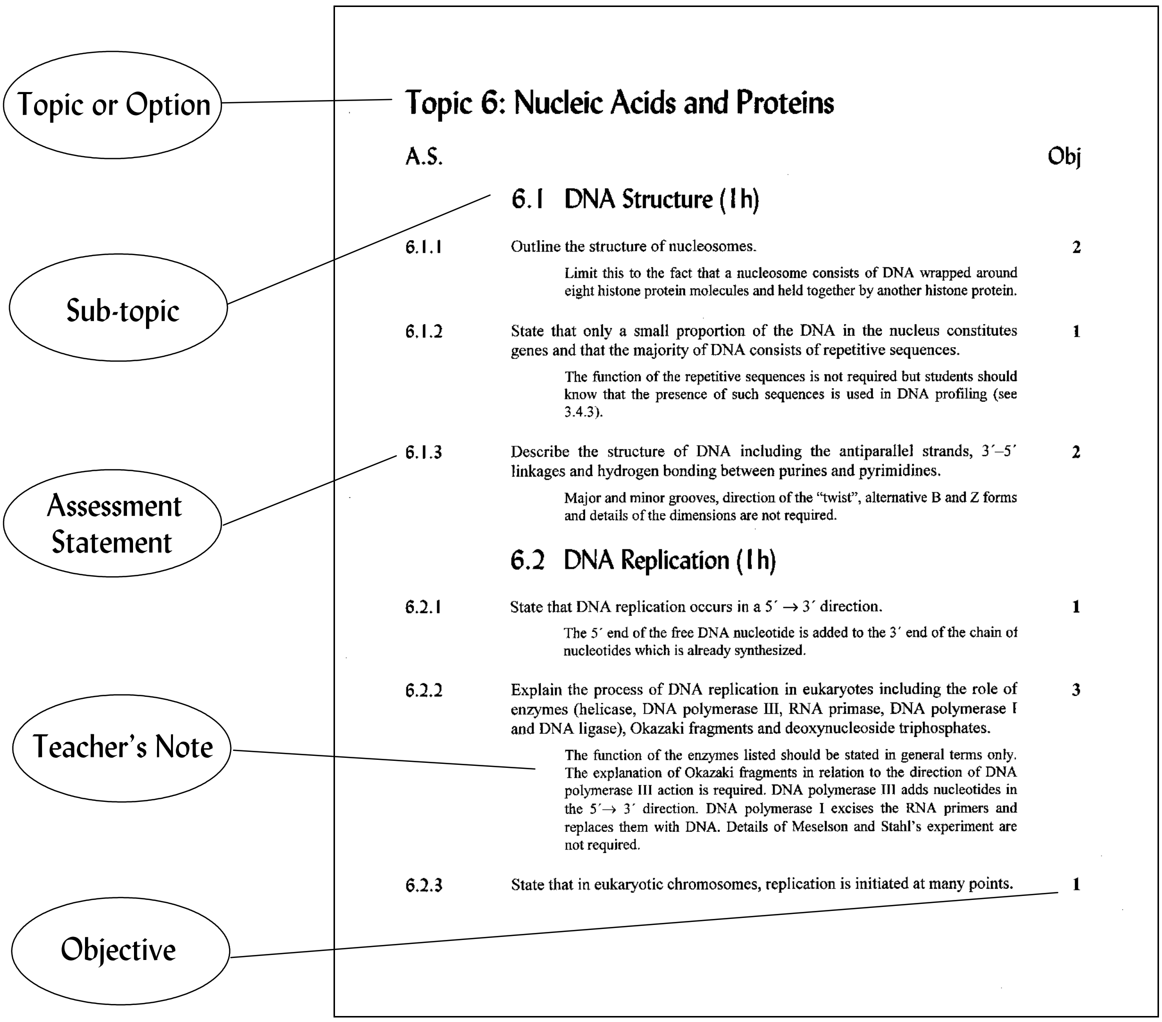
Sub-topics are numbered and the estimated teaching time required to cover the material is indicated (eg 6.1 DNA Structure (1h)). The times are for guidance only and do not include time for practical/investigative work.

Assessment Statements (A.S.)

Assessment statements, which are numbered, are expressed in terms of the outcomes that are expected of students at the end of the course (eg 6.1.1 Outline the structure of nucleosomes). These are intended to prescribe to examiners what can be assessed by means of the written examinations. Each one is classified as objective 1, 2 or 3 (see page 7) according to the action verb(s) used (see page 8). The objective levels are relevant for the examinations and for balance within the syllabus, while the action verbs indicate the depth of treatment required for a given assessment statement. It is important that students are made aware of the meanings of the action verbs since these will be used in examination questions.

Teacher's Notes

Teacher's notes, which are included below some assessment statements, provide further guidance to teachers.



Topic 6: Nucleic Acids and Proteins

A.S.		Obj
	6.1 DNA Structure (1 h)	
6.1.1	Outline the structure of nucleosomes.	2
	Limit this to the fact that a nucleosome consists of DNA wrapped around eight histone protein molecules and held together by another histone protein.	
6.1.2	State that only a small proportion of the DNA in the nucleus constitutes genes and that the majority of DNA consists of repetitive sequences.	1
	The function of the repetitive sequences is not required but students should know that the presence of such sequences is used in DNA profiling (see 3.4.3).	
6.1.3	Describe the structure of DNA including the antiparallel strands, 3′–5′ linkages and hydrogen bonding between purines and pyrimidines.	2
	Major and minor grooves, direction of the "twist", alternative B and Z forms and details of the dimensions are not required.	
	6.2 DNA Replication (1 h)	
6.2.1	State that DNA replication occurs in a 5′ → 3′ direction.	1
	The 5′ end of the free DNA nucleotide is added to the 3′ end of the chain of nucleotides which is already synthesized.	
6.2.2	Explain the process of DNA replication in eukaryotes including the role of enzymes (helicase, DNA polymerase III, RNA primase, DNA polymerase I and DNA ligase), Okazaki fragments and deoxynucleoside triphosphates.	3
	The function of the enzymes listed should be stated in general terms only. The explanation of Okazaki fragments in relation to the direction of DNA polymerase III action is required. DNA polymerase III adds nucleotides in the 5′→ 3′ direction. DNA polymerase I excises the RNA primers and replaces them with DNA. Details of Meselson and Stahl's experiment are not required.	
6.2.3	State that in eukaryotic chromosomes, replication is initiated at many points.	1

AIMS

Through studying any of the 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 will generally involve the formation, testing and modification of hypotheses through observation and measurement, under the controlled conditions of an experiment. It is this approach, along with the falsifiability of scientific hypotheses, that distinguishes the experimental sciences from other disciplines and characterizes each of the subjects within group 4.

It is in this context that all the Diploma Programme experimental science courses should aim to:

1. provide opportunities for scientific study and creativity within a global context which will stimulate and challenge students

2. provide a body of knowledge, methods and techniques which characterize science and technology

3. enable students to apply and use a body of knowledge, methods and techniques which characterize science and technology

4. develop an ability to analyse, evaluate and synthesize scientific information

5. engender an awareness of the need for, and the value of, effective collaboration and communication during scientific activities

6. develop experimental and investigative scientific skills

7. develop and apply the students' information technology skills in the study of science

8. raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology

9. develop an appreciation of the possibilities and limitations associated with science and scientists

10. encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method.

OBJECTIVES

The objectives for all group 4 subjects reflect those parts of the aims that will be assessed. Wherever appropriate, the assessment will draw upon environmental and technological contexts and identify the social, moral and economic effects of science.

It is the intention of all the Diploma Programme experimental science courses that students should achieve the following objectives.

1. Demonstrate an understanding of:
   a. scientific facts and concepts
   b. scientific methods and techniques
   c. scientific terminology
   d. methods of presenting scientific information.
2. Apply and use:
   a. scientific facts and concepts
   b. scientific methods and techniques
   c. scientific terminology to communicate effectively
   d. appropriate methods to present scientific information.
3. Construct, analyse and evaluate:
   a. hypotheses, research questions and predictions
   b. scientific methods and techniques
   c. scientific explanations.
4. Demonstrate the personal skills of cooperation, perseverance and responsibility appropriate for effective scientific investigation and problem solving.
5. Demonstrate the manipulative skills necessary to carry out scientific investigations with precision and safety.

ACTION VERBS

These action verbs indicate the depth of treatment required for a given assessment statement. These verbs will be used in examination questions and so it is important that students are familiar with the following definitions.

Objective 1

Define	give the precise meaning of a word or phrase as concisely as possible
Draw	represent by means of pencil lines (add labels unless told not to do so)
List	give a sequence of names or other brief answers with no elaboration, each one clearly separated from the others
Measure	find a value for a quantity
State	give a specific name, value or other brief answer (no supporting argument or calculation is necessary)

Objective 2

Annotate	add brief notes to a diagram, drawing or graph
Apply	use an idea, equation, principle, theory or law in a new situation
Calculate	find an answer using mathematical methods (show the working unless instructed not to do so)
Compare	give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout (comparisons can be given using a table)
Describe	give a detailed account, including all the relevant information
Distinguish	give the differences between two or more different items
Estimate	find an approximate value for an unknown quantity, based on the information provided and scientific knowledge
Identify	find an answer from a number of possibilities
Outline	give a brief account or summary (include essential information only)

Objective 3

Analyse	interpret data to reach conclusions
Construct	represent or develop in graphical form
Deduce	reach a conclusion from the information given
Derive	manipulate a mathematical equation to give a new equation or result
Design	produce a plan, object, simulation or model
Determine	find the only possible answer
Discuss	give an account including, where possible, a range of arguments, assessments of the relative importance of various factors or comparisons of alternative hypotheses
Evaluate	assess the implications and limitations
Explain	give a clear account including causes, reasons or mechanisms
Predict	give an expected result
Solve	obtain an answer using algebraic and/or numerical methods
Suggest	propose a hypothesis or other possible answer

INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

The role of computers in developing and applying scientific knowledge is well established. Scientists make measurements, handle information and model ideas. They need to process information and communicate it effectively.

Why Use Computers in Science?

Skills in handling information are clearly important life skills. The use of ICT will enhance learning, increase awareness of the technology scientists use for processing information and prepare students better for a rapidly changing situation in the real world. Computers enable students to become more active participants in learning and research and offer a valuable resource for understanding the processes of science. Development of ICT skills will allow students to explore rich materials, access information quickly and easily and lead them into areas previously experienced only through the possession of higher order skills. The computer also allows the teacher more flexibility in both approach and presentation of materials. Creating an ICT culture in classrooms is an important endeavour for all schools.

It is for these reasons that the IBO has incorporated a new aim related to ICT for group 4—aim 7: develop and apply the students' information technology skills in the study of science.

When Should Computers be Used?

The use of computers should complement rather than replace hands-on practical work. However computers can be used in areas where a practical approach is inappropriate or limited.

For example: sensors may be used in data-logging to obtain data over long or very short periods of time, or in experiments that otherwise would not be feasible. Simulation software may be used to illustrate concepts and models which are not readily demonstrable in laboratory experiments because they require expensive equipment or materials that are hazardous or difficult to obtain. The experiments may also involve skills not yet achieved by students or which require more time than is available.

What Sort of Technologies are Available?

The technology for processing information includes such tools as word processors, spreadsheets, database programs, sensors and modelling programs.

Spreadsheets

These multipurpose programs may be used for generating results tables from experimental data, data handling, sorting and searching pre-existing data, and producing graphs. Perhaps their most interesting feature is their use in calculations and mathematical modelling.

Databases

Scientists use database programs to handle the vast amounts of data which may be generated in experiments, or to retrieve other scientists' data. The database may be on disc, CD-Rom or downloaded from the Internet. Scientists use their skills and experience to collect, organize and analyse data, look for patterns and check for errors. To appreciate the value of databases to the scientific community, students should be familiar with using a database to store, sort and graph data.

Data-logging

Sensors and control technology can help scientists by monitoring very fast or very slow changes. Data-logging has the advantage that students can see the data recorded in real time. They can therefore focus on the trends and patterns that emerge rather than on the process of gathering the data. Sensors can also measure with more precision allowing students to have greater confidence in their results.

Software for Modelling and Simulations

A wide range of software programs exist to model (amongst other things) photosynthesis, control of blood sugar, chemical equilibria, the cardiovascular system and wave phenomena such as interference and diffraction. Generic programs are also available which allow students to construct models of, for example, motion and gravity, heat loss or populations in an ecosystem. Some of these programs are available via the Internet.

The Internet, CD-Roms, DVDs and Multimedia

The powerful combination of the spoken word, animation and video in these multimedia products clearly motivates and stimulates the user. Interactive multimedia has considerable potential to link different representations and ways of learning to facilitate understanding in science. It provides information that can be selected or rejected, and search facilities allow many different routes through the material which illustrate new links and patterns.

There is clearly added value in the use of interactive multimedia through visualization and differentiation. To be able to represent visually, for example, the dynamic aspects of kinetic theory or electron movements, helps students imagine the situation and aids the learning of difficult concepts. This complements more traditional teaching approaches.

Word Processing and Graphics

Word processing is not merely a means of writing in electronic form. It can improve the quality of written work from the initial listing of ideas, their development and reworking, through to the final product. Drawing programs, scanners, digital cameras, video cameras, desktop publishing, multimedia authoring and CAD/CAM software also have their place, particularly in design technology and perhaps more widely through the group 4 project.

Internationalism

The ease and widespread use of e-mail should encourage the networking of teachers and students, and this replicates the networking activities of the science community. E-mail (and web sites) could be used to collaborate with other schools world wide, perhaps as part of the group 4 project, or in established collaborative ventures such as the Science Across the World and Globe programs.

Ethical and Moral Dimension

This dimension of the use of ICT need not be made explicit in the group 4 subjects as students will be exposed to it through Theory of Knowledge (TOK), and it will also emerge in the day-to-day experiences of students inside and outside school. Such issues as plagiarism of extended essays, firewalls to prevent access to undesirable web sites, hacking, anti-social behaviour in local networks and on the Internet, privacy of information in databases, freedom of information and web site subscriptions may be encountered.

How to Proceed

Because of the variability of both hardware and software between IB schools, the use of ICT will not be monitored or assessed. For this reason, there is no new objective related to ICT in group 4. However, it is vital to encourage ICT use and to stress its importance in any modern science curriculum. (One common element is the use of graphic calculators in some IB Diploma Programme mathematics courses. This allows for portable, low cost data-logging, modelling and graph plotting.) The IB community can help disseminate ideas and guidance through its workshops and the online curriculum centre.

For further information teachers should access:

- the online curriculum centre to find up-to-date and relevant resources and web site addresses, and to share experiences and resources with other IB teachers
- the web sites of national and international educational bodies promoting ICT
- the web sites of the main educational suppliers and specialized educational software and hardware suppliers, many of whom now operate internationally.

EXTERNAL ASSESSMENT

The external assessment consists of three written papers.

Paper 1

Paper 1 is made up of multiple-choice questions which test knowledge of the core and additional higher level (AHL) material for higher level (HL) students and the core only for standard level (SL) students. The questions are designed to be short, one- or two-stage problems which address objectives 1 and 2 (see page 7). No marks are deducted for incorrect responses. Calculators are not permitted, but students are expected to carry out simple calculations.

Paper 2

Paper 2 tests knowledge of the core and AHL material for HL students and the core only for SL students. The questions address objectives 1, 2 and 3 and the paper is divided into two sections.

In section A, there is a data-based question which will require students to analyse a given set of data. The remainder of section A is made up of short-answer questions.

In section B, students are expected to answer two questions from a choice of four at HL** or one question from a choice of three at SL. These extended response questions may involve writing a number of paragraphs, solving a substantial problem, or carrying out a substantial piece of analysis or evaluation. A calculator is required for this paper.

Paper 3

Paper 3 tests knowledge of the options and addresses objectives 1, 2 and 3. At HL, students will answer several short-answer questions and an extended response question in each of the two options studied. At SL, students answer several short-answer questions in each of the two options studied. A calculator is required for this paper. (In biology, students will also answer a data-based question in each of the two options studied.)

The assessment specifications at HL and SL are summarized on the next page.

There are some variations in external assessment requirements for design technology, arising from the design project. A double asterisk(**) indicates where these variations occur. See the design technology guide for details.

Note: Wherever possible teachers should use, and encourage students to use, the Système International d'Unités (International System of Units—SI units).

Assessment Specifications—Standard Level **

Component	Overall Weighting (%)	Approximate Weighting of Objectives 1+2	3	Duration (hours)	Format and Syllabus Coverage
Paper 1	20	20		¾	30 multiple-choice questions on the core
Paper 2	32	16	16	1¼	Section A: one data-based question and several short-answer questions on the core (all compulsory) Section B: one extended response question on the core (from a choice of three)
Paper 3	24	12	12	1	several short-answer questions in each of the two options studied (all compulsory)

Assessment Specifications—Higher Level **

Component	Overall Weighting (%)	Approximate Weighting of Objectives 1+2	3	Duration (hours)	Format and Syllabus Coverage
Paper 1	20	20		1	40 multiple-choice questions (± 15 common to SL plus about five more on the core and about 20 more on the AHL)
Paper 2	36	18	18	2¼	Section A: one data-based question and several short-answer questions on the core and the AHL (all compulsory) Section B: two extended response questions on the core and AHL (from a choice of four)
Paper 3	20	10	10	1¼	several short-answer questions and one extended response question in each of the two options studied (all compulsory)

For both SL and HL, calculators are not permitted in paper 1 but are required in papers 2 and 3, where programmable graphic display calculators are allowed.

INTERNAL ASSESSMENT

General Introduction

The internal assessment (IA) requirements are the same for all group 4 subjects, with the exception of design technology which has an additional element. The IA, worth 24% of the final assessment (design technology 36%) consists of an interdisciplinary project, a mixture of short- and long-term investigations (such as practicals and subject-specific projects) and, for design technology only, the design project

Student work is internally assessed by the teacher and externally moderated by the IBO. The performance in IA at both higher level and standard level is judged against assessment criteria each consisting of achievement levels 0–3.

Rationale for Practical Work

Although the requirements for IA are mainly centred on the assessment of practical skills, the different types of experimental work 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 scientific work
- developing an appreciation of the benefits and limitations of scientific methodology.

Therefore, there may be good justification for teachers to conduct further experimental work beyond that required for the IA scheme.

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. Higher level and standard level candidates in the same subject may carry out some of the same investigations and, where more than one group of students is taught in a subject and level, common investigations are acceptable.

Syllabus Coverage

The range of investigations 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 candidates must participate in the group 4 project and the IA activities should ideally include a spread of content material from the core, options and, where relevant, AHL material. A minimum number of investigations to be carried out is not specified.

Choosing Investigations

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

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.

Teachers should not feel that all investigations must form part of the practical scheme of work, however their scheme must meet the IB requirements. Each scheme must include at least a few complex investigations which make greater conceptual demands on the 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.

Teachers are encouraged to use the online curriculum centre to share ideas about possible investigations by joining in the discussion forums and adding resources they use onto the relevant sections of the online subject guides.

> Note: Any investigation or part investigation that is to be used to assess candidates should be specifically designed to match the relevant assessment criteria.

Flexibility

The IA model is flexible enough to allow a wide variety of investigations to be carried out. These could include:

- short laboratory practicals over one or two lessons and long-term practicals or projects extending over several weeks
- computer simulations
- data-gathering exercises such as questionnaires, user trials and surveys
- data analysis exercises
- general laboratory and fieldwork.

The Group 4 Project

The group 4 project is an interdisciplinary activity in which all Diploma Programme science students must participate. The intention is that students analyse a topic or problem which can be investigated in each of the science disciplines offered by a school. The exercise should be a collaborative experience where the emphasis is on the **processes** involved in scientific investigation rather than the **products** of such investigation.

In most cases all 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, ie there may be several group 4 projects in the same school.

Design Technology

In design technology, each student must carry out the design project in addition to several investigations and the group 4 project. Higher level students are required to spend 31 hours on the design project and SL students 19 hours.

Practical Work Documentation

Details of an individual student's practical scheme of work are recorded on **form 4/PSOW** provided in the *Vade Mecum*, section 4. Electronic versions may be used as long as they include all necessary information.

In design technology, each candidate must compile a log book. This is a candidate's record of his/her development of the design project and an informal personal record of investigative activities.

IA Time Allocation

The recommended teaching times for the IB Diploma Programme courses are 240 hours for HL and 150 hours for SL. Higher level students are required to spend 60 hours, and SL students 40 hours, on practical activities (excluding time spent writing up work). These times include 10 to 15 hours for the group 4 project.

Note: For design technology, HL students are required to spend 81 hours, and SL students 55 hours, on practical activities.

The time allocated to IA activities should be spread throughout most of the course and not confined to just a few weeks at the beginning, middle or end. Only 2–3 hours of investigative work can be carried out after the deadline for submission of work to the moderator and still be counted in the total hours for the practical scheme of work.

Guidance and Authenticity

All candidates should be familiar with the requirements for IA. It should be made clear to them that they are entirely responsible for their own work. It is helpful if teachers encourage candidates to develop a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work. In responding to specific questions from candidates concerning investigations, teachers should (where appropriate) guide candidates into more productive routes of enquiry rather than respond with a direct answer.

When completing an investigation outside the classroom candidates should work independently where possible. Teachers are required to ensure that work submitted is the candidate's own. If in doubt, authenticity may be checked by one or more of the following methods:

- discussion with the candidate
- asking the candidate to explain the methods used and to summarize the results
- asking the candidate to repeat the investigation.

Safety

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

ICASE Safety Committee

Mission Statement

The mission of the ICASE Safety Committee is to promote good quality, exciting practical science, which will stimulate students and motivate their teachers, in a safe and healthy learning environment. In this way, all individuals (teachers, students, laboratory assistants, supervisors, visitors) involved in science education are entitled to work under the safest possible practicable conditions in science classrooms and laboratories. Every reasonable effort needs to be made by administrators to provide and maintain a safe and healthy learning environment and to establish and require safe methods and practices at all times. Safety rules and regulations need to be developed and enforced for the protection of those individuals carrying out their activities in science classrooms and laboratories, and experiences in the field. Alternative science activities are encouraged in the absence of sufficiently safe conditions.

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.

Criteria and Aspects

There are eight assessment criteria which are used to assess the work of both higher level and standard level candidates:

- *planning (a)*—Pl (a)
- *planning (b)*—Pl (b)
- *data collection*—DC
- *data processing and presentation*—DPP
- *conclusion and evaluation*—CE
- *manipulative skills*—MS
- *personal skills (a)*—PS (a)
- *personal skills (b)*—PS (b)

Each candidate must be assessed at least twice on each of the eight criteria. The two marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This will then be scaled at IBCA to give a total out of 24%.

General regulations and procedures relating to IA can be found in the *Vade Mecum*.

Each of the assessment criteria can be separated into two or three **aspects** as shown on the following pages. Descriptions are provided to indicate what is expected in order to meet the requirements of a given aspect **completely (c)** and **partially (p)**. A description is also given for circumstances in which the requirements are not satisfied, **not at all (n)**.

Planning (a)

	ASPECTS		
LEVELS	Defining the problem or research question	Formulating a hypothesis or prediction	Selecting variables
Complete	Identifies a focused problem or research question.	Relates the hypothesis or prediction directly to the research question and explains it, quantitatively where appropriate.	Selects the relevant independent and controlled variable(s).
Partial	States the problem or research question, but it is unclear or incomplete.	States the hypothesis or prediction but does not explain it.	Selects some relevant variables.
Not at all	Does not state the problem or research question **or** repeats the general aim provided by the teacher.	Does not state a hypothesis or prediction.	Does not select any relevant variables.

Planning (b)

	ASPECTS		
LEVELS	Selecting appropriate apparatus or materials*	Designing a method for the control of variables	Designing a method for the collection of sufficient relevant data
Complete	Selects appropriate apparatus or materials.	Describes a method that allows for the control of the variables.	Describes a method that allows for the collection of sufficient relevant data.
Partial	Selects some appropriate apparatus or materials.	Describes a method that makes some attempt to control the variables.	Describes a method that allows for the collection of insufficient relevant data.
Not at all	Does not select any apparatus or materials.	Describes a method that does not allow for the control of the variables.	Describes a method that does not allow any relevant data to be collected.

* suitable diagrams are acceptable

Data Collection

	ASPECTS	
LEVELS	Collecting and recording raw data	Organizing and presenting raw data
Complete	Records appropriate raw data (qualitative and/or quantitative), including units and uncertainties where necessary.	Presents raw data clearly, allowing for easy interpretation.
Partial	Records some appropriate raw data.	Presents raw data but does not allow for easy interpretation.
Not at all	Does not record any appropriate raw data.	Does not present raw data **or** presents it incomprehensibly.

Data Processing and Presentation

	ASPECTS	
LEVELS	Processing raw data	Presenting processed data
Complete	Processes the raw data correctly.	Presents processed data appropriately, helping interpretation and, where relevant, takes into account errors and uncertainties.
Partial	Some raw data is processed correctly.	Presents processed data appropriately but with some errors and/or omissions.
Not at all	No processing of raw data is carried out **or** major errors are made in processing.	Presents processed data inappropriately **or** incomprehensibly.

Conclusion and Evaluation

	ASPECTS		
LEVELS	Drawing conclusions	Evaluating procedure(s) and results	Improving the investigation
Complete	Gives a valid conclusion, based on the correct interpretation of the results, with an explanation and, where appropriate, compares results with literature values.	Evaluates procedure(s) and results including limitations, weaknesses or errors.	Identifies weaknesses and states realistic suggestions to improve the investigation.
Partial	States a conclusion that has some validity.	Evaluates procedure(s) and results but misses some obvious limitations or errors.	Suggests only simplistic improvements.
Not at all	Draws a conclusion that misinterprets the results.	The evaluation is superficial **or** irrelevant.	Suggests unrealistic improvements.

Manipulative Skills

	ASPECTS	
LEVELS	Carrying out techniques safely	Following a variety of instructions*
Complete	Is competent and methodical in the use of the technique(s) and the equipment, and pays attention to safety issues.	Follows the instructions accurately, adapting to new circumstances (seeking assistance when required).
Partial	Requires assistance in the use of a routine technique. Works in a safe manner with occasional prompting.	Follows the instructions but requires assistance.
Not at all	Does not carry out the technique(s) **or** misuses the equipment, showing no regard for safety.	Does not follow the instructions **or** requires constant supervision.

* Instructions may be given in a variety of forms: oral, written worksheets, diagrams, photographs, videos, flowcharts, audiotapes, models, computer programs etc.

Personal Skills (a)

	ASPECTS		
LEVELS	Working within a team*	Recognizing the contributions of others	Exchanging and integrating ideas
Complete	Collaborates with others, recognizing their needs, in order to complete the task.	Expects, actively seeks and acknowledges the views of others.	Exchanges ideas with others, integrating them into the task.
Partial	Requires guidance to collaborate with others.	Acknowledges some views.	Exchanges ideas with others but requires guidance in integrating them into the task.
Not at all	Is unsuccessful when working with others.	Disregards views of others.	Does not contribute.

* A team is defined as two or more people.

Personal Skills (b)

	ASPECTS		
LEVELS	Approaching scientific investigations with self-motivation and perseverance	Working in an ethical manner	Paying attention to environmental impact
Complete	Approaches the investigation with self-motivation and follows it through to completion.	Pays considerable attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays considerable attention to the environmental impact of the investigation.
Partial	Approaches the investigation with self-motivation or follows it through to completion.	Pays some attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays some attention to the environmental impact of the investigation.
Not at all	Lacks perseverance and motivation.	Pays little attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays little attention to the environmental impact of the investigation.

Achievement Level Matrixes

For a particular criterion, a piece of work is judged to see whether the requirements of each aspect have been fulfilled completely, partially or not at all. This can then be translated into an achievement level 0, 1, 2 or 3 using the achievement level matrixes below. The lowest level of achievement is represented by 0, and 3 represents the highest level of achievement.

Planning (a), Planning (b), Conclusion and Evaluation, Personal Skills (a), Personal Skills (b)

The matrix below refers to *planning (a)*, *planning (b)*, *conclusion and evaluation*, *personal skills (a)* and *personal skills (b)*, where each criterion has three aspects.

Level	3			2			2			2			1		
Completely	✓	✓	✓	✓	✓		✓	✓		✓					
Partially						✓					✓	✓	✓	✓	✓
Not at all									✓						
	Aspects			Aspects			Aspects			Aspects			Aspects		
Level	1			1			1			0			0		
Completely	✓			✓											
Partially		✓					✓	✓		✓					
Not at all			✓		✓	✓			✓		✓	✓	✓	✓	✓
	Aspects			Aspects			Aspects			Aspects			Aspects		

Data Collection, Data Processing and Presentation, Manipulative Skills

The matrix below applies to *data collection*, *data processing and presentation*, and *manipulative skills*, where each criterion has two aspects.

Level	3		2		1		1		0		0	
Completely	✓	✓	✓		✓							
Partially				✓			✓	✓	✓			
Not at all						✓				✓	✓	✓
	Aspects		Aspects		Aspects		Aspects		Aspects		Aspects	

Guidance on the Criteria

Planning (a)

It is generally not appropriate to assess *planning (a)* for most experiments or investigations found in standard textbooks, unless the experiments are modified. It is essential that students are given an open-ended problem to investigate. Although the general aim of the investigation may be provided by the teacher, students must be able to identify a focused problem or specific research question.

For example, the teacher might present the aim of the investigation generally in the form "investigate the factors that affect X". Students should be able to recognize that certain factors will influence X and clearly define the aim of the experiment or identify a focused research question. A hypothesis or prediction should then be formulated in the light of any independent variables that have been chosen. Such a hypothesis must contain more than just an expected observation. It must include a proposed relationship between two or more variables, or at least an element of rational explanation for an expected observation, the basis of which can be investigated experimentally. A typical formulation for a hypothesis might be "if *y* is done, then *z* will occur". Other variables that might affect the outcome should also be mentioned, even if they are not to be specifically investigated. Controlled variables should also be selected.

Planning (b)

The student must design a realistic and appropriate method that allows for the control of variables and the collection of sufficient relevant data. The experimental set-up and measurement techniques must be described.

Data Collection

Data collection skills are important in accurately recording observed events and are critical to scientific investigation. Data collection involves all quantitative or qualitative raw data, such as a column of results, written observations or a drawing of a specimen. Qualitative data is defined as those observed with more or less unaided senses (colour, change of state, etc) or rather crude estimates (hotter, colder, etc), whereas quantitative data implies actual measurements.

Investigations should allow students opportunities to deal with a wide range of observations and data. It is important that the practical scheme of work includes:

- the collection of qualitative and quantitative data
- various methods or techniques
- different variables (time, mass, etc)
- various conditions
- subject-specific methods of collection.

In addition:

- attention to detail should be reflected in the accuracy and precision of the data recorded
- use of data collection tables should be encouraged
- methods of collection and the measurement techniques must be appropriate to each other
- units of measurement must be relevant to the task at hand.

Data Processing and Presentation

The practical scheme of work should provide sufficient investigations to enable a variety of methods of data processing to be used.

Students should also be exposed to the idea of error analysis. That is not to say that error analysis must be carried out for every investigation, nor should it overshadow the purpose of an investigation.

Students should show that they can take raw data, transform it and present it in a form suitable for evaluation.

Processing raw data may include:

- subjecting raw data to statistical calculations (eg producing percentages or means), with the calculations correct and accurate to the level necessary for evaluation
- converting drawings into diagrams
- converting tabulated data into a graphical form
- correctly labelling drawings
- sketching a map from measurements and observations in land form
- proceeding from a sketched idea to a working drawing (eg orthographic projection or sectional views).

The data should be presented so that the pathway to the final result can be followed. Features which should be considered when presenting data include:

- quality of layout (eg choice of format, neatness)
- choice of correct presentation (eg leave as a table, convert to a graph, convert to a flow diagram)
- use of proper scientific conventions in tables, drawings and graphs
- provision of clear, unambiguous headings for drawings, tables or graphs.

Conclusion and Evaluation

Once the data has been processed and presented in a suitable form, the results can be interpreted, conclusions can be drawn and the method evaluated.

Students are expected to:

- analyse and explain the results of experiments and draw conclusions
- evaluate the results.

Analysis may include comparisons of different graphs or descriptions of trends shown in graphs.

Students are also expected to evaluate the procedure they adopted, specifically looking at:

- the processes
- use of equipment
- management of time.

Modifications to improve the investigation should be suggested.

Manipulative Skills

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s), the ability to follow the instructions accurately and adherence to safe working practices.

Personal Skills (a)

Working in a team is when two or more students work on a task collaboratively, face-to-face, with individual accountability. Effective teamwork includes recognizing the contributions of others, which begins with each member of the team expecting every other member to contribute. The final product should be seen as something that has been achieved by all members of the team participating in the tasks involved. Encouraging the contributions of others implies not only recognizing, but also actively seeking, contributions from reluctant or less confident members of the team.

Personal Skills (b)

Issues such as plagiarism, the integrity of data collection and data analysis, may be considered here. Sources of data should be acknowledged and data must be reported accurately, even when anomalous or when an experiment has not given rise to the results expected. Due attention to environmental impact may be demonstrated in various ways including avoidance of wastage, using proper procedures for disposal of waste, and minimizing damage to the local environment when conducting experiments.

Assessing an Investigation

In assessing an investigation it must be noted that:

- the same standards must be applied to both HL and SL students
- level 3 does not imply faultless performance
- only whole numbers should be awarded, not fractions or decimals.

The work being assessed must be that of the student. For example in work on *planning (a)*, the student should define the problem, formulate the hypothesis and select the variables; this information should not be provided by the teacher. In work on *data collection*, the student must decide how to collect, record, organize and present the raw data. The teacher should not, for instance, specify how the data should be acquired or provide a table in which the data is recorded. This principle extends to the other criteria.

To illustrate the use of the achievement level matrixes, consider the following example. A student's work is assessed against the criterion *data processing and presentation*. The teacher feels that the first aspect, *processing raw data*, is met completely whereas the second aspect, *presenting processed data*, is only achieved partially. Using the achievement level matrix for *data processing and presentation*, this translates to a level of 2.

THE GROUP 4 PROJECT

Summary of the Group 4 Project

The group 4 project allows students to appreciate the environmental, social and ethical implications of science. 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 exercise should be a collaborative experience where concepts and perceptions from across the group 4 disciplines are shared. The intention is that students analyse a topic or problem which can be investigated in each of the science disciplines offered by a school. The topic can be set in a local, national or international context.

Project Stages

The 10–15 hours allocated to the group 4 project, which are part of the teaching time set aside for internal assessment, can be divided into four stages: planning, definition of activities, action and evaluation.

Planning

This stage is crucial to the whole exercise and should last 2–4 hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all science 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 discipline 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.

Definition of Activities

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. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

Action

This stage should take 6–8 hours in total 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.

- The students (as individuals, single subject groups or mixed subject groups) should investigate the topic from the perspective of the individual science disciplines.
- There should be collaboration in the action stage; findings of investigations should be shared with others working on the project. This may be difficult if the action stage takes place during normal lessons, but it is possible to use bulletin boards (either physical or electronic) to exchange information or to use times when students are together, such as lunchtimes. Enthusiastic students will no doubt share information informally.
- During this stage it is important to pay attention to safety, ethical and environmental considerations.

Evaluation

The emphasis during this stage, for which 2–4 hours is 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 (perhaps with the aid of an overhead projector, flip charts, posters, video player, computers, etc).
- 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 student or 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.

In addition to the presentation, each student must show evidence of their participation in the project.

Preparation

The impact the project has on the organization of the school is an important consideration. The key is the formulation of an action plan, perhaps in the form of a list of questions, to help draw up a strategy for all the activities involved. The following are suggestions for such a list (these could be adapted to suit the needs of an individual school).

- How might a topic be selected? Possibilities are a questionnaire to students, discussions with students and/or teacher selection.
- Will teachers from other non-science departments be involved?
- Will people from outside the school be used as a source of ideas for the project? If so, what is their availability?
- What communication methods are available for the coordination of activities, exchange of data and joint presentations?
- When should the project be conducted, and over what time period?
- What are the implications in terms of staff and resources?

Strategies

Considerations

Teachers will find that there are many factors to consider when planning the project work, besides deciding at what point to carry out the project and what the starting and completion dates should be. These factors include:

- the way the school's year is organized into terms or semesters
- the number of sciences offered
- the number of IB students
- whether or not the school wishes to collaborate with other schools either locally, nationally or internationally.

The needs of the students should be of foremost importance when weighing up the advantages and disadvantages of the various possibilities.

Ensuring that carrying out the project is a group experience (not restricted to a single science in group 4) may present organizational problems for some schools. The options may be limited because, for example, there is a small number of students, only one science is offered or other IB schools are some distance away. Teachers should take into account factors specific to their school and the general points made in this section when planning their strategies.

Timing

The time-span for carrying out the project is not a full two years.

- The project must be finished, at the latest, 19 months after starting teaching. Therefore, allowing for the planning stages, there may only be 18 months during which the project can be carried out. In the case of those completing the course in one year, such as anticipated SL candidates, the time available is limited further.
- Before starting work on the project students should, ideally, have some experience of working in a team.
- It is very important that students have reached a point where they have a certain degree of scientific knowledge and skills, and have experience of experimental techniques, before undertaking the project

The 10–15 hours that the IBO recommends should be allocated to 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 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 and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation 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 HL and SL

Where circumstances dictate that the project is only carried out every two years, HL beginners and more experienced SL students are combined.

General Strategies

1. Collaborate with other IB schools, including:
   - direct contact with local schools
   - post, fax, telephone, e-mail, video conferencing.

   This is particularly useful for small schools or those with a single science, and where schools have well-established contacts they wish to exploit, or new ones they wish to develop. Where schools in different countries are linked, the importance of internationalism can be reinforced.
2. Carry out the project only every two years so that first- and second-year students can work together to make a larger group, bearing in mind the restriction on timing. (This is perhaps only necessary for small schools and may be difficult in terms of timing.)
3. Encourage IB students to work with non-IB students in the school who may be following courses leading to national or other equivalent qualifications. (This may be useful for small schools or those with a single science.)
4. Encourage participation of local teachers or experts from local industries, businesses, colleges or universities. (This may be helpful to small schools or those distant from other IB schools.)
5. Collaborate with students taking group 3 subjects such as geography, psychology or economics. (This is only relevant to schools not offering the full IB Diploma Programme.)

Selecting a Topic

In most cases all students in a single school will 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, each undertaking their own project. The students may choose the topic or propose possible topics; teachers then decide which one is the most viable based on resources, staff availability etc. Alternatively, the teachers select the topic or propose 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 below. 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 the students.
- Conduct an initial “brainstorming” session of potential topics or issues.
- Discuss, for 10 minutes, two or three topics that seem interesting.
- Select one topic by consensus.
- Examine the topic. Students in each science subject write down relevant aspects that could be studied given the local circumstances, resources etc.
- Each subject group reads out their list and a master copy is made.
- Students in each discipline make a list of potential investigations that could be carried out. All students then discuss issues such as possible overlap and collaborative investigations.

Assessment

The group 4 project forms one part of a candidate's overall practical experience and does not contribute any fixed percentage to internal assessment. A school may choose:

- not to assess the project at all
- to assess the project according to the criteria for the school's local or national requirements
- to assess the project against one or more of the IB Diploma Programme internal assessment criteria.

The project may produce evidence for the full range of criteria, particularly *planning (a)* and *(b)*, and *personal skills (a)* and *(b)*.

Given the diverse nature of the activities associated with the project, it may be difficult for a single teacher to gain a fair overview of an individual student's contribution, especially in regard to *planning* and *personal skills*. It may be necessary for teachers to exchange observations and comments concerning student performance. Group, peer and self-evaluation can also contribute valuable extra information.

Participation

The evidence of a candidate's involvement in the project, required by the IBO in a moderation sample, can take a variety of forms. It must be accompanied by a copy of the written instructions and/or a summary of the verbal instructions given in relation to the project.

For each student in the moderation sample, the evidence may be:

- a statement written by the student about his/her own individual contributions
- a copy of a self-evaluation form
- a copy of a peer-evaluation form
- an individual laboratory report or complete project report
- rough work or a record of data collected by the student
- photographs, eg of a final poster produced by the group.

PART 2—ENVIRONMENTAL SYSTEMS

NATURE OF THE SUBJECT

The prime intent of this course is to provide students with a coherent perspective on the environment; one that is essentially scientific and that enables them to adopt an informed and responsible stance on the wide range of pressing environmental issues that they will inevitably come to face.

It is intended that students develop a profound understanding of the environment, rooted firmly in the underlying principles of science, rather than a purely journalistic appreciation of environmental issues. The course consequently acknowledges the value of empirical, quantitative and objective data in describing and analysing environmental systems.

This intent extends well beyond the academic. The course requires moral and political responses from the students. While this is possible in all the Diploma Programme science courses, environmental systems most easily (and necessarily) lends itself to the educational development of these domains. Students' attention can be constantly drawn to their own relationship with their environment and the significance of choices and decisions they make in their own lives. On a broader scale, the course naturally leads students to an appreciation of the nature and values of internationalism since the resolution of the major environmental issues rests heavily upon international relationships and agreements.

Overview of Structure

The course is structured in two sections: core and options. In general, the core encompasses the full scope of the subject while the options allow for a more detailed study of particular aspects. Both leave considerable freedom for schools to choose their own exemplar material to support the teaching of the required principles.

The order in which the syllabus is arranged is **not** the order in which it should be taught and it is up to individual teachers to decide on an arrangement that suits their circumstances. Option material may be taught within the core if desired.

Core

The core examines the fundamental structure and functioning of natural systems and the broad impacts of human activities. It begins by outlining the central concepts and terminology associated with a systems approach, including the definitions of systems, their equilibria and processes. These principles are then applied to the study of natural ecosystems, their component parts and the functional relationships that maintain their dynamic integrity. The same principles are then employed in an examination of "physical" systems of the atmosphere, hydrosphere and lithosphere.

In looking at the atmosphere, the relationship of the human species with the biosphere is considered in detail for the first time, and the three major human impacts are examined: ozone depletion, global warming and acid deposition. This continues with the human component of the biosphere, looking at human population growth and resource exploitation, and the combined implications these have on long-term stability.

Options

The first option (which each student must study) includes methodologies appropriate for the practical investigation and modelling of ecosystems. It is written in generic terms to enable schools to explore local marine, terrestrial, freshwater or urban ecosystems depending on which are most convenient for exemplifying particular topics. It involves field and laboratory techniques for the quantitative modelling of ecosystems. The generic terms employed in the writing of this option give schools the opportunity to select natural systems that are most accessible to them.

The remaining three options (of which each student must study one) look at specific environmental issues that have both local and global significance. They take a more detailed look at environmental issues that have already been introduced in the core material. The first of these options examines the methods and associated impacts of exploiting various energy and food resources, and includes a means of modelling the impact of resource exploitation by human settlements. The second explores the significance of biodiversity and what can, and is, being done to maintain it on both a local and global scale. The last option considers pollution from a variety of sources and how it may be measured, monitored and prevented.

Systems Approach

The systems approach is central to the course and has been employed for a number of reasons. The very nature of environmental issues demands a holistic treatment. In reality, an ecosystem functions as a whole and the traditional reductionist approach of science inevitably tends to overlook or, at least, understate this important quality. Furthermore, the systems approach is common to many disciplines (eg economics, geography, politics, ecology). It emphasizes the similarities between the ways in which matter, energy and information flow (not only in biological systems but in, for example, transport and communication systems). This approach therefore integrates the perspectives of different disciplines.

Local and Global Material

Another important aspect of the course is the balance of local and global material. The “local” has been included to enable students to identify with their immediate environment and become actively involved. The “global” is an important counterpart to provide the broader context within which the local material finds its significance.

Environmental Systems as an Experimental Science

Many environmental studies courses currently exist and the content and approach of these vary widely. To gain credibility as a science these courses must take a strictly quantitative and empirical approach. However, most environmental issues are far too complex to yield themselves fully to such treatment as they involve the less predictable aspects of human behaviour, politics and economics. A realistic and sensible study of these issues must therefore stray to some extent beyond the bounds of conventional scientific disciplines.

The systems methodology, with its focus on the formation of quantitative empirical models, parallels very closely the characteristic features of conventional scientific method. By employing this approach, a scientific rigour may more easily be maintained throughout the course. Appropriate manipulation and analysis of quantitative data and the testing and testability of models are expected from all elements of the course with the intention of meeting group 4 requirements.

Suggested Teaching Approach

There are a number of ways to teach this course successfully.

Practical Work

The single most important aspect is hands-on practical work, both in the laboratory and out in the field. The syllabus not only directly requires the use of field techniques, but many elements can only be covered effectively through this approach. The better practical scheme of work will be one that moves toward the holistic modelling of particular environments rather than using a series of isolated ecological exercises. If several techniques are employed to measure various components of a single ecosystem, the interrelatedness of these components can be examined and the final result may be a more integrated and holistic model.

Exemplar Material

To ensure the scientific nature of the subject it will be important throughout the course (even in the more discursive areas) to provide candidates with named and testable exemplar material containing valid quantitative data and graphical models. The practical scheme of work should also reflect this exemplar material, with students being required to quantify and model their observations wherever appropriate without relying solely on qualitative verbal descriptions.

Local Focus

The teaching of this course should be firmly rooted in the local environment. There are many references throughout the syllabus to “local examples” and the successful delivery of the course will involve teachers in research and fieldwork to meet this requirement.

Ethical and Political Focus

An important intent of this course is to encourage and develop students’ moral and political responses to the course material. The teaching approach therefore needs to be conducive to students evaluating the scientific, ethical and political aspects of issues.

Systems Approach

Teaching should employ the systems approach referred to throughout the syllabus. Those teachers coming to the subject from an academic background in geography may well have had more formal experience of this approach than those coming from the pure sciences. Teachers less familiar with the systems approach would be well advised to refer to an appropriate text. The central concepts and terminology, once established, can be frequently employed and referred to throughout the teaching of the course so that students can naturally draw parallels and make appropriate connections right across the syllabus. The methods of description and analysis provided by this approach may then be carried forward from the classroom study of natural and semi-natural environments, to the solution of environmental problems in everyday life.

SYLLABUS OVERVIEW

The syllabus for the Diploma Programme environmental systems course is divided into two parts: the core and the options. A syllabus overview is provided below.

Core [80h]

Topics		Teaching hours
1	Systems and models	5
2	The ecosystem	30
3	Global cycles and physical systems	27
4	Human population and carrying capacity	18

Options

A	Analysing ecosystems	15
B	Impacts of resource exploitation	15
C	Conservation and biodiversity	15
D	Pollution management	15

Candidates are required to study option A and one other option chosen from B–D.
The duration of each option is 15 hours.

SYLLABUS OUTLINE

Core [80h]

			Teaching hours
Topic 1	**Systems and models**		**[5]**
Topic 2	**The ecosystem**		**[30]**
	2.1	Structure	10
	2.2	Function	10
	2.3	Changes	10
Topic 3	**Global cycles and physical systems**		**[27]**
	3.1	The atmosphere	4
	3.2	Depletion of stratospheric ozone	3
	3.3	Tropospheric ozone	1
	3.4	The issue of global warming	4
	3.5	Acid deposition	2
	3.6	The hydrosphere	5
	3.7	The lithosphere	3
	3.8	The soil system	5
Topic 4	**Human population and carrying capacity**		**[18]**
	4.1	Population dynamics	7
	4.2	Resources—natural capital	5
	4.3	Limits to growth	6

Options

Option A	**Analysing ecosystems**		**[15]**
	A.1	Measuring physical components of the system	2
	A.2	Measuring biotic components of the system	5
	A.3	Measuring productivity of the system	4
	A.4	Measuring changes in the system	4
Option B	**Impacts of resource exploitation**		**[15]**
	B.1	Exploitation of energy resources	5
	B.2	Exploitation of food resources	5
	B.3	Environmental demands of human populations	5

Options (continued)

			Teaching hours
Option C	**Conservation and biodiversity**		**[15]**
	C.1	Biodiversity in ecosystems	3
	C.2	Evaluating biodiversity and vulnerability	6
	C.3	Conservation of biodiversity	6
Option D	**Pollution management**		**[15]**
	D.1	Nature of pollution	1
	D.2	Detection and monitoring of pollution	5
	D.3	Impacts of pollution	2
	D.4	Approaches to pollution management	7

SYLLABUS DETAILS

Topic 1: Systems and Models (5h)

A.S.		Obj
	This topic may best be viewed as a theme to be used in the delivery of other topics, rather than as an isolated teaching topic. It is essential that the systems approach is used throughout this course. This approach identifies the elements of systems and examines the relationships and processes that link these elements into a functioning entity. The systems approach also emphasizes the similarities between environmental systems, biological systems and artificial entities such as transport and communication systems. This approach stresses that there are concepts, techniques and terms that can be transferred from one discipline (such as ecology) to another (such as engineering). This topic identifies some of the underlying principles that can be applied to living systems, from the level of the individual up to that of the whole biosphere. It would therefore be helpful to, wherever possible, describe and analyse the systems addressed in the terms laid out in this topic.	
1.1.1	Outline the concept and characteristics of a system.	**2**
1.1.2	Define the terms *open system*, *closed system* and *isolated system*. These terms should be applied when characterizing real systems. • An open system exchanges matter and energy with its surroundings (eg an ecosystem). • A closed system exchanges energy but not matter; the "Biosphere II" experiment was an attempt to model this. Closed systems do not occur naturally on Earth. • An isolated system exchanges neither matter nor energy. No such systems exist (with the possible exception of the entire cosmos).	**1**
1.1.3	Describe how the first and second laws of thermodynamics are relevant to environmental systems. The first law concerns the conservation of energy. The second law explains the dissipation of energy that is then not available to do work, bringing about disorder. The second law is most simply stated as, "in any isolated system entropy tends to increase spontaneously". This means that energy and materials go from a concentrated to a dispersed form (the availability of energy to do work diminishes) and the system becomes increasingly disordered. Both laws should be examined in relation to the energy transformations and maintenance of order in living systems.	**2**

A.S.		Obj
1.1.4	Explain the nature of equilibria. A steady-state equilibrium should be understood as the common property of most open systems in nature. A static equilibrium, in which there is no change, should be appreciated as a condition to which natural systems can be compared. (Since there is disagreement in the literature regarding the definition of dynamic equilibrium, this term should be avoided.) Students should appreciate, however, that some systems may undergo long-term changes to their equilibrium while retaining an integrity to the system (eg succession). The relative stability of an equilibrium—the tendency of the system to return to that original equilibrium following disturbance rather than adopting a new one—should also be understood.	**3**
1.1.5	Define and explain the principles of *positive feedback* and *negative feedback*. The self-regulation of natural systems is achieved by the attainment of equilibrium through feedback systems. Negative feedback is a self-regulating method of control leading to the maintenance of a steady state equilibrium—it counteracts deviation. Positive feedback leads to increasing change in a system—it accelerates deviation. Feedback links involve time lags.	**1, 3**
1.1.6	Describe transfer and transformation processes. Transfers normally flow through a system and involve a change in location. Transformations lead to an interaction within a system in the formation of a new end product, or involve a change of state. Using water as an example, run-off is a transfer process and evaporation is a transformation process. Dead organic matter entering a lake is an example of a transfer process; decomposition of this material is a transformation process.	**2**
1.1.7	Distinguish between *flows* (inputs and outputs) and *storages* (stock) in relation to systems. Identify flows through systems and describe their direction and magnitude.	**2**
1.1.8	Construct and analyse quantitative models involving flows and storages in a system. Natural storages, yields and outputs should be included in the form of clearly constructed diagrammatic and graphical models.	**3**

Topic 2: The Ecosystem

A.S. Obj

2.1 Structure (10h)

2.1.1 Distinguish between *biotic* and *abiotic* (physical) components of an ecosystem. **2**

2.1.2 Define the term *trophic level*. **1**

2.1.3 Identify and explain trophic levels in food chains and food webs selected from the local environment. **2, 3**

Relevant terms (eg producers, consumers, decomposers, herbivores, carnivores, top carnivores) should be applied to local, named examples and other food chains and food webs.

2.1.4 Explain the principles of pyramids of numbers, pyramids of biomass and pyramids of productivity, and construct such pyramids from given data. **3**

Pyramids are graphical models of the quantitative differences that exist between the trophic levels of a single ecosystem. A pyramid of biomass represents the standing stock of each trophic level measured in units such as grams of biomass per square metre (g m^{-2}).

In accordance with the second law of thermodynamics, there is a tendency for numbers and quantities of biomass and energy to decrease along food chains, therefore the pyramids become narrower as one ascends. Pyramids of numbers can sometimes display different patterns, eg when individuals at lower trophic levels are relatively large. Similarly, pyramids of biomass can show greater quantities at higher trophic levels because they represent the biomass present at a given time (there may be marked seasonal variations). Both pyramids of numbers and pyramids of biomass represent storages.

Pyramids of productivity refer to the flow of energy through a trophic level and invariably show a decrease along the food chain (see 2.2.3). For example, the turnover of two retail outlets cannot be compared by simply comparing the goods displayed on the shelves; the rate at which they are being stocked and goods sold needs to be known. Similarly, a business may have substantial assets but cash flow may be very limited. In the same way, pyramids of biomass simply represent the momentary stock, whereas pyramids of productivity show the rate at which that stock is being generated. Biomass, measured in units of mass or energy (eg J m^{-2} or g m^{-2}), should be distinguished from productivity measured in units of flow (eg J m^{-2} yr^{-1} or g m^{-2} yr^{-1}).

A pyramid of energy may either be represented as the standing stock (biomass) measured in units of energy (J m^{-2}) or as productivity measured in units of flow of energy (J m^{-2} yr^{-1}), depending on the text consulted. As this is confusing, this syllabus avoids the term pyramid of energy.

A.S.		Obj
2.1.5	Discuss how the pyramid structure affects the functioning of an ecosystem. Examples: concentration of non-biodegradable toxins in food chains, limited length of food chains, vulnerability of top carnivores. (Definitions of the terms biomagnification, bioaccumulation and bio-concentration are not required.)	**3**
2.1.6	Define the terms *species*, *population*, *community*, *niche* and *habitat* with reference to local examples.	**1**
2.1.7	Define the term *biome*.	**1**
2.1.8	Outline the distribution and relative productivity of tropical rainforests, deserts, temperate forests, tundra and any one other biome. Refer to prevailing climate and limiting factors. For example, tropical rainforests are found close to the equator where there is high insolation and rainfall and where light and temperature are not limiting. The other biome may be, for example, temperate grassland or a local example.	**2**
2.1.9	Compare the biomes studied in 2.1.8 in terms of climate, productivity and structure. Limit climate to temperature, precipitation and insolation.	**2**
2.1.10	Describe and explain population interactions using examples of named species. Include competition, parasitism, mutualism, predation and herbivory. Mutualism is an interaction in which both species derive benefit. Interactions should be understood in terms of the influences each species has on the population dynamics of others, and upon the carrying capacity of the others' environment. Graphical representations of these influences should be interpreted.	**2, 3**

2.2 Function (10h)

2.2.1	Explain the role of producers, consumers and decomposers in the ecosystem.	**3**
2.2.2	Describe photosynthesis and respiration in terms of inputs, outputs and energy transformations. Biochemical details are not required. Details of chloroplasts, light-dependent and light-independent reactions, mitochondria, carrier systems, ATP and specific intermediate biochemicals are not expected. Photosynthesis should be understood as requiring carbon dioxide, water, chlorophyll and certain visible wavelengths of light to produce organic matter and oxygen. The transformation of light energy into the chemical energy of organic matter should be appreciated. Respiration should be recognized as requiring organic matter and oxygen to produce carbon dioxide and water. Without oxygen, carbon dioxide and other waste products are formed. Energy is released in a form available for use by living organisms, but is ultimately lost as heat.	**2**

A.S.		Obj
2.2.3	Describe and explain the transfer and transformation of energy and material as they flow through an ecosystem.	**2, 3**

Explain pathways of incoming solar radiation incident on the ecosystem including:

- loss of radiation through reflection and absorption
- conversion of light to chemical energy
- loss of chemical energy from one trophic level to another
- efficiencies of transfer
- overall conversion of light to heat energy by an ecosystem
- re-radiation of heat energy to the atmosphere.

Construct and interpret simple energy flow diagrams illustrating the movement of energy through ecosystems, including the productivity of the various trophic levels.

The distinction between storages of energy illustrated by boxes in energy-flow diagrams (representing the various trophic levels), and the flows of energy or productivity often shown as arrows (sometimes of varying widths) needs to be emphasized. The former are measured as the amount of energy or biomass per unit area and the latter are given as rates, eg J m^{-2} day^{-1}.

Processes involving the transfer and transformation of carbon, nitrogen, oxygen, phosphorus and water as they cycle through an ecosystem should be described, and the conversion of organic and inorganic storage noted where appropriate. Interpret and construct diagrams of these cycles from given data. The laws of thermodynamics (see 1.1.3) should be related to the energy and material flow through ecosystems.

2.2.4	Define the terms *gross productivity, net productivity, primary productivity, secondary productivity, gross primary productivity* and *net primary productivity.*	**1**

Productivity is production per unit time. Gross productivity (GP) is the total gain in energy or biomass per unit time, which could be through photosynthesis in primary producers or absorption in consumers.

Net productivity (NP) is the gain in energy or biomass per unit time remaining after allowing for respiratory losses (R). Other metabolic losses may take place, but these may be ignored when calculating and defining net productivity for the purpose of this course.

2.2.5	Calculate the values of gross and net productivity from given data.	**2**

For both producers and consumers, calculations can be made using the following equation:

$$NP = GP - R$$

In addition, the equation for consumers only is:

$$GP = \text{food eaten} - \text{fecal losses}$$

The term assimilation is sometimes used instead of gross secondary productivity.

2.2.6	Explain the terms *negative feedback mechanism* and *positive feedback mechanism* in relation to ecosystems.	**3**

Examples can be found in population dynamics and mineral cycling.

A.S.		Obj

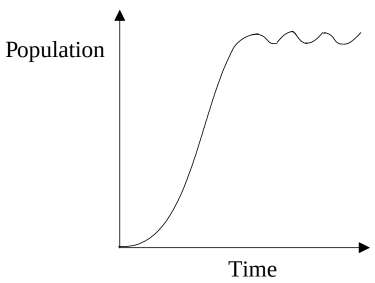
2.3 Changes (10h)

2.3.1 Explain the concepts of limiting factors and carrying capacity in the context of population growth. **3**

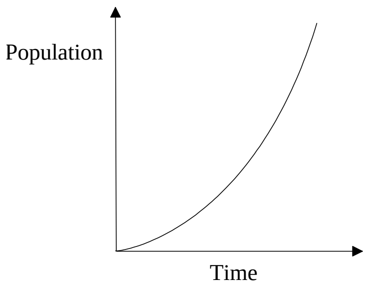
2.3.2 Describe and explain “S” and “J” population growth curves. **2, 3**

Explain changes in both numbers and rates of growth in standard S and J population growth curves. Population curves should be sketched, described, interpreted and constructed from given data.

S curve



J curve



2.3.3 Describe the role of density-dependent and density-independent factors, and internal and external factors, in the regulation of populations. **2**

According to theory, density-dependent factors operate as negative feedback mechanisms leading to stability or regulation of the population.

Both types of factors may operate on a population. Many species, particularly *r*-strategists, are probably regulated by density-independent factors, of which weather is the most important factor. Internal factors might include density-dependent fertility or size of breeding territory, and external factors might include predation or disease.

2.3.4 Describe the principles associated with survivorship curves including, *K*- and *r*-strategists. **2**

K- and *r*-strategists represent idealized categories and many organisms occupy a place on the continuum.

Students should be familiar with interpreting features of survivorship curves including logarithmic scales.

2.3.5 Describe the concept and processes of succession in a named habitat. **2**

Study named examples of organisms from a pioneer community, seral stages and climax community.

The concept of succession, occurring over time, should be carefully distinguished from the concept of zonation which refers to a spatial pattern.

A.S.		Obj
2.3.6	Explain the changes in energy flow, gross and net productivity, diversity and mineral cycling in different stages of succession. In early stages gross productivity is low due to the initial conditions and low density of producers. The proportion of energy lost through community respiration is relatively low too, so net productivity is high, ie the system is growing and biomass is accumulating. In later stages, with an increased consumer community, gross productivity may be high in a climax community. However, this is balanced by respiration, so net productivity approaches zero and the production:respiration (P:R) ratio approaches 1.	3
2.3.7	Describe factors affecting the nature of climax communities. Climatic and edaphic factors determine the nature of a climax community, unless human or other factors maintain an equilibrium at a sub-climax community.	2

Topic 3: Global Cycles and Physical Systems

A.S.		Obj
	3.1 The Atmosphere (4h)	
3.1.1	Describe the overall structure and composition of the atmosphere and outline the concept of lapse rate. Lapse rate is the rate at which temperature declines with increasing altitude in the troposphere.	2
3.1.2	Describe and explain the global atmospheric energy budget. There should be a qualitative understanding of latent and sensible heat flux, and how water can absorb or release heat as it changes state. Interpret and produce diagrams of the global energy budget including flows and storage of energy. Analyse the global energy budget from a systems point of view, examining inputs and outputs of energy. Memorization of actual figures is not required.	2, 3
3.1.3	Explain the role of atmospheric circulation in redistributing heat from the equator to polar regions. Consider reasons for the differences in insolation per unit area between the equator and poles. Examination of the global energy budget should lead to an awareness of the global imbalances of solar energy inputs and outputs.	3
3.1.4	Describe major patterns of atmospheric circulation including the tricellular model, tropical cyclones and depressions. The function of these circulation mechanisms in the redistribution of energy should be understood.	2
3.1.5	Explain how atmospheric circulation gives rise to broad climatic regions and, consequently, biomes. Consider the location of broad climatic belts, ie tropical, arid, temperate and polar, as a natural consequence of air circulation patterns (eg falling and drying air flow causes arid belts at approximately 30 degrees North and South). There should be a clear understanding of the relationship between latitude, precipitation and temperature as they influence the distribution of biomes (see 2.1.8).	3
	3.2 Depletion of Stratospheric Ozone (3h)	
3.2.1	Describe the role of ozone in the absorption of ultraviolet radiation. Ultraviolet radiation is absorbed during the formation and destruction of ozone from oxygen. Memorization of chemical equations is not required.	2

A.S.		Obj
3.2.2	Explain the interaction between ozone and halogenated organic gases. Halogenated organic gases are very stable under normal conditions but can liberate halogen atoms when exposed to ultraviolet radiation in the stratosphere. These atoms react with monatomic oxygen and slow the rate of ozone reformation. Pollutants enhance the destruction of ozone thereby disturbing the equilibrium of the ozone production system (see 1.1.4).	3
3.2.3	State the effects of ultraviolet radiation on living tissues and biological productivity. The effects include mutation and subsequent effects on health and damage to photosynthetic organisms, especially phytoplankton and their consumers such as zooplankton.	1
3.2.4	Describe three methods of reducing the manufacture and release of ozone-depleting substances. For example, recycling refrigerants, alternatives to gas-blown plastics, alternative propellants and alternatives to methyl bromide.	2
3.2.5	Describe and evaluate the role of national and international organizations in reducing the emissions of ozone-depleting substances. Examine the role of the United Nations Environmental Programme (UNEP) in forging international agreements on the use of ozone-depleting substances, and study the relative effectiveness of these agreements and the difficulties in implementing and enforcing them. In addition, students should be familiar with what steps national governments are taking to comply with these agreements, and what named local organizations are doing to persuade governments to comply.	2, 3

3.3 Tropospheric Ozone (1h)

3.3.1	State the source and outline the effect of tropospheric ozone. When fossil fuels are burned, two of the pollutants emitted are hydrocarbons (from unburned fuel) and nitrogen oxide (NO). Nitrogen oxide reacts with oxygen to form nitrogen dioxide (NO_2), a brown gas which contributes to urban haze. Nitrogen dioxide can also absorb sunlight and break up to release oxygen atoms that combine with oxygen in the air to form ozone. Ozone is a toxic gas and an oxidizing agent. It damages crops and forests, irritates eyes, can cause breathing difficulties in humans and may increase susceptibility to infection. It is highly reactive and can attack fabrics and rubber materials.	1, 2
3.3.2	Outline the formation of photochemical smog. Photochemical smog is a mixture of about one hundred primary and secondary pollutants formed under the influence of sunlight. Ozone is the main pollutant. The frequency and severity of photochemical smogs in an area depends on local topography, climate, population density and fossil fuel use. Precipitation cleans the air and winds disperse the smog. Thermal inversions trap the smogs in valleys (eg Los Angeles, Santiago, Mexico City, Rio de Janeiro, Sao Paulo, Beijing) and concentrations of air pollutants can build to harmful and even lethal levels.	2

A.S. Obj

3.4 The Issue of Global Warming (4h)

3.4.1 Describe the role of greenhouse gases in maintaining mean global temperature. **2**

The greenhouse effect is a normal and necessary condition for life on Earth. Consider carbon dioxide (CO_2) levels in geological times.

3.4.2 Describe how human activities add to greenhouse gases. **2**

Water, CO_2, methane and CFCs are the main greenhouse gases. Human activities are increasing levels of CO_2, methane and CFCs in the atmosphere.

3.4.3 Outline three global and three local ways that emissions of greenhouse gases can be reduced. **2**

- Global—intergovernmental and international agreements, carbon tax, alternative energy sources.
- Local—allow students to explore their own lifestyle in the context of local greenhouse gas emissions.

3.4.4 Discuss qualitatively the effects of increased mean global temperature on the distribution of biomes, and consequently on global agriculture. **3**

Students should know the variety of sometimes conflicting arguments surrounding this issue. They should be able to discuss:

- thermal expansion of the oceans
- melting of the polar ice caps
- increased evaporation in tropical latitudes leading to increased snowfall on the polar ice caps, which reduces the mean global temperature (an example of negative feedback)
- the effect of air pollutants (aerosols) in reflecting radiation, thus offsetting the warming trends.

Any feedback mechanisms associated with global warming may involve very long time lags. Note the complexity of the problem and the uncertainty of global climate models. Cross reference with 2.1.8 and 3.2.5.

3.5 Acid Deposition (2h)

3.5.1 Outline the chemistry leading to the formation of acidified precipitations. **2**

Refer to the conversion of sulfur dioxide and nitrogen dioxide into the sulfates and nitrates of dry deposition and the sulfuric and nitric acids of wet deposition. Knowledge of chemical equations is not required.

3.5.2 Describe three possible effects of acid deposition on soil, water and living organisms. **2**

Include:

- one direct effect, eg acid on aquatic organisms and coniferous forests
- one toxic effect, eg aluminium ions on fish
- one nutrient effect, eg leaching of calcium.

A.S.		Obj
3.5.3	Explain why the effect of acid deposition is regional rather than global. Refer to areas downwind of major industrial regions which are adversely affected by acid rain and link them to sources of sulfur dioxide and nitrogen dioxide emissions. Consider the effect of geology (rocks and soils) on water acidity through buffering.	**3**
3.5.4	Outline and evaluate methods to reduce emissions of the principal causal agents of acid deposition. Measures to reduce fossil fuel combustion should be considered, eg reducing demand for electricity and private cars and switching to renewable energy. Refer to clean-up measures at “end of pipe” locations (points of emission). Consider the role of international agreements in effecting change.	**2, 3**
3.5.5	Outline methods for restoring acidified soils and waters, and evaluate their efficacy. Consider liming. The cost-effectiveness of spreading ground limestone in Swedish lakes in the early 1980s provides a good case study.	**2, 3**

3.6 The Hydrosphere (5h)

3.6.1	Describe the Earth’s water budget. Only a small fraction (2.6% by volume) of the Earth’s water supply is fresh water. Of this fresh water, over 80% is in the form of ice caps and glaciers, 0.59% is groundwater and the rest is made up of lakes, soil water, atmospheric water vapour, rivers and biota in decreasing order of storage size. Precise figures are not required.	**2**
3.6.2	Describe and evaluate the sustainability of freshwater resource usage. Irrigation, industrialization and population increase all make demands on the supplies of fresh water. Global warming may disrupt rainfall patterns and disrupt water supplies. The hydrological cycle supplies humans with fresh water but we are withdrawing water from underground aquifers and degrading it with wastes at a greater rate than it can be replenished. Consider the increased demand for fresh water, inequity of usage, methods of reducing use and increasing supplies.	**2, 3**
3.6.3	Outline the role of ocean currents in the global transfer of energy. The global atmospheric energy model cannot be understood without reference to the role of ocean currents in the transfer of energy. Students should know that cold currents flow from poles to the equator and that warm currents, driven by wind and the Earth’s rotation, flow away from the equator. Naming all the individual currents is not required, although examples should be noted.	**2**

A.S.		Obj
3.6.4	Outline the role of ocean currents in the regulation of climate. The rate at which water absorbs and releases heat relative to the land, and the consequent moderating effect on climate, should be understood. The transport of heat by ocean currents and the influence on climate should also be understood, eg the North Atlantic Drift moderating the climate of north-western Europe which, in the absence of this current, would otherwise have a sub-arctic climate; the Humbolt current off Peru and the Benguela current off Namibia.	2
3.6.5	Describe the El Niño Southern Oscillation (ENSO) phenomenon and its impacts. Students should make reference to relationships among trade winds, ocean surface currents, nutrient upwelling, productivity of fish stocks (eg those off the Peruvian coast) and more distant climatic effects. Periodic disruption of tropical easterly trade winds results in a mass of warm water in the Pacific expanding eastwards towards South America. This raises the surface temperature of the ocean and prevents nutrient-laden waters from upwelling, thus limiting productivity. Reasons for the disruption in trade winds are not required. Descriptions of climatic effects elsewhere should be limited to correlations between El Niño and atypical weather patterns in, for example, the western USA, Australia, Indonesia and southern Africa.	2

3.7 The Lithosphere (3h)

3.7.1	Describe the structure of the Earth’s internal zones and the theory of plate tectonics. Include the crust, mantle and core, as well as convection cells and mantle plumes in the asthenosphere. The terms *constructive margins*, *destructive margins*, *subduction* and *mid-oceanic ridge* should be understood. Students will be expected to draw and label diagrams showing the interactions between plates, and the formation and destruction of crust.	2
3.7.2	Explain how plate activity has influenced evolution and biodiversity. The consequences of plate tectonics on speciation should be understood (ie the separation of gene pools, formation of physical barriers and land bridges) together with the implications these consequences have for evolution. Also focus on the role of plate activity in generating new and diverse habitats, thus promoting biodiversity.	3

A.S. | Obj

3.8 The Soil System (5h)

3.8.1 Outline how soil systems integrate aspects of living systems. **2**

Emphasize a systems approach. Students should draw diagrams that show links between the soil, lithosphere, atmosphere and living organisms. The soil as a living system should be considered with reference to the soil profile.

Transfers of material (including deposition) result in reorganization of the soil. There are inputs of organic and parent material, precipitation, infiltration and energy. Outputs include leaching, uptake by plants and mass movement. Transformations include decomposition, weathering and nutrient cycling.

3.8.2 Describe three stages of soil formation. **2**

Consider:

- initial mechanical and chemical weathering processes resulting in the inorganic component
- introduction of living organisms—the biotic component
- decomposition and the formation of an organic component.

Note the time required for soil formation (hence, soil is a non-renewable resource).

3.8.3 Compare the structure and properties of sand, clay and loam soils, including their relevance to primary productivity. **2**

Consider mineral content, drainage, water-holding capacity, air spaces, biota and potential to hold organic matter, and link these to primary productivity.

3.8.4 Outline the processes that cause soil degradation. **2**

Human activities such as overgrazing, deforestation, unsustainable agriculture and irrigation cause processes of degradation. These include soil erosion, toxification and salinization. Desertification (enlargement of deserts through human activities) can be associated with this degradation. Each year about 11 million hectares of arable land is lost from production through soil degradation processes.

3.8.5 Evaluate soil conservation measures. **3**

Explore:

- soil conditioners (lime to increase pH, organic materials)
- wind reduction techniques (wind breaks, shelter belts, strip cultivation)
- cultivation techniques (terracing, contour-plowing)
- efforts to stop plowing of marginal lands.

There are three broad classes of natural capital.

A.S.		Obj
4.2.3	Distinguish between *natural capital* and *natural income*.	**2**

Natural capital can be explained in terms of standing stocks and income flows. The stock is the present accumulated quantity of natural capital and the income is any sustainable rate of harvest. For example, forests and fish stocks are forms of natural capital and the sustainable yields or harvests from such stocks are natural income.

4.2.4 Explain the concept of *sustainability* in terms of natural capital and natural income. **3**

The term "sustainability" has been given a precise meaning in this syllabus. The term "sustainable development", however, is not used because of the wide variation in the way that it is defined in different disciplines, by the public and in the media. Furthermore, the concept of sustainable development involves value judgments which fall outside the scope of a science course such as this.

Students should understand that any society that supports itself in part by depleting essential forms of natural capital is unsustainable. If human well-being is dependent on the goods and services provided by certain forms of natural capital, then long-term harvest (or pollution) rates should not exceed rates of capital renewal. Sustainability means living, within the means of nature, on the "interest" or sustainable income generated by natural capital.

4.2.5 Calculate and explain sustainable yields from given data. **2, 3**

Sustainable yield (SY) may be calculated as the rate of increase in natural capital, ie that which can be exploited without depleting the original stock or its potential for replenishment. For example, the annual sustainable yield for a given crop may be estimated simply as the annual gain in biomass or energy through growth and recruitment. Thus,

$$\text{SY} = \left(\frac{\text{total biomass}}{\text{energy}} \text{ at time } t+1\right) - \left(\frac{\text{total biomass}}{\text{energy}} \text{ at time } t\right)$$

SY = (annual growth and recruitment) – (annual death and emigration)

4.2.6 Identify various values associated with natural capital and evaluate how these values influence this capital's appraisal and use. **2, 3**

Examples include ecological, economic and aesthetic values. In industrial societies people tend to emphasize monetary or economic valuations of nature. In some cases the economic value of a natural capital stock can be determined from the market price of the goods or services it produces. However, there are no formal markets for many valuable ecological processes such as waste assimilation, flood and erosion control, nitrogen-fixation, photosynthesis, etc. These ecological services may be essential for human existence, but we have tended to take them for granted.

Furthermore, organisms or ecosystems that are valued on aesthetic or intrinsic grounds may not provide commodities identifiable as either goods or services, and so remain unpriced or undervalued from an economic viewpoint. Organisms or ecosystems regarded as having intrinsic value, for instance from an ethical, spiritual or philosophical perspective, are valued regardless of their potential use to humans. Therefore diverse perspectives may underlie the evaluation of natural capital.

By examining carefully the requirements of a given species and the resources available, it might be possible to estimate the carrying capacity of that environment for the species. This is problematic in the case of

4.3.2 Explain how reuse, recycling, remanufacturing and absolute reductions in energy and material use can affect human carrying capacity. **3**

Human carrying capacity is determined by the rate of energy and material consumption, the level of pollution and the extent of human interference in global life support systems. While recycling, reuse and remanufacturing reduce these impacts, they can also increase human carrying capacity.

4.3.3 Discuss how national and international development policies and cultural influences can affect human population dynamics and growth. **3**

Many policy factors influence human population growth. Domestic and international development policies that target the death rate through agricultural development, improved public health and sanitation, and better service infrastructure may stimulate rapid population growth by lowering mortality without significantly affecting fertility. Some analysts believe that birth rates will come down by themselves as economic welfare improves and that the population problem is therefore better solved through policies to stimulate economic growth. Education about birth control encourages family planning. Parents may be dependent on their children for support in their later years and this may create an incentive to have many children. Urbanization may also be a factor in reducing crude birth rates. Policies directed toward the education of women, enabling women to have greater personal and economic independence, may be the most effective method for reducing population pressure.

A.S.		Obj
4.3.4	Describe and explain the relationship between population, resource consumption and technological development, and their influence on carrying capacity and material economic growth.	**2, 3**

Because technology plays such a large role in human life, many economists argue that human carrying capacity can be expanded continuously through technological innovation. For example, if we learn to use energy and material twice as efficiently, we can double the population or the use of energy without necessarily increasing the impact (load) imposed on the environment. However, to compensate for foreseeable population growth (possibly doubling between the years 2000 and 2040) and the economic growth that is deemed necessary, especially in developing countries, it is suggested that efficiency would have to be raised by a factor of 4 to 10 to remain within global carrying capacity.

Option A: Analysing Ecosystems

Note: The objectives for this option can only be achieved satisfactorily if it is taught by means of a substantial amount of fieldwork.

The techniques required in this option may be exemplified through practical work in marine, terrestrial, freshwater or urban ecosystems, or any combination of these. The selection of environments can be made according to the local systems available to the students, and the most convenient systems for demonstrating the techniques in question. However, there is an advantage in using the various practical measurements to quantify different aspects of the same ecosystem, where possible. In this way the techniques are not simply rehearsed in isolation, but can be used to build up a holistic model of that system.

A.S.		Obj

A.1 Measuring Physical Components of the System (2h)

A.S.		Obj
A.1.1	List the significant abiotic (physical) factors of an ecosystem.	**1**
A.1.2	Describe and evaluate methods for measuring at least three abiotic factors within an ecosystem.	**2, 3**

Students should know methods for measuring any three significant abiotic factors and how these may vary in a given ecosystem with depth, time or distance. For example:

- marine—salinity, pH, temperature, dissolved oxygen, wave action
- freshwater—turbidity, flow velocity, pH, temperature, dissolved oxygen
- terrestrial—temperature, light intensity, wind speed, particle size, slope, soil moisture, drainage, mineral content.

This activity may be carried out effectively in conjunction with an examination of related biotic components.

A.2 Measuring Biotic Components of the System (5h)

A.S.		Obj
A.2.1	Construct simple keys and use published keys for the identification of organisms.	**3**

Students could practise with keys supplied and then construct their own keys for up to eight species.

A.S.		Obj
A.2.2	Describe and evaluate methods for estimating abundance of organisms.	**2, 3**

Methods should include capture/mark/release/recapture (Lincoln index) and quadrats for measuring population density, percentage frequency and percentage cover.

A.S.		Obj
A.2.3	Describe and evaluate methods for estimating the biomass of trophic levels in a community.	2, 3

Dry weight measurements of quantitative samples could be extrapolated to estimate total biomass.

A.2.4	Define the term *diversity*.	1

Diversity is often considered as a function of two components: the number of different species and the relative numbers of individuals of each species.

A.2.5	Apply Simpson's diversity index and outline its significance.	2

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

where D = diversity index

N = total number of organisms of all species found

n = number of individuals of a particular species

D is a measure of species richness. A high value of D suggests a stable and ancient site and a low value of D could suggest pollution, recent colonization or agricultural management. The index is normally used in studies of vegetation but can also be applied to comparisons of animal (or even all species) diversity.

A.3 Measuring Productivity of the System (4h)

A.3.1	Describe and evaluate a method for measuring gross and net primary productivity in an ecosystem.	2, 3

For marine and freshwater ecosystems, the light and dark bottle technique should be used for measuring gross and net productivity of aquatic plants. While methods for measuring primary productivity in vegetation for terrestrial ecosystems might not be feasibly carried out as student investigations, possible methods should be described and evaluated (eg measuring changes in biomass of covered and uncovered quadrats of grassland, and measuring absorption of CO_2 in enclosed communities).

A.3.2	Describe and evaluate a method for measuring gross and net secondary productivity in an ecosystem.	2, 3

Gross secondary productivity might be simply estimated as food eaten minus feces produced.

As a laboratory investigation, an aquarium population of invertebrate herbivores (eg brine shrimps) or a terrarium population of invertebrate herbivores (eg silkworms) might be fed on a known producer biomass for a period of time. The remaining food material and feces are collected, dried and weighed. Net productivity might be measured as the increase in biomass of a consumer population over time. As a laboratory or field investigation, biomass might be estimated as a fixed percentage of wet weight to avoid the killing of organisms for dry weight measurements. Alternatively, secondary data could be used.

A.S.		Obj

A.4 Measuring Changes in the System (4h)

A.4.1	Describe and evaluate methods for measuring changes in abiotic and biotic components of an ecosystem along an environmental gradient or over time.	**2, 3**
A.4.2	Outline methods for assessing changes in abiotic and biotic components of an ecosystem due to a specific human activity. Methods and changes should be selected appropriately for the human activity chosen. Suitable human impacts for study might include toxins from mining activity, landfills, eutrophication, effluent, oil spills and overexploitation.	**2**

Option B: Impacts of Resource Exploitation

A.S. | Obj

B.1 Exploitation of Energy Resources (5h)

B.1.1 Evaluate the advantages and disadvantages of five sources of energy. **3**

Consider fossil fuels, nuclear, solar and hydroelectric power and one other source. These sources should be evaluated for efficiency (ie cost of extraction, conversion, transport and safety), sustainability and adverse effects.

B.2 Exploitation of Food Resources (5h)

B.2.1 State the relative proportions of fish, meat and cereals consumed in developed and developing countries. **1**

B.2.2 Compare the efficiency of terrestrial and aquatic food production systems. **2**

Compare these in terms of their trophic levels and efficiency of energy conversion. There is no need to consider individual production systems in detail. In terrestrial systems, most food is harvested from relatively low trophic levels (producers and herbivores). However, in aquatic systems, perhaps largely due to human tastes, most food is harvested from higher trophic levels where the total storages are much smaller. Although energy conversions along the food chain may be more efficient in aquatic systems, the initial fixing of available solar energy by primary producers tends to be less efficient due to the absorption and reflection of light by water.

B.2.3 Compare the inputs and outputs of materials and energy (energy efficiency), the system characteristics and the environmental impacts for two named food production systems. **2**

The systems selected should both be terrestrial or both aquatic. In addition, the inputs and outputs of the two systems should differ qualitatively and quantitatively (not all systems will be different in all aspects). The pair of examples could be North American cereal farming and subsistence farming in some parts of South-east Asia, intensive beef production in the developed world and the Masai tribal use of livestock, or commercial salmon farming in Norway/Scotland and rice-fish farming in Thailand. Other local or global examples are equally valid.

Factors to be considered might include:

- inputs—fertilizers (artificial and natural), irrigation water, pesticides, fossil fuels, food distribution, human labour, seed, breeding stock
- system characteristics—selective breeding, genetically engineered organisms, monoculture versus polyculture, sustainability
- environmental impact—pollution, habitat loss, reduction in biodiversity, soil erosion
- outputs—food (quality and quantity), pollutants, soil erosion.

B.2.4 Evaluate the implications for future global food supply of changes in the management of food production systems. **3**

Consider maximizing yield and improving storage and distribution methods of food production systems. Consider also how humans could change dietary habits, eg eat less meat.

Describe and explain the differences between the ecological footprints of two human populations; one from a developing region and one from a developed region. **2, 3**

> Data for food consumption are often given in grain equivalents, so that a population with a meat-rich diet would tend to consume a higher grain equivalent than a population that feeds directly on grain. Grain production will be higher with intensive farming strategies. Populations more dependent on fossil fuels will have higher CO_2 emissions. Fixation of CO_2 is clearly dependent on climatic region and vegetation type. These, and other factors, will often explain the differences in the ecological footprints of populations in developing and developed countries.

Option C: Conservation and Biodiversity

A.S.		Obj
	C.1 Biodiversity in Ecosystems (3h)	
C.1.1	Define the terms *biodiversity*, *genetic diversity*, *species diversity* and *habitat diversity*.	1
C.1.2	Outline the mechanism of natural selection as a possible driving force for speciation. Speciation is the process by which change in the frequency of genetic traits in the population occurs in response to environmental pressure. The concept of fitness should be understood. The history of the development of the modern theory of evolution is not expected, neither is a detailed knowledge of genetics (including allele frequency).	2
C.1.3	State that isolation can lead to different species being produced that are unable to interbreed to yield fertile offspring. Isolation of populations, behavioural differences that preclude reproduction and the inability to produce fertile offspring (leading to speciation) should all be examined, with examples.	1
C.1.4	Explain the relationships among ecosystem stability, diversity, succession and habitat. Consider how: • diversity changes through succession • habitat diversity and type lead to greater species and genetic diversity • a complex ecosystem, with its variety of nutrient and energy pathways, provides stability • human activities modify succession, eg logging, grazing, burning • human activities often simplify ecosystems, rendering them unstable, eg North American wheat farming versus tall grass prairie.	3
	C.2 Evaluating Biodiversity and Vulnerability (6h)	
C.2.1	Identify factors that lead to loss of diversity. These include: • natural hazard events (eg volcanoes, drought) • global catastrophic events (eg ice age, meteor impact) • habitat degradation, fragmentation and loss • introduction/escape of non-native and genetically modified species, and monoculture • pollution • hunting, collecting and harvesting.	2

A.S.		Obj
C.2.2	Describe the vulnerability of tropical rainforests and their relative value in contributing to global biodiversity. Tropical rainforests should be compared with other major ecosystems. Take particular note of agriculture when considering vulnerability.	**2**
C.2.3	Discuss current estimates of numbers of species and past and present rates of species extinction. Examine the fossil record for evidence of mass extinctions in the past, and compare the possible causes of these to present day extinctions. The time frame of these periods of extinction should be considered.	**3**
C.2.4	Describe and explain the factors that may make species more or less prone to extinction. The following factors (among others) will affect the risk of extinction: numbers, degree of specialization, distribution, reproductive potential and behaviour, and trophic level. An ecosystem's capacity to survive change may depend on diversity, resilience and inertia.	**2, 3**
C.2.5	State and explain the criteria used to determine a species' conservation status. Students should know criteria by which species are placed in the unknown, rare, vulnerable, endangered and extinct categories in the red data books. (These are available for each country.) Use evolutionary and ecological significance of species as criteria for determining conservation status. Taxonomic details are not required.	**1, 3**
C.2.6	Describe the case histories of three species: one that has become extinct, another that is currently endangered, and a third that was endangered and has now been removed from the endangered list. Students should know the ecological, socio-political and economic pressures that caused or are causing the chosen species' extinction. The species' ecological roles and the possible consequences of their disappearance should be understood.	**2**
C.2.7	Describe the case history of a natural area of biological significance that is threatened by human activities. Students should know the ecological, socio-political and economic pressures that caused or are causing the degradation of the chosen area, and the consequent threat to biodiversity.	**2**

C.3 Conservation of Biodiversity (6h)

C.3.1	State the arguments for preserving species and habitats. Students should appreciate arguments based on ethical, aesthetic, genetic resource and commercial (including opportunity cost) considerations. They should also appreciate life support/ecosystem support functions (see 4.2.6).	**1**

A.S.		Obj
C.3.2	Compare the role and activities of governmental and non-governmental organizations in preserving and restoring ecosystems and biodiversity. Consider the United Nations Environment Programme (UNEP) as a governmental organization and the Worldwide Fund for Nature (WWF) and Greenpeace as non-governmental organizations. Compare them in terms of use of the media, speed of response, diplomatic constraints and enforceability.	**2**
C.3.3	Outline the World Conservation Strategy. This is proposed by the International Union for the Conservation of Nature (IUCN), UNEP and WWF.	**2**
C.3.4	State and explain the criteria used to design reserves. In effect, protected areas may become “islands” within a country and will normally lose some of their diversity. The principles of island biogeography might be applied to the design of reserves. Appropriate criteria are discussed in the World Conservation Strategy.	**1, 3**
C.3.5	Evaluate the success of a named protected area. The granting of protected status to a species or ecosystem is no guarantee of protection without community support, adequate funding and proper research. Consider a specific local example.	**3**
C.3.6	Discuss and evaluate the strengths and weaknesses of the species-based approach to conservation. Students should consider the relative strengths and weaknesses of the following: • The Convention on International Trade in Endangered Species (CITES) • captive breeding and reintroduction programmes, and zoos • aesthetic versus ecological value.	**3**

Option D: Pollution Management

Note: Not all pollutants are considered here, some are considered in topic 3.

A.S.		Obj

D.1 Nature of Pollution (1h)

D.1.1	Define *pollution*.	**1**
D.1.2	Distinguish between the terms *point source pollution* and *non-point source pollution* and the challenges they present for management. Point source pollution is generally more easily managed because its impact is more localized making it easier to control emission, attribute responsibility and take legal action.	**2**
D.1.3	State the major sources of pollutants. Sources of pollutants are combustion of fossil fuels, domestic waste, industrial waste, manufacturing and agricultural systems.	**1**

D.2 Detection and Monitoring of Pollution (5h)

D.2.1	Describe two direct methods of monitoring pollution. Students should describe one method for air and one for soil or water.	**2**
D.2.2	Define the term *biochemical oxygen demand* (BOD) and explain how it is used to assess pollution levels in water.	**1, 3**
D.2.3	Describe and explain one indirect method of measuring pollution levels using a biotic index. This will involve levels of tolerance, diversity and abundance of organisms. A polluted and an unpolluted site (eg upstream and downstream of a point source) should be compared.	**2, 3**
D.2.4	Describe the form and use of environmental impact assessments (EIAs). Students should have the opportunity to see an actual EIA study. They should realize that an EIA involves production of a baseline study before any environmental development, assessment of possible impacts, and monitoring of change during and after the development.	**2**

D.3 Impacts of Pollution (2h)

This section explores the widespread impacts of inorganic nutrients as one type of pollutant.

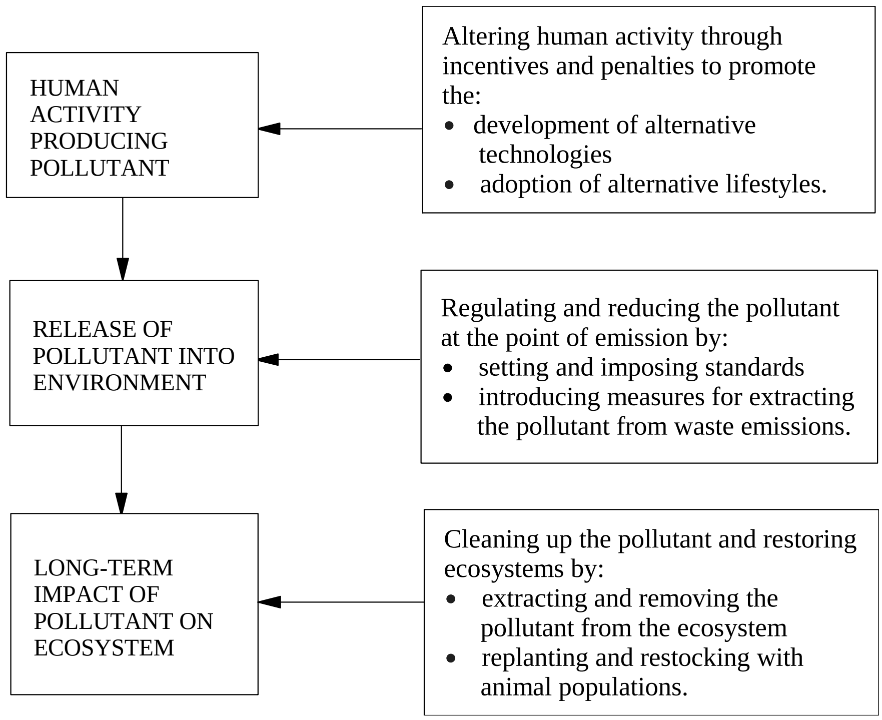
D.3.1	Outline the processes of eutrophication. Include increase in nitrates and phosphates leading to rapid growth of algae, accumulation of dead organic matter, high rate of decomposition and lack of oxygen. The role of positive feedback should be noted in these processes.	**2**

A.S.		Obj
D.3.2	Evaluate the impacts of eutrophication. Include death of aerobic organisms, increased turbidity, loss of macrophytes, reduction in length of food chains and loss of species diversity.	3

D.4 Approaches to Pollution Management (7h)

Pollutants are produced through human activities and create long-term effects when released into ecosystems. Strategies for reducing these impacts can be directed at three different levels in the process: altering the human activity, regulating and reducing quantities of pollutant released at the point of emission and cleaning up the pollutant and restoring ecosystems after pollution has occurred (see diagram below). Students should be able to illustrate the value and limitations of each of the three different levels of intervention, and appreciate the advantages of employing the earlier strategies over the later ones.

Process of pollution **Strategies for reducing impacts**



D.4.1	Explain and evaluate pollution management strategies for eutrophication. • "Altering the human activity producing pollution" can be exemplified by switching to alternative fertilizers, alternative methods of enhancing crop growth, alternative detergents, etc. • "Regulating and reducing pollutants at the point of emission" can be illustrated by sewage treatment processes that remove nitrates and phosphates from the waste. • "Clean up and restoration" can be exemplified by pumping mud from eutrophic lakes and reintroducing plant and fish species.	3

A.S.		Obj
D.4.2	Explain and evaluate pollution management strategies for solid domestic (municipal) waste. Students should consider their own and their community's generation of waste. Consider total volume, paper, glass, metal, plastics, organic waste (kitchen or garden), packaging, etc.	**3**
D.4.3	Explain and evaluate pollution management strategies for a named example of industrial waste. Appropriate examples include radioactive waste, oil spills, heavy metals from mining or a named local example.	**3**

GLOSSARY

It is not intended that students learn and recall the exact wording of these definitions. They are included here to ensure general agreement between teachers, students and examiners of the spellings and explanations that will be acceptable in examinations.

The words shown in italics are the same as those shown in italics in the assessment statements. These are the terms that students are expected to be able to define. The non-italicized words have been included to help reduce ambiguity.

abiotic factor	A non-living, physical factor that may influence an organism or ecosystem, eg temperature, sunlight, pH, salinity, precipitation.
altitude	The height above mean sea level, usually measured in metres.
biochemical oxygen demand (BOD)	A measure of the amount of dissolved oxygen required to break down the organic material in a given volume of water through aerobic biological activity.
biodegradable	Capable of being broken down by natural biological processes, eg the activities of decomposer organisms.
biodiversity	The amount of biological or living diversity per unit area. It includes the concepts of species diversity (the number of species of organisms per unit area), habitat diversity (the variety of habitat, or number of ecological niches per unit area) and genetic diversity (the richness of an area with respect to genetic material).
biomass	The mass of organic material in organisms or ecosystems, usually per unit area. Sometimes the term dry weight biomass is used where mass is measured after the removal of water. Water is not organic material and inorganic material is usually relatively insignificant in terms of mass.
biome	A collection of ecosystems sharing similar climatic conditions, eg tundra, tropical rainforest, desert.
biosphere	That part of the Earth inhabited by organisms, ie the narrow zone (a few kilometres in thickness) in which plants and animals exist. It extends from the upper part of the atmosphere (where birds, insects and wind-blown pollen may be found) down to the deepest part of the Earth's crust to which living organisms venture.
biotic factor	A living, biological factor that may influence an organism or ecosystem, eg predation, parasitism, disease, competition.

carrying capacity	The maximum number of a species or “load” that can be sustainably supported by a given environment.
climax community	A community of organisms that is more or less stable, and that is in equilibrium with natural environmental conditions such as climate; the end-point of ecological succession.
community	A group of populations living and interacting with each other in a common habitat.
competition	A common demand by two or more organisms upon a limited supply of a resource (eg food, water, light, space, mates, nesting sites). It may be intraspecific or interspecific.
crude birth rate	The number of births per thousand individuals in a population per year.
crude death rate	The number of deaths per thousand individuals in a population per year.
cyclone (tropical), typhoon	Vortex-like centres of very low pressure, associated with extremely high, often destructive winds blowing towards the centre or “eye”. Tropical cyclones form over the warm, tropical waters of the Indian and Pacific Oceans and the Caribbean Sea.
demographic transition	A general model describing the changing levels of fertility and mortality in a human population over time. It was developed with reference to the transition experienced as developed countries (eg those of North America, Europe, Australasia) passed through the processes of industrialization and urbanization.
depression (temperate cyclone)	A region of relatively low pressure (up to 2000 km across) in middle latitudes, in which winds spiral inwards and counter-clockwise in the northern hemisphere and clockwise in the south. Depressions or temperate cyclones are associated with windy, cloudy and wet weather.
diversity	A generic term for heterogeneity. The scientific meaning of diversity becomes clear from the context in which it is used; it may refer to heterogeneity of species or habitat, or to genetic heterogeneity.
diversity, genetic	The range of genetic material present in a gene pool or population of a species. Domestication and plant breeding lead to a loss of genetic variety, hence the importance of “gene banks”.
diversity, habitat	The range of different habitats in an ecosystem, community or biome associated with the variety of niches that may be exploited by different species. Conservation of habitat diversity usually leads to the conservation of species and genetic diversity.

diversity index	A numerical measure of species diversity that is derived from both the number of species (variety) and their proportional abundance.
diversity, species	The variety of species per unit area. This includes both the number of species present and their relative abundance.
doubling time	The number of years it would take a population to double its size at its current growth rate. A natural increase rate of 1% will enable a human population to double in 70 years. Other doubling times can then be calculated proportionately, ie the doubling time for any human population is equal to 70 divided by the natural increase rate.
ecological footprint	The area of land and water required to support a defined human population at a given standard of living. The measure takes account of the area required to provide all the resources needed by the population, and the assimilation of all wastes. (A method of calculation is provided in section B.3.2).
ecosystem	A community of interdependent organisms and the physical environment they inhabit.
entropy	A measure of the amount of disorder, chaos or randomness in a system; the greater the disorder, the higher the level of entropy.
environmental impact assessment (EIA)	A method of detailed survey required, in many countries, before a major development. Ideally it should be independent of, but paid for by, the developer. Such a survey should include a baseline study to measure environmental conditions before development commences, and to identify areas and species of conservation importance. The report produced is known as an environmental impact statement (EIS) or environmental management review in some countries. The monitoring should continue for some time after the development.
equilibrium	A state of balance among the components of a system.
eutrophication	The natural or artificial enrichment of a body of water, particularly with respect to nitrates and phosphates, that results in depletion of the oxygen content of the water. Eutrophication is accelerated by human activities that add detergents, sewage or agricultural fertilizers to bodies of water.
evolution	The cumulative, gradual change in the genetic characteristics of successive generations of a species or race of an organism, ultimately giving rise to species or races different from the common ancestor. Evolution reflects changes in the genetic composition of a population over time.
feedback	The return of part of the output from a system as input, so as to affect succeeding outputs.

feedback, negative	Feedback that tends to damp down, neutralize or counteract any deviation from an equilibrium, and promotes stability.
feedback, positive	Feedback that amplifies or increases change; it leads to exponential deviation away from an equilibrium.
fertility	In the context of human populations this refers to the potential for reproduction exhibited in a population. It may be measured as fertility rate, which is the number of births per thousand women of child-bearing age. It may alternatively be measured as total fertility, which is simply the average number of children a woman has in her lifetime.
global warming	The increase, or possible future increase in the average temperature of the Earth's atmosphere, as the result of the build-up of greenhouse gases (eg carbon dioxide, methane).
greenhouse gases	Those atmospheric gases which absorb infrared radiation, causing world temperatures to be warmer than they would otherwise be. This process is sometimes known as "radiation trapping". The natural greenhouse effect is caused mainly by water and carbon dioxide. Human activities have led to an increase in the levels of carbon dioxide, methane and nitrous oxide in the atmosphere and there are fears that this may lead to **global warming**.
habitat	The environment in which a species normally lives.
Hadley cell	A meridional circulation model of the atmosphere; low-level movement of air from about 30° latitude to the equator, rising air near the equator, polewards flow aloft, and descending near 30°.
halogenated organic gases	Usually known as halocarbons and first identified as depleting the ozone layer in the stratosphere. Now known to be potent greenhouse gases.
isolation	The process by which two populations become separated by geographical, behavioural, genetic or reproductive factors. If gene-flow between the two sub-populations is prevented, new species may evolve. See **evolution**.
K-strategists	Species using *K*-strategies will usually concentrate their reproductive investment in a small number of offspring thus increasing their survival rate and adapting them for living in long-term climax communities.
latitude	The angular distance from the equator (ie north or south of it) as measured from the centre of the Earth (usually in degrees).
model	An artificial construction designed to represent the properties, behaviour or relationship between individual parts of the real entity being studied.

mutualism
A relationship between individuals of two or more species in which all benefit and none suffer. (The term symbiosis will not be used.)

natural capital
A term sometimes used by economists for natural resources that, if appropriately managed, can produce a "natural income" of goods and services. The natural capital of a forest might provide a continuing natural income of timber, game, water and recreation.

natural capital, non-renewable
Natural resources which cannot be replenished within a time scale of the same order as that at which they are taken from the environment and used, eg fossil fuels.

natural capital, renewable
Natural resources that have a sustainable yield or harvest equal to or less than their natural productivity, eg food crops, timber.

natural capital, replenishable
Non-living natural resources that depend on the energy of the sun for their replenishment, eg groundwater.

natural increase, rate of
The form in which human population growth rates are usually expressed.

$$\frac{\text{Crude birth rate} - \text{crude death rate}}{10}$$

Inward and outward migration is ignored.

niche
A species' share of a habitat and the resources in it. An organism's ecological niche depends not only on where it lives but on what it does. (The part of the habitat in which a species can live in the absence of competitors and predators is called its fundamental niche. The part it actually occupies is its realized niche.)

parasitism
A relationship between two species in which one species (the parasite) lives in or on another (the host), gaining all or much (in the case of a partial parasite) of its food from it.

plankton
Very small marine or freshwater organisms living in, and drifting with, the body of the water. Phytoplankton are photosynthesizing organisms (eg unicellular algae that form the base of many food chains); zooplankton consists of minute animals.

plate tectonics
The movement of the eight major and several minor internally rigid plates of the lithosphere in relation to each other and to the partially mobile asthenosphere below.

pollution
The addition to an environment of a substance or an agent (such as heat) by human activity, at a rate greater than that at which it can be rendered harmless by the environment, and which has an appreciable effect on the organisms within it.

pollution, non-point source	The release of pollutants from numerous, widely dispersed origins (eg gases from the exhaust systems of vehicles).
pollution, point source	The release of pollutants from a single, clearly identifiable site (eg a factory chimney or the waste disposal pipe of a factory into a river).
population	A group of organisms of the same species living in the same area at the same time, and which are capable of interbreeding.
production ecology	The study of the flow of energy within and between trophic levels of ecosystems.
productivity, gross primary (GPP)	The quantity of organic matter produced, or solar energy fixed, by photosynthesis in green plants per unit area per unit time.
productivity, net primary (NPP)	Gross primary productivity less the biomass or energy lost by plants through respiration (R): NPP = GPP – R. The quantity of biomass potentially available to consumers in an ecosystem is indicated by NPP. It is measured in units of mass or energy per unit area per unit time.
productivity, secondary	The biomass gained by heterotrophic organisms, through feeding and absorption, measured in units of mass or energy per unit area per unit time.
r-strategists	Species using *r*-strategies will tend to spread their reproductive investment among a large number of offspring so that they are well adapted to colonize new habitats rapidly and make opportunistic use of short-lived resources.
sere	The set of communities that succeed one another over the course of succession at a given location.
smog	The term now used for any haziness in the atmosphere caused by air pollutants. Photochemical smog is produced through the effect of ultraviolet light on the products of internal combustion engines. It may contain ozone and is damaging to the human respiratory system and eyes.
soil	The loose aggregate of mineral and other particles that covers the land, and in which terrestrial plants generally grow.
soil profile	A vertical section through a soil, from the surface down to the parent material, revealing the soil layers or horizons.
speciation	The process through which new species form. (See also **evolution**.)
species	A group of organisms that interbreed and produce fertile offspring.

stable equilibrium	The condition of a system in which there is a tendency for it to return to a previous equilibrial condition following disturbance.
standing crop	See **biomass**.
steady-state equilibrium	The condition of an open system in which there are no changes over the longer term, but in which there may be oscillations in the very short term. There are continuing inputs and outputs of matter and energy, but the system as a whole remains in a more-or-less constant state (eg a climax ecosystem).
succession	The orderly process of change over time in a community. Changes in the community of organisms frequently cause changes in the physical environment that allow another community to become established and replace the former through competition. Often, but not inevitably, the later communities in such a sequence or sere are more complex than those that appear earlier.
sustainability	The extent to which a given interaction with the environment exploits and utilizes the natural income without causing long-term deterioration to the natural capital. For example, a system of harvesting renewable resources at a rate that will be replaced by natural growth might be considered to demonstrate sustainability.
system	An assemblage of parts, together with the relationships between them, which together constitute an entity or whole.
system, closed	A system in which energy is exchanged across the boundaries of the system, but matter is not.
system, isolated	A system that exchanges neither matter nor energy with its environment.
system, open	A system in which both matter and energy are exchanged across the boundaries of the system (eg natural ecosystems).
trophic level	The position that an organism occupies in a food chain, or a group of organisms in a community that occupy the same position in food chains.
zonation	The arrangement or patterning of plant communities or ecosystems into parallel or sub-parallel bands in response to change, over a distance, in some environmental factor. The main biomes display zonation in relation to latitude and climate. Plant communities may also display zonation with altitude on a mountain, or around the edge of a pond in relation to soil moisture.

MATHEMATICAL REQUIREMENTS

All Diploma Programme environmental systems students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- carry out simple calculations within an environmental systems context involving means, decimals, fractions, percentages, ratios, approximations and reciprocals
- use standard notation (eg 3.6×10^6)
- use direct and inverse proportion
- interpret frequency data in the form of bar charts, column graphs and histograms, and interpret pie charts
- understand the significance of the standard deviation of a set of data
- recognize basic geometric shapes
- plot graphs (with suitable scales and axes) and sketch graphs
- interpret graphs, including the significance of gradients, changes in gradients, intercepts and areas
- demonstrate sufficient knowledge of probability (eg in assessing risks in environmental impact).

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