Marine science guide

First assessment May 2016

Notes

- This document should be read in conjunction with the *Handbook of procedures for the Diploma Programme* section B11: School-based Syllabuses (SBS).
- As an SBS, **Marine Science** may be offered only by schools authorized by the IB to do so prior to the commencement of the course.
- A student may not combine an SBS with a pilot programme or another SBS within the same Diploma.
- Any queries arising from this documentation should be directed in the first instance to the Subject Manager, via IB Answers.

Diploma Programme
Marine science guide

This syllabus has been designed and developed by the United World College of the Pacific/Lester B Pearson, Canada, in conjunction with the International Baccalaureate.

The International Baccalaureate is a not-for-profit educational foundation, of 15 Route des Morillons, 1218 Le Grand-Saconnex, Geneva, Switzerland.

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IB mission statement

The International Baccalaureate aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end the organization works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.

IB learner profile

The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

As IB learners we strive to be:

INQUIRERS
We nurture our curiosity, developing skills for inquiry and research. We know how to learn independently and with others. We learn with enthusiasm and sustain our love of learning throughout life.

KNOWLEDGEABLE
We develop and use conceptual understanding, exploring knowledge across a range of disciplines. We engage with issues and ideas that have local and global significance.

THINKERS
We use critical and creative thinking skills to analyse and take responsible action on complex problems. We exercise initiative in making reasoned, ethical decisions.

COMMUNICATORS
We express ourselves confidently and creatively in more than one language and in many ways. We collaborate effectively, listening carefully to the perspectives of other individuals and groups.

PRINCIPLED
We act with integrity and honesty, with a strong sense of fairness and justice, and with respect for the dignity and rights of people everywhere. We take responsibility for our actions and their consequences.

OPEN-MINDED
We critically appreciate our own cultures and personal histories, as well as the values and traditions of others. We seek and evaluate a range of points of view, and we are willing to grow from the experience.

CARING
We show empathy, compassion and respect. We have a commitment to service, and we act to make a positive difference in the lives of others and in the world around us.

RISK-TAKERS
We approach uncertainty with forethought and determination; we work independently and cooperatively to explore new ideas and innovative strategies. We are resourceful and resilient in the face of challenges and change.

BALANCED
We understand the importance of balancing different aspects of our lives—intellectual, physical, and emotional—to achieve well-being for ourselves and others. We recognize our interdependence with other people and with the world in which we live.

REFLECTIVE
We thoughtfully consider the world and our own ideas and experience. We work to understand our strengths and weaknesses in order to support our learning and personal development.

The IB learner profile represents 10 attributes valued by IB World Schools. We believe these attributes, and others like them, can help individuals and groups become responsible members of local, national and global communities.

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Purpose of this document

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

Additional resources

Past examination papers as well as markschemes for Marine Science can be obtained free of charge from the IB: please contact IB Answers.

Teachers of the subject are encouraged to communicate with each other where possible to provide details of useful resources, for example: websites, books, videos, journals or teaching ideas.

Acknowledgment

The IB wishes to thank the educators and associated schools for generously contributing time and resources to the production of this guide.

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The Diploma programme

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

The Diploma programme model

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

Figure 1
Diploma Programme model

Choosing the right combination

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

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

The core of the Diploma Programme Model

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

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

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

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

Approaches to teaching and approaches to learning

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

- empower teachers as teachers of learners as well as teachers of content
- empower teachers to create clearer strategies for facilitating learning experiences in which students are more meaningfully engaged in structured inquiry and greater critical and creative thinking
- promote both the aims of individual subjects (making them more than course aspirations) and linking previously isolated knowledge (concurrency of learning)
- encourage students to develop an explicit variety of skills that will equip them to continue to be actively engaged in learning after they leave school, and to help them not only obtain university admission through better grades but also prepare for success during tertiary education and beyond
- enhance further the coherence and relevance of the students' Diploma Programme experience
- allow schools to identify the distinctive nature of an IB Diploma Programme education, with its blend of idealism and practicality.

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

The IB mission statement and the IB learner profile

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

Academic honesty

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

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

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

Acknowledging the ideas or work of another person

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

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

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

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

Learning diversity and learning support requirements

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

Nature of Science

The Nature of science (NOS) is an overarching theme in the biology, chemistry, physics and marine science courses. This section, titled Nature of science, is in the biology, chemistry, physics and marine science guides to support teachers in their understanding of what is meant by the nature of science. The "Nature of science" section of the guide provides a comprehensive account of the nature of science in the 21st century. It will not be possible to cover in this document all the themes in detail in the science courses, either for teaching or assessment.

It has a paragraph structure (1.1, 1.2, etc.) to link the significant points made to the syllabus (landscape pages) references on the NOS. The NOS parts in the subject-specific sections of the guide are examples of a particular understanding. The NOS statement(s) above every sub-topic outline how one or more of the NOS themes can be exemplified through the understandings, applications and skills in that sub-topic. These are not a repeat of the NOS statements found below but an elaboration of them in a specific context. See the section on “Format of the syllabus”.

Technology

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2. The understanding of science

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

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

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

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

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

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

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

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

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

3. The objectivity of science

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

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

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

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

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

3.6. Although scientists cannot ever be certain that a result or finding is correct, we know that some scientific results are very close to certainty. Scientists often speak of “levels of confidence” when discussing outcomes. The discovery of the existence of a Higgs boson is such an example of a “level of confidence”. This particle may never be directly observable, but to establish its “existence” particle physicists had to pass the self-imposed definition of what can be regarded as a discovery— the 5-sigma “level of certainty”—or about a 0.00003% chance that the effect is not real based on experimental evidence.

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

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

4. The human face of science

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

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

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

- The Manhattan project, the aim of which was to build and test an atomic bomb. It eventually employed more than 130,000 people and resulted in the creation of multiple production and research sites that operated in secret, culminating in the dropping of two atomic bombs on Hiroshima and Nagasaki.
- The Human Genome Project (HGP), which was an international scientific research project set up to map the human genome. The $3-billion project beginning in 1990 produced a draft of the genome in 2000. The sequence of the DNA is stored in databases available to anyone on the internet.
- The IPCC (Intergovernmental Panel on Climate Change), organized under the auspices of the United Nations, is officially composed of about 2,500 scientists. They produce reports summarizing the work of many more scientists from all around the world.
- CERN, the European Organization for Nuclear Research, an international organization set up in 1954, is the world's largest particle physics laboratory. The laboratory, situated in Geneva, employs about 2,400 people and shares results with 10,000 scientists and engineers covering over 100 nationalities from 600 or more universities and research facilities.

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

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

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

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

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

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

5. Scientific literacy and the public understanding of science

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

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

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

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

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

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

The flow chart below is a part of an interactive flow chart showing the scientific process of inquiry in practice. The interactive version can be found at "How science works: The flowchart." Understanding Science. University of California Museum of Paleontology. 1 February 2013 <**http://undsci.berkeley.edu/article/scienceflowchart**>.

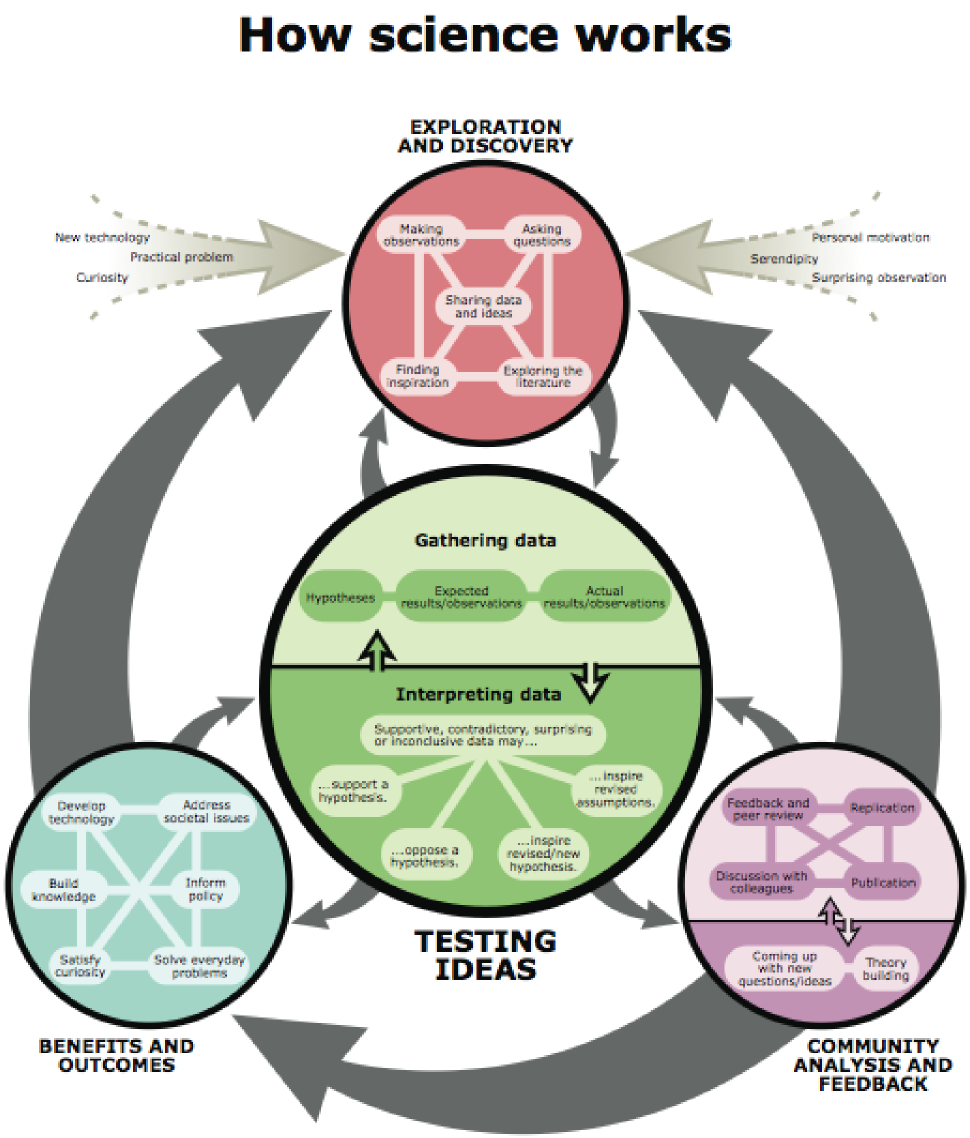

Figure 2
Pathways to scientific discovery

Nature of Marine Science

The oceans comprise over two thirds of the surface of the planet and more than half of the global population lives in coastal cities, yet many aspects of marine science remain a mystery to humans. Scientists are only beginning to delve into and understand the mostly unexplored realm of the open ocean and the deep sea. With the development of new technology and increasing international cooperation, much is being learned about interactions between marine organisms and about their habitats, about essential sea-surface to atmosphere interactions, and about geological dynamics.

The nature of marine science is multidisciplinary as it encompasses natural sciences including: biology, chemistry, physics, geology, and meteorology, as well as social sciences such as geography, economics, politics and history. El Niño, fishing rights, global warming, coral bleaching, ocean pollution, storm & tsunami preparedness and oil exploration are among the many current international issues that revolve around the oceans.

Historically, the oceans have been a source of fascination and inspiration and have played a significant role in the lives of many humans. The resources extracted from the oceans, the transport of goods across oceans and the services provided by the oceans have a huge impact on human population dynamics. Many coastal populations are dependent on the oceans as a source of food and, as stores of fossil fuels are being depleted, the harvesting of energy from the oceans is increasingly of interest. In addition, the oceans provide many essential ecological services including the production of oxygen, the absorption of the greenhouse gas, carbon dioxide, and the processing of wastes. Ocean processes also play a major role in the regulation of climate. Because of our close connection with the ocean it is essential to understand the variety of human interactions with the marine environment.

Unfortunately, many human activities are having a negative impact on the oceans. Overfishing, pollution, habitat destruction, the introduction of alien species, and urban development are altering the marine ecosystems. In order to conserve the marine habitat, upon which so many rely, it is essential that global citizens have an understanding of their impact on the ocean. This is true regardless of where they are living, due to the interconnectedness between the oceans and all other ecosystems of the biosphere.

The study of marine science lends itself very well to hands-on work and consequently is easily carried out in a coastal location where there will be many opportunities for practical work both in the field and in the laboratory. In addition, topics in physical oceanography lend themselves to the use of ocean modeling and analysis of satellite imagery which may be studied anywhere. In all practical work, students are encouraged to develop an appreciation for the question, How do we know what is true? This question invites an essential of experimental sciences, verification. The technologies used in marine science make these questions especially pertinent.

Approaches to Teaching

There are a variety of approaches to the teaching of marine science. By its very nature, marine science lends itself to an experimental approach, and it is expected that this will be reflected throughout the course. Because of the continual flow of information about oceans via satellite linkages, regular use of Earth-monitoring websites should accompany the course.

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. Sections of the option material may be taught within the core material if desired or the option material can be taught as a separate unit.

Science and the international dimension

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

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

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

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

Students' attention should be drawn to sections of the syllabus with links to international-mindedness. Examples of issues relating to international-mindedness are given within sub-topics in the syllabus content. Teachers could also use resources found on the Global Engage website (http://globalengage.ibo.org).

Prior learning

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

Links to the Middle Years Programme

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

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

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

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

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

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

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

Science and theory of knowledge

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

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

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

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

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

Aims

Group 4 Aims

Through studying 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 is the emphasis on a practical approach through experimental work that characterizes each these subjects.

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

1. appreciate scientific study and creativity within a global context through stimulating and challenging opportunities

2. acquire a body of knowledge, methods and techniques that characterize science and technology

3. apply and use a body of knowledge, methods and techniques that characterize science and technology

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

5. develop a critical awareness of the need for, and the value of, effective collaboration and communication during scientific activities

6. develop experimental and investigative scientific skills including the use of current technologies

7. develop and apply 21st century communication skills in the study of science

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

9. develop an appreciation of the possibilities and limitations of science and technology

10. develop an understanding of the relationships between scientific disciplines and their influence on other areas of knowledge.

Assessment Objectives

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

1. Demonstrate knowledge and understanding of:
    a. facts, concepts, and terminology
    b. methodologies and techniques
    c. communicating scientific information.

2. Apply:
    a. facts, concepts, and terminology
    b. methodologies and techniques
    c. methods of communicating scientific information.

3. Formulate, analyse and evaluate:
    - hypotheses, research questions and predictions
    - methodologies and techniques
    - primary and secondary data
    - scientific explanations.

4. Demonstrate the appropriate research, experimental, and personal skills necessary to carry out insightful and ethical investigations.

Syllabus Outline

Syllabus component	Teaching hours
Core	**95**
1. Origin and structure of oceans	5
2. Dynamics of Earth's crust	8
3. Patterns of water movement	20
4. Properties of ocean water	12
5. Life in oceans	50
Options	**15**
A. Marine ecosystems and conservation	15
B. Atmosphere, ocean and climate	15
C. Geology of ocean basins	15
Practical scheme of work	**40**
Practical activities	20
Individual investigation (internal assessment - IA)	10
Group 4 Project	10
Total teaching hours	**150**

The recommended teaching time is 150 hours to complete SL courses as stated in the document *General regulations: Diploma Programme for students and their legal guardians* (2011) (page 4, Article 8.2).

Format of the syllabus

The format of the syllabus section of the group 4 guides is the same for physics, chemistry, biology and marine science. This new structure gives prominence and focus to the teaching and learning aspects.

Topics or options

Core topics are numbered, and options are indicated by a letter. For example, “Topic 1: Origin and structure of oceans”, or “Option B: Atmosphere, ocean and climate".

Sub-topics

Sub-topics are numbered as follows, “4.1 Physical properties of seawater”.

Each sub-topic begins with an essential idea. The essential idea is an enduring interpretation that is considered part of the public understanding of science. This is followed by a section on the “Nature of science”. This gives specific examples in context illustrating some aspects of the nature of science. These are linked directly to specific references in the "Nature of science" section of the guide to support teachers in their understanding of the general theme to be addressed.

Under the overarching Nature of science theme there are two columns. The first column lists "Understandings", which are the main general ideas to be taught. There follows an “Applications and skills” section that outlines the specific applications and skills to be developed from the understandings. A "Guidance" section gives information about the limits and constraints and the depth of treatment required for teachers and examiners. The contents of the “Nature of science” section above the two columns and contents of the first column are all legitimate items for assessment. In addition, some assessment of international-mindedness in science, from the content of the second column, will take place as in the previous course.

The second column gives suggestion to teachers about relevant references to international-mindedness. It also gives examples of TOK knowledge questions (see *Theory of knowledge* guide published 2013) that can be used to focus students' thoughts on the preparation of the TOK prescribed essay. The “Utilization” section may link the sub-topic to other parts of the subject syllabus, to other Diploma Programme subject guides or to real-world applications. Finally, the "Aims" section refers to how specific group 4 aims are being addressed in the sub-topic.

Format of the guide

Topic 1: <Title>

Essential idea: This lists the Essential idea for each sub-topic.

<table>
<tr><th colspan="2">1.1 Sub-topic</th></tr>
<tr><td colspan="2">Nature of science: Relates the sub-topic to the overarching theme of Nature of science</td></tr>
<tr><td>Understandings:
▪ This section will provide specifics of the content requirements for each sub-topic.
Applications and skills:
▪ The content of this section gives details of how students are to apply the understandings. For example, these application could involve demonstrating mathematical calculations or practical skills.
Guidance:
▪ This section will provide specifics and give constraints to the requirements for the understandings and applications and skills.</td><td>International-mindedness:
▪ Ideas that teachers can easily integrate into the delivery of their lessons.
Theory of Knowledge:
▪ Examples of TOK knowledge questions.
Utilization:
▪ Links to other topics within the marine science guide, to a variety of real-world applications and to other Diploma Programme courses.
Aims:
▪ Links to the group 4 subject aims.</td></tr>
</table>

Group 4 experimental skills

"I hear and I forget. I see and I remember. I do and I understand."

Confucius

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

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

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

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

The "Applications and skills" section of the syllabus lists specific lab skills, techniques and experiments that students must experience at some point during their study of their group 4 course. Other recommended lab skills, techniques and experiments are listed in the "Aims" section of the subject-specific syllabus pages. Aim 6 of the group 4 subjects directly relates to the development of experimental and investigative skills.

Mathematical requirements

All Diploma Programme marine science students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- carry out calculations involving means, decimals, fractions, percentages and ratios
- represent and interpret frequency data in the form of bar charts, graphs and histograms direct and inverse proportion
- plot graphs (with suitable scales and axes) involving two variables that show linear or non-linear relationships
- plot and interpret scattergraphs to identify a correlation between two variables, and appreciate that the existence of a correlation does not establish a causal relationship
- determine the mode and median of a set of data, calculate and analyse standard deviation
- select statistical tests appropriate for the analysis of particular data and interpret the results.

Use of information communication technology

The use of information communication technology (ICT) is encouraged throughout all aspects of the course in relation to both the practical programme and day-to-day classroom activities. Marine science teachers should make use of the ICT pages of the biology teacher support materials.

Planning your course

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

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

The IB learner profile and group 4 subjects

The marine science course is closely linked to the IB learner profile. By following the course, students will have engaged with the attributes of the IB learner profile. For example, the requirements of the internal assessment provide opportunities for students to develop every aspect of the profile. For each attribute of the learner profile, a number of references from the Group 4 courses are given below.

Learner profile attribute	**Biology, chemistry, physics, marine science**
Inquirers	Aims 2 and 6 Practical work and internal assessment
Knowledgeable	Aims 1 and 10, international-mindedness links Practical work and internal assessment
Thinkers	Aims 3 and 4, theory of knowledge links Practical work and internal assessment
Communicators	Aims 5 and 7, external assessment Practical work and internal assessment
Principled	Aims 8 and 9 Practical work and internal assessment. ethical behaviour/practice (*Ethical practice in the Diploma Programme* poster, *IB animal experimentation policy),* academic honesty
Open-minded	Aims 8 and 9, international-mindedness links Practical work and internal assessment, the group 4 project
Caring	Aims 8 and 9 Practical work and internal assessment, the group 4 project, ethical behaviour/practice (*Ethical practice in the Diploma Programme* poster, *IB animal experimentation policy)*
Risk-takers	Aims 1 and 6 Practical work and internal assessment, the group 4 project
Balanced	Aims 8 and 10 Practical work and internal assessment, the group 4 project and field work
Reflective	Aims 5 and 9 Practical work and internal assessment, the group 4 project

Syllabus content

Recommended teaching hours

Core		**95 hours**
Topic 1 Origin and Structure of Oceans		
1.1	Physical structure of the oceans	
1.2	Describing ocean basins	
1.3	Origin of the oceans	
Topic 2 Dynamics of Earth's Crust		
2.1	Plate tectonics and seismic activity	
2.2	Evidence of tectonics	
2.3	Tsunamis	
Topic 3 Patterns of Water Movement		
3.1	Interactions between atmosphere and ocean	
3.2	Water cycle	
3.3	Waves	
3.4	Tides	
3.5	Surface currents	
3.6	Deep ocean circulation	
Topic 4 Properties of Ocean Water		
4.1	Physical properties of water	
4.2	Chemical properties of seawater	
4.3	Ocean acidification	
4.4	Ocean water profiles	
Topic 5 Life in Oceans		
5.1	Plankton and productivity	
5.2	Open ocean ecosystem	
5.3	Rocky shore ecosystem	
5.4	Estuary ecosystems	
5.5	Coral reef ecosystems	
5.6	Polar ocean ecosystems	
5.7	Deep sea and hydrothermal vent ecosystems	
Options		**15 hours**
A. Marine ecosystems and conservation		
A.1	Plankton as the link among all marine ecosystems	
A.2	Kelp forests/seagrass beds/salt marshes and mangrove forests	
A.3	Sediment-covered ecosystems	
A.4	Threats to marine ecosystems	
A.5	Conservation and public policy	
B. Atmosphere, ocean and climate		
B.1	Hurricanes and typhoons	
B.2	Climate, the oceans and the cryosphere	
B.3	Climate record and climate change	
B.4	Climate modeling	
B.5	Science to mitigate coastal disasters	
C. Geology of ocean basins		
C.1	Coastal dynamics	
C.2	Sediments and oozes	
C.3	Mining the ocean floor	
C.4	Human activity and marine disasters	
C.5	Using science to understand marine catastrophes	

Core

Topic 1: Origin and structure of oceans (5 hours)

Essential idea: There is one World Ocean divided into many basins with hydrospheric, lithospheric and atmospheric components

<table>
<tr><th colspan="2">1.1 Physical Structure of Oceans</th></tr>
<tr><td colspan="2">Nature of science: Paradigm shifts change perspective of scientific exploration--old paradigm saw individual bodies of water and ownership by nations; new paradigm describes One World Ocean with ocean basins named and viewed as inter-related with the whole system; promotes international cooperation among scientists. [2.3]</td></tr>
<tr><td>Understandings:
▪ spatial understanding of oceans includes two surface dimensions as well as vertical dimensions
▪ effect of latitude is a recurring factor in each topic of study
▪ examination of oceans includes the water as well as lithosphere beneath with coastlines and atmosphere
▪ geographic coordinate system of latitude and longitude is used to describe locations

Applications and skills:
▪ naming and locating the world's oceans and major seas
▪ recognizing chart projections with their advantages and distortions
▪ using physical globe to increase understanding of spatial relationships

Guidance:
▪ In addition to the 5 named oceans, major seas should also be located including Mediterranean, Yellow, Red, Black, North, Baltic, Arabian, South China, Beaufort, Weddell, Ross and Caribbean Seas as well as Gulf of Mexico, Persian Gulf and other seas, bays and gulfs of local importance.</td><td>International-mindedness:
Examine the questions of jurisdiction over waters, especially in the Arctic Ocean. What happens when national codes disagree? Who decides?

Theory of Knowledge:
How does observing maps on a globe rather than a flat map change perceptions and understanding of Earth?

Utilization:
▪ oceans influence weather and climate and are used to make predictions
▪ understanding of oceans is used to facilitate commerce, industry and to explore solutions to the human energy crisis
▪ Geography Option B sub-topics 1 and 4
Aims:
Aim 1: appreciate scientific study and creativity within a global context</td></tr>
</table>

Essential idea: The lithosphere determines characteristics of ocean basins with marginal and oceanic features and interfaces with continents at coastlines.

<table>
<tr><th colspan="2">1.2 Describing Ocean Basins</th></tr>
<tr><td colspan="2">Nature of science:
Use of models to represent reality [1.10]
Verification among techniques increases certainty and improves the level of confidence [3.6]</td></tr>
<tr><td>Understandings:
▪ bathymetry can be used to determine the topography of ocean basins
▪ satellite altimetry is used for mapping the ocean topography and can be verified by bathymetric techniques

Applications and skills:
▪ skill: contour mapping from data collected by echo-soundings; create a topographic profile from a transect of a contour map (practical 1)
▪ skill: labeling features on a model or map of a continental margin and ocean floor
▪ skill: drawing and explaining the hypsographic curve

Guidance:
▪ identification of abyssal plain, basin, canyon, continental shelf, fracture zone, mid-oceanic ridge, seamount and trench is expected
▪ locations of named features include Mid-Atlantic Ridge, East Pacific Rise, Mariana Trench and Challenger Deep</td>
<td>International-mindedness:
▪ Satellites are international ventures. for example the Topex-Poseidon is a joint venture between France and the USA

Theory of Knowledge:
▪ Why do we believe that satellite to sea-surface altimetry data can tell us the topography below the sea surface? How is this certainty established?

Utilization:
▪ sharing bathymetry of harbors enhances safety

Aims:
▪ aims 6/7: Develop an understanding of satellite altimetry and its use in mapping the topography of oceans

▪ aim 9: recognize the limitations (and therefore the need for independent verification) of satellite and bathymetric technologies</td></tr>
</table>

Essential idea: Earth has changed in the billions of years since its origin.

<table>
<tr><th colspan="2">1.3 Origin of Oceans</th></tr>
<tr><td colspan="2">Nature of science: The underlying assumption of science is that the universe has an independent reality accessible to human senses and reasoning [1.1]
The use of verifiable patterns provides evidence for analysis that must be examined without bias in order to be scientific in nature. [3.5]</td></tr>
<tr><td>Understandings:
conditions of the early planet including atmospheric composition and lack of water.
alternative ideas about how oceans formed
evidence used to explore the changing planet
Applications and skills:
timeline of events since formation of planet
evidence of atmospheric qualities from ice cores
Guidance:
This topic provides opportunity to examine the nature of science dilemma that occurs when an event cannot be repeated. The use of verifiable patterns provides evidence for analysis that must be examined without bias in order to be scientific in nature.</td><td>International-mindedness:

Theory of Knowledge:
discussion: Does an event need to be repeatable for it to be studied scientifically?

Utilization:

Aims:
Aim 6 Develop investigative skills including the use of current technologies-ice cores used to examine past atmospheres of Earth.</td></tr>
</table>

Topic 2: Dynamics of Earth's crust (8 hours)

Essential idea: Plate tectonics explains dynamics of Earth's crust and remodeling of oceans.

2.1 Plate tectonics and seismic activity

Nature of science: Wegener's ideas about continental drift were initially explored and then dismissed for several decades by the scientific community? In the 1960s a revision of his ideas brought about a paradigm shift in the scientific community. [2.3]

Use of models as representations of the real world [1.10]

Understandings:

- Earth has several moving plates outlined by intense earthquake activity at the edges of plates
- mechanisms have been proposed for the movement of plates
- movements include subduction, seafloor spreading, mountain building
- plate movement over a hotspot has created the Emperor seamounts and the Hawaiian islands
- marine trenches, island arcs, rift valleys, seamounts, mid-ocean ridges result from seismic activities due to plate tectonics

Applications and skills:

- skill: modeling plate actions
- skill: mapping plates and their movements on a globe
- skill: determining an earthquake epicenter from seismic readings
- limitations of models

Guidance:

- students should recognize generic features and be able to locate and name only the following features: East Pacific Rise, Mariana Trench, Challenger Deep and the Mid-Atlantic Ridge. Plate activities and names of features local to the school should also be included.

International-mindedness:

The online video, "The Blue Marble," has photographs from Earth taken by an astronaut who uses them to enhances our understanding that we all live on a beautiful planet together.

Theory of Knowledge:

consider: How have the images of Earth from satellites promoted our knowledge about plate tectonics facilitating the paradigm shift of the 1960s?

Utilization:

Prediction of seismic events helps save lives and protect property.

Geography Option D sub-topic 1

Aims:

- **Aim 6** Develop investigative skills including the use of satellite data.
- **Aim 7** Apply 21st century communication skills in the use of satellite data
- **Aim 9** Develop an appreciation of the limitations of models as representations of the real world

Essential idea: Data from several different types of instruments used across the world ocean make it possible to construct an understanding of plate tectonics.

<table>
<tr><td colspan="2">2.2 Evidence of Tectonics</td></tr>
<tr><td colspan="2">Nature of science:
Looking for patterns, trends and discrepancies [3.1]
Importance of verification among data sets in the building of a theory [1.3, 1.8]</td></tr>
<tr><td>Understandings:
▪ evidence includes magnetic anomalies, temperature data, earthquake epicenter profiles, etc.
▪ use of hotspot data in the Pacific to measure rate and direction of movements of the Pacific Plate

Applications and skills:
▪ skill: examining data from edges of plates
▪ data sets collected by magnetometers, seismographs, bathythermographs and core samplings can be analysed
▪ skill: analysing of the velocity of plate movement

Guidance:
Connections should be made between the data sets and models of plate interactions.
Attention should be paid to where the data sets were taken</td>
<td>International-mindedness:
Cabled observatories such as MARS / NEPTUNE contribute to the data collected and shared internationally.

Theory of Knowledge:
To what extent has the evidence for tectonics been responsible for the paradigm shift of the 1960s? Why was the evidence necessary?

Utilization:

Aims:
▪ Aim 2 Acquire understanding of techniques that characterize science including bathythermographs, magnetometers, seismographs and core samplings.

▪ Aim 3 Apply the body of knowledge gained by these techniques.

▪ Aim 4 Synthesize scientific data from these techniques to explain crustal dynamics</td></tr>
</table>

Essential idea: A tsunami is a shallow-water ocean wave that develops in response to a subduction earthquake or submarine landslide that may not have much effect on the open ocean, but may have devastating effect as it reaches land.

2.3 Tsunamis

Nature of science: Developing tools that can accurately detect and thereby be used to predict the magnitude and timing of an arriving tsunamis has been an engineering challenge. [1.8]

Understandings:

- tsunamis are generated by subsidence earthquakes, as well as submarine landslides and meteorites large enough to displace a large volume of water as well as volcanic eruptions and calving glaciers
- the wave characteristics change as the wave crosses the ocean and approaches shore. (in open oceans a wave may be less than a meter high with a period of 10 to 30 min and a wavelength of 100 - 200 km, but at a coast it may be 100 m high with shorter wavelengths as the energy of the wave is compressed into a smaller column of water.)
- tsunamis are detected by DART*with tsunameters that communicate with surface buoys and satellite communication
- subduction tsunamis that occur near a coastline cause subsidence of the shore which complicates the effect of the tsunamis

Applications and skills:

- skill: Use archival data to calculate the dimensions of a named tsunami.

Guidance:

- Excellent documentaries are available as well as You-tube clips about recent tsunamis events.
- *DART refers to Deep-ocean Assessment and Reporting of Tsunamis
- Students should be able to describe how the detection and warning
- devices work.
- Information on the subsidence tsunamis along the coast of Washington-Oregon USA can be obtained. It indicates how scientists have established the actual hour at which the earthquake occurred in 1700 and its probable magnitude using Japanese harbor records, tree ring analysis and sediment core samples from coastal marshes. Refer to the work of Brian Atwater and Curt Peterson.

International-mindedness:

UNESCO has worked since the 2004 tsunamis in the Indian ocean to establish a tsunamis warning system there.

Theory of Knowledge:

Utilization:

National governments and international organizations work to mitigate the tsunamis hazard.

topic 3.3 and 2.2

Aims:

- **Aim 2/3** Acquire and apply a body of knowledge, methods and techniques to study tsunamis

Topic 3: Patterns of water movement (20 hours)

Essential idea: There is a dynamic interplay between atmosphere and ocean.

3.1 Interactions between atmosphere and ocean

Nature of science: Use of models to represent reality [1.10]
Looking for patterns, trends and discrepancies [3.1]

Understandings:

- structure of the atmosphere including the tricellular model of atmospheric circulation
- the ocean influences the atmosphere because of the thermal properties of water
- both atmosphere and ocean are influenced by Earth's rotation (Coriolis effect)
- differential heating of land and ocean waters, which heats air which sets up convection systems in the atmosphere that generate wind causing water to move as waves and currents
- speed and direction of wind determine currents
- duration, speed and fetch of wind over water determines the development of waves
- Ocean currents can influence climates of continents

Applications and skills:

- skill: measuring differences in heating of air over water and air over land to construct a model of influences of sea and coastal land and the diurnal occurrence of sea and land breezes
- skill: map prevailing winds and the resulting surface current patterns

Guidance:

There are several online videos to show Coriolis effect.
Use of globes enhances student understanding.

International-mindedness:

Exchange of information among nations improves global understanding of atmospheric and oceanic events.

Theory of Knowledge:

Utilization:

link this sub-topic with 3.2, 3.3 and 4.2
Geography Option B
These principles lead to weather prediction.

Aims:

- **Aim 3** Apply and use body of knowledge and techniques with regard to differential heating of land, water and air.
- **Aim 10** Scientific study of atmosphere and oceanic factors influences human activities as weather is more predictable.

Essential idea: Powered by the sun, the water cycle encompasses the flows of water, energy, water-borne materials and their interplay with life in the Earth's system[1]

3.2 Water cycle

Nature of science: Discrepant events lead to deeper understanding. [1.4 / 1.5]

Understandings:
- chemical and physical properties of water allow co-existence as vapour, liquid and solid within the temperature and pressure ranges found on Earth.
- sublimation, evaporation, transpiration, condensation and deposition have energy consequences that influence temperature and moisture of atmosphere
- movement of water from one reservoir to another also moves energy/heat.
- water is the principle greenhouse gas in the atmosphere
- stability of the water cycle, or lack of stability, dictates the changes in climate
- the high heat capacity of water affects the ocean system

Applications and skills:
- skill: Constructing a diagram of the water cycle indicating storages/reservoirs and flows.
- skill: Calculating energy exchanges for hydrologic processes

Guidance:
- an enhanced view of the water cycle to include the thermodynamic properties which have implications for understanding climate and climate change is expected.
- distinctions between heat and temperature.
- The use of discrepant events, observation and reasoning can be used to introduce understanding about thermodynamic processes in the atmosphere.

International-mindedness:
The principles involved in examination of the global water cycle and its importance to human activity is a global initiative to which oceans play a major role.

Theory of Knowledge:
How can it be true that heat energy is added to a water system and the temperature does not change? This question can be approached with regard to logic as a way of knowing and the disconnect that happens when predictions based in logic do not occur.

Utilization:
biology topic 2.2
Geography topic 3, Option B, sub-topic 2

Aims:
- **Aim 4** Develop an ability to analyse, and synthesize information about the properties of water, the water cycle and thermodynamics of Earth's ocean-atmosphere system.
- **Aim 8** Appreciate scientific study within a global context through discussion of the implications of the water cycle, thermodynamics and climate

[1]Water in the Earth System, American Meteorological Society, 2002.

Essential idea: Kinetic energy of wind is transferred to the ocean surface causing surface waves that propagate away from the place of origin horizontally along the ocean/atmosphere interface.

<table>
<tr><td colspan="2">3.3 Waves</td></tr>
<tr><td colspan="2">Nature of science: Theories are used to explain natural phenomena. [2.1]</td></tr>
<tr><td>
Understandings:

anatomy of a wave including direction of water movement within a wave
waves are measured as to height, wavelength, steepness, speed, period and frequency
energy/movement passes through the water causing waves
wave train indicates the direction of movement of energy
causes of waves and factors affect wave propagation including depth of water, wind speed, duration and fetch
swells are waves that are no longer under the influence of the wind
types of waves: deep water waves, shallow water waves, episodic (rogue) waves, internal waves, standing waves (seiches), swells, breakers

Applications and skills:

skill: use wave tank measuring changes in waves in relationship to water depth
skill: drawing profile of water movement in waves as they enter shallow water
skill: calculating steepness and celerity of waves from given dimensions
skill: showing changes in direction of a wave train as it enters a bay or strikes a headland
<u>application:</u> effects of wave energy on coastal erosion

Guidance:
Waves are directly measured as to height, length, period (time), and frequency and have calculated dimensions of celerity (speed) and steepness.
Terms for the types of waves are not mutually exclusive to one another. i.e.: a swell can also be either a deep water or a shallow water wave.
</td><td>
International-mindedness:

Theory of Knowledge:
In what ways does the precise language used in description of waves improve communication about their dynamics?

Utilization:

Physics
Surfers use information about waves including satellite tracking to find the best surfing waves.
Beach erosion is directly related to wave energy weathering.

Aims:

Aim 2 Acquire and use the body of knowledge about waves
Aim 3 Apply and use scientific methods and techniques used in the study of fluid dynamics.

</td></tr>
</table>

Essential idea: Tides have astronomical causes and local effects.

3.4 Tides

Nature of science: Local conditions affect the generalized expectations for applied theories.
Natural phenomena have complex explanations in order to have predictive value. (i.e. equilibrium tidal theory predicts that the highest tides each month will occur at the new and full moons, but usually they do not. How can this be reconciled?) [1.11]

Understandings:

- tide patterns are based upon water level and timing
- patterns are described as diurnal, semi-diurnal, mixed, spring and neap
- equilibrium tidal theory and dynamic tidal analysis contribute to understanding tides
- landmasses, phase of the moon, shape of ocean basins, latitude, declination of the moon and weather affect tide patterns and the currents resulting from them
- tide tables predict times of high and low tides
- tides are used to produce an alternative energy source

Applications and skills:

- skill: using a current table to estimate times and velocities of maximum ebb and flood tides and estimating slack water time
- skill: using a tide prediction table to generate a graph of one month of the expected tide pattern at a given tide station (practical 2)
- skill: using the internet to examine and explain a real water level in comparison to the predicted tide water changes at a named tide station.
- discussion of the importance of tide and tidal current prediction

Guidance:

- Equilibrium tidal theory includes astronomic relationships between sun, moon and Earth (orbits and rotations). Further it explores the tide raising forces (gravity, momentum). A concept of the tidal bulge is useful.
- Dynamic tidal analysis involves summation of the wave forms that occur at a location. Use concept of tide as a wave.

International-mindedness:
Tide changes in different national coastlines can be studied especially as potential energy sources.

Theory of Knowledge:
Here is a situation where over-simplification of an explanation leads to misunderstanding. One could contemplate why predictions made using the equilibrium theory does not reflect the true changes in water level at a location (Why does the highest tide NOT occur at the new or full moon?). or Why does the sun-Earth gravity which is much larger than the moon-Earth gravity have less of a tide-rising effect?
This raises the question, how can we be sure that our knowledge/explanations are correct?

Utilization:

- The work of Sir Isaac Newton in explaining tides is useful here.
- Prediction of tides and tide generated currents are important to commerce especially fishing, shipping as well as human safety.
- Geography Option B

Aims:

- **Aim 7** With the internet, use real-time data on water levels at tide stations and compare them with their predictions. Discuss use of satellites for tracking tides.

Essential idea: Prevailing winds and Earth's rotation set ocean surface currents in motion.

3.5 Surface currents

Nature of science: Benjamin Franklin crossed the Atlantic Ocean several times on his voyages from the American colonies to England. He took many readings of the ocean water and charted them against existing maps. The detail and quantity of data collected lead to recognition of a major current between the two continents. It is an example of collection of data that served to confirm earlier information separately mapped by Resen based upon the data of Frobisher. [1.5, 1.8]

Understandings:

- There is a dynamic relationship between prevailing winds, land masses, Earth's rotation and velocity of surface currents in ocean
- Earth's rotation causes the Coriolis effects.
- Currents transport heat, water, debris.
- Currents are measured as to their speed, direction, temperature and size (volume of water)

Applications and skills:

- skill: On a map draw major gyres for Pacific and Atlantic Oceans.
- skill: Mapping current patterns and calculating speed by use of shipping debris records.
- skill: Determining velocity of a wind driven current from dimensions of the wind (speed and direction)
- skill: Designing or explaining the design of a device to measure a current in a body of water.

Guidance:

- Naming of all the individual currents is not necessary, but the Gulf Stream and two other named examples of surface currents should be included
- Use of globes will enhance authentic understanding.
- When measuring currents, it is important to list the modifiers of these dimensions.

International-mindedness:

Examination of how Polynesian peoples used currents in their navigation promotes another view of discovery.

Theory of Knowledge:

- Consider how Benjamin Franklin studied the Gulf Stream and North Atlantic Drift. In what ways did his methods demonstrate science as an area of knowledge? What have been the implications of his findings? How did his work confirm the work of others?
- How did Polynesian navigators use currents to develop their knowledge of navigation? Was this investigation science?

Utilization:

- Understanding currents facilitated human exploration.
- Shipping industry uses knowledge of currents to reduce cost of fuel.

Aims:

- **Aims 2 /3** Use pattern recognition to develop a body of knowledge and apply it to the science of ocean studies.

Essential idea: Surface events and differences in seawater density putting ocean water in motion transporting heat and salt on a global scale.

3.6 Deep ocean circulation

Nature of science: Discovery of the global ocean conveyor belt demonstrates the value of collaboration and decades of persistent research. [1.4 and 4.1]

Understandings:
- Salinity and temperature affect density of seawater.
- Density varies; more dense water sinks whereas less dense water rises resulting in thermohaline circulation.
- evaporation, sea ice formation, and wind shear increase salinity and thereby, density of surface water
- Evaporation by winds, causes water in the north Atlantic to become salty and sink, setting the Ocean Conveyor into motion.
- Upwelling (caused by winds) causes deep dense water to rise to the surface.
- The ocean conveyor moves ocean water in a persistent pattern.
- Patterns of upwelling and downwelling occur seasonally and have implications for ecosystems.
- The El Niño and La Niña phenomena have impacts on ecosystems, climate and economies
- While the causes are not fully recognized, El Niño and La Niña sequences have been described.

Applications and skills:
- skill: Using data from the TAO/TRITON Array in the Pacific to explore a question.

Guidance:
- Presentation could be made with a discrepant event here as one would not expect dense water to rise. Students could speculate or experiment to determine how upwelling occurs.
- Description of disruption to the normal Walker Circulation by El Niño and La Niña should be explored.

International-mindedness:
- The impact of El Niño and La Niña are global and the economic impact affects most nations around the world. Collaboration and sharing of information gleaned from international satellites has helped improve planning worldwide.
- The TAO/TRITON array is supported by NOAA(USA), JAMSTEC (Japan), and IRD (France)

Theory of Knowledge:

Utilization:
- connections can be made between convection cells in the atmosphere topic 3.1 and thermohaline (also convective in pattern) in the ocean.
- Geography Option B sub-topic 2

Aims:
- **Aim 7** Use of TAO/TRITON Array gives students experience with 21st century technology.
- **Aim 5** The value of effective collaboration and communication by scientists is clear with regard to El Niño and La Niña .

Topic 4: Properties of ocean water (12 hours)

Essential idea: The structure of water molecules results in intermolecular hydrogen bonding that determines the significant physical properties of water.

<table>
<tr><td colspan="2">4.1 Physical properties of water</td></tr>
<tr><td colspan="2">Nature of science: Understanding of the structure of water molecules has created a consistent understanding across a range of phenomena. [2.2-2.3]</td></tr>
<tr><td>Understandings:
▪ water molecule and its hydrogen bonds leads to many properties of water
▪ light, sound and heat are transmitted through oceans
▪ temperature, pressure and salinity affect density of seawater
▪ density differences influence the vertical structure of oceans
Applications and skills:
▪ skill: Determining the effects of temperature and/or salinity on density.
▪ Examining the changes in intensity and spectra of light at depths in ocean
Guidance:
▪ Properties of water should include high specific heat capacity, transparency, surface tension, cohesion, adhesion, viscosity.
▪ Students should be able to recall that liquid water is most dense at 3.98°C and that solid water (ice) is less dense than liquid water.</td><td>International-mindedness:

Theory of Knowledge:
Thermodynamics is studied differently in different scientific disciplines. Why would different approaches to essentially the same phenomenon occur?

Utilization:
▪ link to topic 3.2, 3.6
▪ physics topic
▪ chemistry topic
▪ biology topics 4.2
▪ Geography Option B, sub-topic 1

Aims:
▪ Aim 3 Apply knowledge of structure of water molecules to explain phenomena</td></tr>
</table>

Essential idea: Seawater is composed of dissolved gases and salts (in relatively consistent concentrations) with the water being the most variable component.

4.2 Chemical properties of seawater	
Nature of science: Making accurate quantitative measurements while understanding the limitations and sources of error of each technique is crucial to measurement of salinity, pH, density and temperature of in situ ocean waters. [3.1 and 3.4]	
Understandings: ▪ the solvent properties of water make it the solvent that can dissolve many salts as well as gases ▪ relative proportions of salts within seawater is relatively constant though the concentration of salt to water varies ▪ sources of salt; sources of dissolved gases ▪ relative concentrations of dissolved nitrogen, oxygen and carbon dioxide gases is different from their relative concentrations in the atmosphere. ▪ temperature affects the concentration of dissolved gasses ▪ there is little variation seawater pH because of the buffering capacity of seawater ▪ nitrate, phosphate, silicate, iron, and calcium are nutrients required by photosynthetic organisms ▪ nutrient concentrations fluctuate seasonally **Applications and skills:** ▪ skill: Measuring salinity by two or more methods ▪ skill: Measuring dissolved gases by two or more methods ▪ skill: Demonstrating the effect of temperature on dissolved gas concentration ▪ skill: Measuring the buffering capacity of seawater ▪ skill: Evaluating methods of measuring salinity, dissolved gases, pH ▪ skill: Designing a practical to explore one property of seawater (practical 3) **Guidance:** ▪ salinity may be measured by titration, conductivity, distillation and density. ▪ pH can be measured by conductivity, chemical reaction with indicators (color indicators) ▪ dissolved gases can be measured by chemical tests, sensors. ▪ Each technique introduces sources of error, so this is a good place to help students explore measurement and its foibles.	**International-mindedness:** International standards of measurement help to maintain more reliable data for international use. **Theory of Knowledge:** Techniques for measurement of salinity have changed the basis for its measurement. How has this change occurred? How does a scientist decide which technique to use? **Utilization:** ▪ link to 3.6 ▪ Biology 4.4 ▪ Geography Option B, sub-topic 1 **Aims:** ▪ **Aim 2** Acquire measurement skills consistent with science and technology.

Essential idea: Although the ocean is vast, carbon dioxide levels in the atmosphere have an effect of ocean environments.

<table>
<tr><th colspan="2">4.3 Ocean acidification</th></tr>
<tr><td colspan="2">Nature of science: Scientists look for patterns and correlations to discover how changes in one system affect changes in another system. [3.1]
Problem-solving requires risk analysis, precautionary principle and international dialogue to meet the concerns for human-enhanced carbon dioxide levels in the atmosphere and the impact on ocean acidification. [4.8]</td></tr>
<tr><td>Understandings:
▪ carbon dioxide is more soluble in water than in air
▪ the ocean is a carbon dioxide sink/reservoir
dissolved carbon dioxide raises the acidity of oceans
▪ increased atmospheric carbon dioxide leads to acidification of ocean waters
▪ there are dire consequences of acidification on marine ecosystems

Applications and skills:
▪ analysing data about ocean acidification and a named ecosystem
▪ skill: measuring pH effects of carbon dioxide forced into aqueous solution
▪ discussion of what can be done to solve acidification problems
▪ skill: drawing a representation of the carbon cycle and annotating marine reservoirs and relative residence times.
Guidance:
▪ Several studies are available on line including primary data for analysing atmospheric carbon dioxide increase as well as coral reef decline with increased acidity.</td><td>International-mindedness:
Many cultural identities are at risk with the loss of large coral reef systems.

Theory of Knowledge:
How does emotion affect our responses to the negative impact of acidification of oceans on coral reef ecosystems? Does emotion support or detract from the best actions?

Utilization:
Geography Option B sub-topic 2

Aims:
▪ Aim 10 Develop an understanding of the influence of atmospheric science and ecology on the decision-making process.</td></tr>
</table>

Essential idea: Oceans have predictable patterns of variation in physical and chemical characteristics

<table>
<tr><th colspan="2">4.4 Ocean water profiles</th></tr>
<tr><td colspan="2">Nature of science: Marine scientists collect data from direct and indirect measurements in search for patterns, trends and discrepancies. [3.1]</td></tr>
<tr><td>
Understandings:

Physical and chemical characteristics of in situ ocean water vary with depth
Tools for measuring and monitoring surface and deep waters have been developed.
Wind has an influence on the ocean profiles causing mixing as well as upwelling.
The deep water conveyor belt moves deep ocean water causing whole ocean mixing at a slow pace.

Applications and skills:

skill: describing methods for collecting data to construct profiles of thermoclines, haloclines and pycnoclines
skill: describing the distribution of oxygen and carbon dioxide with depth.
skill: Construct a temperature-depth profile and identify the thermocline or model the development of a thermocline. (practical 4)
skill: developing a density-depth profile and identify the pycnocline
skill: developing a salinity-depth profile and with a halocline
application: explore formation of Mediterranean Intermediate Water in the Atlantic Ocean

Guidance:
The design of Argo Floats and CTD devices should be discussed. Using an aquarium, thermometers at various depths and a strong light, a model thermocline can be generated for practical 4.
</td><td>
International-mindedness:
Data-sharing of ocean conditions is an international venture.

Theory of Knowledge:
How can we know whether or not a present condition is a predictable pattern or an anomaly?

Utilization:
Geography Option B sub-topic 1

Aims:

Aim 4 Develop an ability to analyse, evaluate and synthesize single point data with other similarly collected data.
Aim 7 Use of 21st century communications should be used data available on this topic from the TAO/TRITON Array and other sources.

</td></tr>
</table>

Topic 5: Life in Oceans (50 hours)

Essential idea: Planktonic organisms are present and have a significant role in all marine ecosystems.

5.1 Plankton and productivity	
Nature of science: Looking for patterns, trends and discrepancies has lead scientists to realize the central importance of plankton to marine ecosystems. [3.1]	
Understandings: • Plankton may be multi-cellular organisms, bacteria, or viruses • there are autotrophic bacteria as well as phytoplankton • There is a great abundance of viruses in marine waters. • Plankton may be photosynthetic and play an essential role in food chains • Light, temperature and nutrients affect primary production by phytoplankton • some phytoplankton cause Harmful Algal Blooms that have effects on marine ecosystems and on human health • phytoplankton play in important role in the global carbon cycle • zooplankton and heterotrophic bacteria have important roles in marine ecosystems. **Applications and skills** • skill: Describing and evaluating two methods of sampling plankton. • skill: microscopic examination and sketches of phytoplankton and zooplankton (practical 5) • skill: calculating the primary productivity, gross primary production & net primary production for an ecosystem from data. • skill: Describe and evaluate two methods of measuring primary productivity. • Analysing marine food webs in terms of carbon cycling with indications of carbon and energy budgets **Guidance:** Essential terminology includes plankton, phytoplankton, zooplankton, bacteria, viruses. Microscopic plankters can be obtained from commercial suppliers or even found on-line for purposes of Practical 5.	**International-mindedness:** **Theory of Knowledge:** **Utilization:** Environmental Systems and Societies, Topic 2.5.4-2.5.7 **Aims:** • **Aim 2** Acquire a body of knowledge, methods and techniques that characterize the science of marine biology. • **Aim 6** Develop investigative scientific skill including the use or remote sensing.

Essential idea: The location and physical characteristics of the open ocean affect the inhabiting organisms and their adaptations.

5.2 Open ocean ecosystem

Nature of science: Use theories to explain natural phenomena. [2.2]
An understanding of science is vital when society needs to make decisions about fishing and pollution. [5.1] [5.3]

Understandings:

- Open ocean ecosystem has distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
- Adaptations for survival in the open ocean include thermoregulation in marine mammals, buoyancy in diatoms, squid, fish and sea otters, and diving in marine mammals
- Adaptations for feeding in the open ocean include cruising, lunging, echolocation as well as herding and bubble-netting.
- Adaptations for predator avoidance including schooling and counter-shading
- Further adaptations include vertical migration by both phytoplankton and zooplankton, and migrations by salmon, sea turtles, sea birds and mammals
- Other adaptations of interest in the open ocean include mammal communication and bioluminescence
- Human impact on the open ocean includes over-fishing, destructive fishing and bycatch
- Noise pollution, chemical pollution and solid wastes as well as plastic pollution interrupt the health of the open ocean.

Applications and skills:

- skill: **d**escrib**ing** named organisms **that** provide examples of the adaptations application: discussion and evaluation of the problems of pollution and over-fishing.
- application: study impact of marine plastic debris on Laysan albatrosses

Guidance:

- Candidates are expected to describe examples of open ocean species including 1 autotroph, 2 invertebrates and 3 vertebrates
- Candidates should distinguish between plankton and nekton, giving 3 or more examples of each.
- Many documentaries have been made of open ocean fish, mammals and birds.

International-mindedness:

Restoration of endangered fish populations requires international agreements and cooperative monitoring.

Theory of Knowledge:

How can an understanding of the dangers of plastic pollution be made part of public knowledge? What has been done? What else can be done?

Utilization:

Geography Option B.3
Topic 3.5

Aims:

- **Aim 4** Develop an ability to analyse, evaluate and synthesize scientific information on fishing practice.
- **Aim 8** Become critically aware of the human impact upon oceans and the ethical implications of this information
- **Aim 7** Use of 21st century communications should be used to explore simulations and data available on this topic.
- **Aim 10** Understand the relationships between fisheries biology and its relationship to management decisions.

Essential idea: Location and physical characteristics of rocky shore ecosystems affect the inhabiting organisms and adaptations.

5.3 Rocky shore ecosystems

Nature of science: Use models as representations of the real world—zones of stress and limits of tolerance graphs are models of the real world that have predictive power and explain community structure. [1.10]

Understandings:

- Rocky shore ecosystems have distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
- Changes in water level due to daily tides poses biotic and abiotic problems to intertidal species.
- Biological adaptations include water conservation, protection from wave action, evaporative cooling, spatial refugia, anti-herbivory chemicals, and competition for space; named organisms exhibiting each of these adaptations.
- Tide pools have distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
- Tide pool organisms are eurythermal, euryhaline and euroxic animals; named organisms exhibiting one or more of these adaptations.
- Human impact includes over-harvesting, trampling, alien species, oil spills and coastal development.

Applications and skills:

- Use dichotomous key to identify intertidal species of seaweeds or invertebrates.
- Describe and evaluate methods used to measure intertidal zonation.
- skill: Quantitative zonation study in the rocky intertidal region including transect and quadrat data and kite diagrams.
- skill: Apply Simpson's Inverse Diversity Index to data collected at a rocky shore or from on-line data sources comparing zones or different times of year (practical 6).
- Discussion of methods for mitigating human impact on rocky shores
- skill: developing graphs to show zones of stress and limits of tolerance for named species of rocky shore intertidal zones.

Guidance:

- Candidates are expected to describe examples of rocky intertidal zone species including 3 seaweeds, 5 invertebrates and 1 vertebrate
- expected terminology: high tide zone, mid-tide zone, low tide zone, intertidal zone

International-mindedness:

Theory of Knowledge:

Utilization:

topic 3.4
biology topic 5.3, option C.4
Environmental Systems and Societies 2.3.5
Geography option B.6

Aims:

- **Aim 2/3** Acquire and apply methods and techniques used to study marine ecology
- **Aim 4** Develop an ability to analyse, evaluate and synthesize scientific information about rocky shore ecosystems.
- **Aim 8** Become critically aware of the human impact upon coastal ecosystems and the ethical implications of this information
- **Aim 7** Use of 21st century communications should be used to explore simulations and data available about rocky shore ecosystems.

Essential idea: Location and physical characteristics of estuary ecosystems affect the inhabiting organisms and adaptations.

<table>
<tr><th colspan="2">5.4 Estuary ecosystems</th></tr>
<tr><td colspan="2">Nature of science: Use theories to explain natural phenomena. [2.2]
Scientists provide information to businessmen, politicians, fishermen and cultural organizations in land use decisions. [5.1]</td></tr>
<tr><td>Understandings:
• Estuaries may be salt wedge, well-mixed, partially mixed and fjord-type estuaries
• Each type of estuary has distinct characteristics of topography, temperature, salinity, light, nutrients, oxygen, substrate and energy
• Many organisms in estuaries are euryhaline as the salinity of estuaries changes as prominence of tidal influx alternates with river influence
• Estuaries are important as nurseries for many species of fish and invertebrates.
• Human impacts upon estuaries include over-harvesting, alien species, aquaculture, agricultural run-off, coastal development and dam construction, chemical pollution.
Applications and skills:
• skill: A detailed, quantitative and qualitative study of a selected estuary can be made using a field study or on-line data including both biotic and abiotic components
• application: discussion of the importance of estuaries as nurseries and the survival of commercially important species including salmon.
• application: Dredging of estuaries is an issue as many estuaries are naturally filling with soil. What criteria should be used to determine whether or not to dredge an estuary?
Guidance:
• Candidates are expected to describe examples of estuarine species including 5 invertebrates and 2 vertebrates.</td>
<td>International-mindedness:
Although estuaries are within sovereign boundaries, their management is of international concern.
Theory of Knowledge:
By what means can knowledge claims about an issue be discerned? How can knowledge claims of stakeholders be verified and disputes resolved?
Utilization:
Geography Option B.5
Aims:
• Aim 2/3 Acquire and apply methods and techniques used to study marine ecology
• Aim 4 Develop an ability to analyse, evaluate and synthesize scientific information on estuaries.
• Aim 8 Become critically aware of the human impact upon estuaries and the ethical implications of this information
• Aim 7 Use of 21st century communications should be used to explore simulations and data available on estuaries and their importance.
• Aim 10 Understand the relationships between a healthy functional estuary and the competing needs of human societies, commerce and aquaculture.</td></tr>
</table>

Essential idea: The location and physical characteristics of coral reef ecosystems affect the inhabiting organisms and their adaptations.

<table>
<tr><th colspan="2">5.5 Coral reef ecosystems</th></tr>
<tr><td colspan="2">Nature of science: Use theories to explain natural phenomena. [2.2]
Studies of coral reef bleaching have brought surprises to understanding the relationships between symbionts and their coral hosts. [1.4]</td></tr>
<tr><td>Understandings:
Coral reefs have distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy.
formation of coral reefs
coral reefs that are located in tropical oceans have narrow abiotic requirements for reef-building corals.
corals have mutualistic symbiosis with organisms that are essential to their survival.
climate change has a relationship to coral bleaching
aquarium and souvenir trades, overfishing, tourism, and chemical pollution are human threats
coral diseases, predators including Acanthaster planci.
Applications and skills:
skill: drawing a coral reef food web and annotating the trophic levels.
application: conducting a survey of saltwater aquarium shop to determine the sources of 10 organisms being sold.
Guidance:
Candidates are expected to describe examples of coral reef species including 1 seaweed, 5 invertebrates and 4 vertebrates.
Many documentaries are available with photography of organisms in their natural habitat.</td>
<td>International-mindedness:

Theory of Knowledge:
Why are sections of coral reef dynamited? What goals are being achieved? What ethical considerations should be employed?

Utilization:
Geography B.6

Aims:
Aim 4 Develop an ability to analyse, evaluate and synthesize scientific information on coral reef systems.
Aim 7 Use of 21st century communications should be used to explore simulations and data available on coral bleaching and other conditions of coral reefs.
Aim 8 Become critically aware of the human impact upon coral reefs and the ethical implications of this information</td></tr>
</table>

Essential idea: The location and physical characteristics of polar ocean ecosystems affect the inhabiting organisms and their adaptations.

5.6 Polar ocean ecosystems

Nature of science: Use theories to explain natural phenomena. [2.2]

Understandings:

- The polar oceans (Arctic and Southern) have distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
- Adaptations for survival include
  - physical adaptations (blubber, thick coats, small extremities),
  - behavioural adaptations (huddling)
  - physiological adaptations (slow metabolism, lack of red blood cells, antifreeze in fish blood, heat exchangers)
- resource exploitation, mining, overfishing, sealing and whaling are threats to the ecosystem
- tourism and pollution also threaten the ecosystem as the sea ice decreases.

Applications and skills:

- application: describing efforts going into conservation of polar seas by governmental and non-governmental organizations.
- application: case studies of penguins in the Southern Ocean and/or polar bears in the Arctic Ocean provide clues to the impact of global warming on these species.
- skill: explore mammalian dive reflex--bradycardia
- application: satellite monitoring of extent and concentration of sea ice at both poles has been done since 1979 and can be used to correlate with population estimates of polar species.

Guidance:

- Candidates are expected to describe examples of polar ocean species including 2 invertebrates and 4 vertebrate**s.**

International-mindedness:

Rapid loss of ice habitats due to global warming has raised international concern.

Sovereignty of nations bordering the Arctic Ocean with its mineral and transport rights have seen increased interest as there are more days with waterways ice-free.

Theory of Knowledge:

How shall decisions be made about who has the rights to resources and whether or not to exploit them? What knowledge claims should be considered? How do reason and emotion impact these decisions?

Utilization:

Aims:

- **Aim 4** Develop an ability to analyse, evaluate and synthesize scientific information on polar ecosystems.
- **Aim 8** Become critically aware of the human impact upon oceans and the ethical implications of this information
- **Aim 7** Use of 21st century communications should be used to explore simulations and data available on this ecosystem.

Essential idea: The location and physical characteristics of deep sea and hydrothermal vent ecosystems provide fascinating information about the extreme environments of the ocean.

<table>
<tr><td colspan="2">5.7 Deep sea and hydrothermal vent ecosystems</td></tr>
<tr><td colspan="2">Nature of science: Curiosity has lead to studying the deep ocean and hydrothermal vents. This has produced many unplanned and surprising discoveries. [1.4/1.5]</td></tr>
<tr><td>Understandings:
• The deep sea ecosystems have distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
• Biological adaptations to the deep sea ecosystem include decreased metabolism, special swim bladders, and techniques for finding food, and finding mates; named examples of each adaptation.
• Hydrothermal vents have distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
• Biological adaptations to hydrothermal vents include decreased metabolism, sulphide binding (by Riftia hemoglobin) and chemosynthetic mutualistic bacteria; named examples of each adaptation
• ocean dumping, mineral exploration/extraction and carbon storage all affect deep sea and hydrothermal vent ecosystems.
Applications and skills:
• Locate on a map or globe hydrothermal vents and deep sea ecosystems
• application: discussion of human impact upon deep sea ecosystems and hydrothermal vents.
Guidance:
• Candidates are to describe named examples of organisms from the deep sea including 2 invertebrates and 3 vertebrates.
• Candidates are to describe named examples of organisms from the hydrothermal vents including 1 autotroph, 2 invertebrates and 1 vertebrate.</td><td>International-mindedness:

Theory of Knowledge:

Utilization:

Aims:
• Aim 4 Develop an ability to analyse, evaluate and synthesize scientific information on hydrothermal vents and deep sea ecosystems.
• Aim 8 Become critically aware of the human impact upon coastal ecosystems and the ethical implications of this information</td></tr>
</table>

Option A: Marine Ecosystems (15 hours)

Essential idea: A great variety of plankton with special adaptations for survival and unique lifestyles inhabit oceans.

A.1 Marine plankton as the link among all marine ecosystems

Nature of science: Use careful observations to explain natural phenomena. [2.2] The idea of adding iron sulfate to the open ocean to stimulate phytoplankton and reduce atmospheric carbon dioxide may be fanciful, but it has attracted the imagination of serious scientists as a possible way to slow global warming. [1.5]

Understandings:

- the morphology of planktonic diatoms, dinoflagellates and coccolithophores varies.
- asexual and sexual reproduction in diatoms provides an example of planktonic lifecycle.
- adaptations that phytoplankton and zooplankton possess to survive in marine ecosystems.
- Zooplankton include meroplankton and holoplankton
- relative primary productivity varies among marine ecosystems.
- the microbial loop describes a micro-food chain that can work within or alongside a classical food chain.
- the place of krill in marine food webs.
- lack of nutrients (especially iron) in the open ocean reduce the presence of phytoplankton

Applications and skills:

- application: discussion of the ways in which marine plankton are the link among all marine ecosystems
- skill: Comparing morphology of diatoms, dinoflagellates and coccolithophores
- skill: illustrating the life cycles of one phytoplankton species and one larval planktonic species
- application: comparing primary productivity of two marine ecosystems

Guidance:

- Krill are small crustaceans that feed on plankton; larval krill are zoo-plankton. The distinction is the ability of adult krill to swim against a current in the ocean.

International-mindedness:

How should the precautionary principle be applied to the idea of iron fertilization of the open ocean? What international agencies should be consulted? What scientific studies should be done?

Theory of Knowledge:

The precautionary principle is meant to guide decision- making in conditions where a lack of certainty exists. Is certainty ever possible in the natural sciences?

Utilization:

topic 5.1

Aims:

- **Aim 2** Acquire a body of knowledge, methods and techniques that characterize the science of marine biology.
- **Aim 6** Develop investigative scientific skill including the use or remote sensing.
- **Aim 7** Use of 21st century communications should be used to explore simulations and data available on this topic.
- **Aim 8** Become critically aware of the human impact upon oceans and the ethical implications of this information

Essential idea: The location and physical characteristics of the Kelp forests / Seagrass beds / Salt marshes and Mangrove Forest ecosystems affect the inhabiting organisms and their adaptations and have important implications of coastal peoples.

A.2 Kelp forests / Seagrass beds / Salt marshes and Mangrove Forests

Nature of science: An understanding of science is vital when society needs to make decisions about endangering ecosystems. [5.1] [5.3]

Understandings:

- Plant / algae dominated ecosystems include kelp forests, seagrass beds, salt marshes and mangrove forests.
- Each of these ecosystems has distinct characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
- Adaptations of organisms living in these ecosystems are varied; named organisms expected for each adaptation
- shrimp farming has been a major threat to mangrove forests
- humans have threatened plant / algae dominated ecosystems.

Applications and skills:

- skill: exploring the importance of detritus in grass dominated ecosystems. Draw a food web to include detritivores.
- application: study of Yad Fon in Thailand illustrates a successful response to human irresponsibility.

Guidance:

- Candidates are expected to describe examples of species including 3 autotrophs, 4 invertebrates and 2 vertebrates from each ecosystem.

International-mindedness:

Different approaches have been used to restore mangrove forests including those in Thailand (Yad Fon), Vietnam and the Philippines.

Theory of Knowledge:

How has the cultural knowledge of Thai coastal people contributed to the success of Yad Fon? What were the knowledge structures with which they had to contend?

Utilization:

Geography B.6

Aims:

- **Aim 4** Develop an ability to analyse, evaluate and synthesize scientific information on sensitive coastal ecosystems.
- **Aim 8** Become critically aware of the human impact upon coastal ecosystems and the ethical implications of this information
- **Aim 7** Use of 21st century communications should be used to explore simulations and data available on this topic.

Essential idea: Sediment-covered ecosystems are dynamic ecosystems where burrowing is an adaptation for feeding, evading predators and avoiding fluctuations in environmental conditions

<table>
<tr><th colspan="2">A.3 Sediment covered ecosystems</th></tr>
<tr><td colspan="2">Nature of science: Use careful observations to explain natural phenomena. [2.2]</td></tr>
<tr><td>
Understandings:
• <u>Sandy shores</u> have distinct locations and characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
• There is a dynamic equilibrium of sandy shores in response to currents and wave action with movement of sand.
• Zonation due to tides is seen on sandy shores
• Biological adaptations to sandy shores include deposit feeding, suspension feeding and camouflage in addition to methods for burrowing; named descriptions of each adaptation.
• <u>Mudflats</u> have distinct locations and characteristics of temperature, salinity, light, nutrients, oxygen, substrate and energy
• Adaptations of mudflat organisms include euryoxic animals and sulphide detoxification
• <u>Human impact</u> on sediment-covered shores includes resource exploitation, invasive species, fish farming, coastal development and pollution
Applications and skills:
• skill: Using a transect line to examine distribution of 3-5 organisms from the sublittoral to the supralittoral zone of a sandy beach or mudflat including meiofauna if present.
• application: discussion of issues of fish farming, alien species and coastal development.
• skill: Comparing the composition of substrates of mudflats and sandy shores by measuring particle size, pH, moisture content (when the tide is out), mineral content, nutrients, etc.
Guidance:
• Candidates should be able to describe organisms from sandy shores and mudflats including 5 invertebrates and 1 vertebrates from each.
• Expected terminology: meiofauna, euryoxic, detoxification
</td><td>
International-mindedness:
Reducing the number of invasive alien species will require international cooperation.

Theory of Knowledge:
The concept of alien species is pervasive in environmental biology. How has this language been useful to environmentalists? When is a species no longer an alien species?

Utilization:
Option C.1

Aims:
• Aim 2/3 Acquire and apply methods and techniques used to study marine ecology
• Aim 4 Develop an ability to analyse, evaluate and synthesize scientific information on sediment covered ecosystems.
• Aim 8 Become critically aware of the human impact upon coastal ecosystems and the ethical implications of this information
• <u>Aim 7 Use of 21st century communications should be used to explore simulations and data available on this topic.</u>
</td></tr>
</table>

Essential idea: Threats caused naturally and by humans can be approached scientifically to provide information for decision-making.

<table>
<tr><th colspan="2">A.4 Threats to Marine Ecosystems</th></tr>
<tr><td colspan="2">Nature of science: Scientists work to assist with reducing ecological threats by collecting information to describe problems so that measured and informed problem-solving can occur. [4.8]</td></tr>
<tr><td>Understandings:
• threats to biodiversity of oceans and health of ecosystems have natural and human affected causes.
• climate change affects marine systems

Applications and skills:
• skill: exploring a biodiversity/conservation problem and possible solutions in detail. Local problems are encouraged as personal involvement may occur.

Guidance:
• What is expected here is that candidates will bring together ideas explored with each ecosystem into an over-all picture of how scientific understanding of threats to oceans may be connected.
• Communication with other schools is encouraged.
• Definitions for biodiversity and conservation should be developed.</td><td>International-mindedness:
Students can be encouraged to contact schools in other parts of the world to exchange information and opinions on conservation issues.

Theory of Knowledge:
How can the public come to know about the threats to marine ecosystems?

Utilization:
Biology option C.4
Topic 5

Aims:
• Aim 10 Develop an understanding of how study by marine scientists can inform decision-making in coastal communities, where economics, politics and cultures struggle with sustainability.</td></tr>
</table>

Essential idea: Threats caused naturally and by humans call for conservation and management efforts by the international community.

A.5 Conservation and Public Policy

Nature of science: Scientists work to assist with reducing ecological threats by solving problems to improve man's stewardship of marine ecosystems. [4.8]

Understandings:

- groups of people can find answers to these threats
- organizations at local, national and global levels each have important parts to play in the solutions.
- science has a role to play in the solutions

Applications and skills:

- skill: examining the issues surrounding the designation of some areas of the ocean as nature reserves, sanctuaries, no-fishing zones, or other designations intended to mitigate over-exploitation of fish stocks.
- application: determining who is responsible for conservation of marine resources in local state, region, nation or international. Contact these people, agencies, or groups and explore how their actions impact one or more problems.

Guidance:

- What is expected here is that candidates will bring together ideas explored with each ecosystem into an over-all picture of how scientific understanding of threats to oceans may be addressed individually, locally and globally.
- Communication with other schools is encouraged.
- Definitions for biodiversity and conservation should be developed.
- It is important that students recognize the importance and value of all stakeholders in solving real-world problems.

International-mindedness:

Students can be encouraged to contact schools in other parts of the world to exchange information and opinions on conservation issues.
Students will recognize that there are many international organizations in a position to make sustainable changes.

Theory of Knowledge:

How does our understanding of what is important affect decision-making with regard to issues of biodiversity and conservation? Is it possible to make unbiased decisions? Could two people or groups of people come to different, yet ethical, decisions about the same problem?

Utilization:

Biology option C.4
Topic 5

Aims:

- **Aim 10** Develop an understanding of how study by marine scientists can inform decision-making in coastal communities, where economics, politics and cultures struggle with sustainability.

Option B: Atmosphere, ocean and climate (15 hours)

Essential idea: Models can be developed to study hurricanes and their coastal impact.

B.1 Hurricanes and typhoons

Nature of science: Models, based on theoretical understanding, are developed to explain processes that are not observable. [1.10] Theories and laws can be used to describe phenomena and make predictions about future occurrences. [2.2]

Understandings:

- Hurricane or typhoon is an intense tropical storm that originates over warm ocean waters with wind speed of at least 119 km per hour (74 mph),
- Hazards from hurricanes include storm surges, flooding rains, strong winds and tornados
- conditions for generating a tropical cyclone include high sea -surface temperatures, adequate Coriolis effect and weak winds aloft.
- Energy source for hurricanes is latent heat released when water vapour evaporated from the ocean condenses.
- Depending upon wind speed, tropical storms are labeled as disturbance, depression, storm and hurricane

Applications and skills:

- application: SLOSH and topographic analysis from models help in the prediction of flooding
- skill: On a map track an approaching hurricane from coordinate data and time using available interval
- skill: using models estimating likely storm intensity

Guidance:

Typhoon is the term used in the Pacific Ocean and is equivalent to the term *hurricane* which is more frequently used with storms in the Atlantic ocean.

International-mindedness:

Nations with developed detection and warning systems share their information with nations that do not have the infrastructure for themselves.

Theory of Knowledge:

Utilization:

Isaac's Storm by Erik Larson is an non-fictional book describing the human experience of the hurricane that devastated Galveston in 1900

Aims:

- **Aim 2/3** Acquire and apply methods and techniques used to study marine weather phenomena
- **Aim 9** Even with sophisticated technologies, prediction of hurricanes has limitations and uncertainties.

Essential idea: Climate describes long-term average conditions and is strongly influenced by oceans.

B.2 Climate, the oceans, and the cryosphere

Nature of science: Scientists use observed and measured patterns to form explanations and make predictions. [2.2]

Understandings:

- Factors that affect climate include latitude, proximity to large bodies of water (ocean), net incoming solar radiation, long-term average atmospheric circulation and prevailing ocean circulation.
- Climate responds daily, seasonally, decadally and on to time-scales that are millions of years; oceanic influences are similar in periodicity.
- El Niño, La Niña and the southern oscillation involve a sequence of events that are a response to changes along the equatorial Pacific
- Teleconnections is a relatively new term in atmospheric science and is defined by the American Meteorological Society as "A linkage between weather changes occurring in widely separated regions of the globe"
- Teleconnections result in El Niño and La Niña events having ripple effects on weather and climate in the mid-latitudes.
- The ocean conveyor belt distributes heat affecting climate
- Ice on Antarctica, sea ice in the Southern ocean and the Arctic ocean have major impact on Earth's climate

Applications and skills:

- skill: Tracking SST of the Pacific Ocean to predict whether or not an El Niño, La Niña, or average year is developing.
- skill: data-mining: seasonal changes in SST of either the Pacific or the Atlantic. From the data hypothesizing about the causes or impacts of these changes. Archived data may be used.
- skill: data-mining the extent of sea ice at either of the poles over a period of time. Posing questions that can be answered by analysis of the data.

Guidance:

Data mining can be used and students can design an experimental question, display the data, process the data, make conclusions and evaluate. This kind of practical can be used for Internal Assessment

International-mindedness:

El Niño, La Niña and the southern oscillation have global consequences. Many nationalities have invested in the tracking of the phenomena using the TAO/TRITON array, Jason-1, etc.

Theory of Knowledge:

Much scientific data describing oceans and atmosphere is collected every hour and published on the internet. How can we mine this data to develop research questions and design experiments for which conclusions can be made to further develop our knowledge about Earth processes? Is a scientist required to collect his/her data to use it authentically in research?

Utilization:

Topic 3.1 and 3.2

Aims:

Aim 7 Use of 21st century satellite communications to track SST, extent of sea ice, currents, etc.

Essential idea: By examining the changes of the past, current climate change can be more realistically studied.

B.3 Climate record and climate change

Nature of science: Since climatic events cannot be tested, how can they be considered scientific? [2.6]

Understandings:

- scientists use climatic evidence in rock, fossils, pollen, tree growth rings, deep-sea sediment cores and ice cores.
- characteristics of climate change are difficult to make as it is variable geographically and from time to time; it can involve changes in averages or changes in extremes
- generally climate change is more abrupt than gradual
- forcing mechanisms are unreliable predictors.
- causes of climate change may include solar output variability (sunspots), Milankovitch cycles, volcanic eruptions, relative distribution of ocean and land, human activity
- Increase in atmospheric carbon dioxide is driving carbon dioxide across the air/sea interface

Applications and skills:

- skill: constructing a timeline of prehistoric climates
- application: predicting consequences for climate if the ocean conveyor belt stops as it has in the past. Designing ~~an~~ experiment ~~to~~ examining whether or not this is likely to happen.
- skill: examining the recent findings of the IPCC; critically evaluating the science behind the knowledge claim.
- skill: Calculating the your personal carbon footprint.
- application: discussing the precautionary principle with regard to human enhanced greenhouse gases and global warming.

Guidance:

This topic is not an invitation to debate whether or not global warming is occurring, but rather to examine the data that has been collected and to critically evaluate it scientifically.

International-mindedness:

The IPCC (International Panel on Climate Change) works carefully to help provide accurate scientific information for public use.

Theory of Knowledge:

- The precautionary principle is meant to guide decision-making in conditions where a lack of certainty exists. Is certainty ever possible in the natural sciences?
- How has evidence from ice cores been used to speculate about climate events in the past? Is the evidence sufficient to make such knowledge claims? Since these events cannot be tested, how can they be considered scientific (see Nature of Science 2.6)

Utilization:

- Adelie penguins have unique behaviours that allow study of past climate conditions. www.penguinscience.com/classroom_home.php
- **topic 4.3**

Aims:

- **Aim 4** Develop an ability to analyse, evaluate and synthesize scientific information on the climate record and current climate change

Essential idea: Climate modeling is complex with results that depend upon the inputs selected and the mathematical equations used to build the model.

<table>
<tr><th colspan="2">B.4 Climate modeling</th></tr>
<tr><td colspan="2">Nature of science: models, some simple, some very complex, based on theoretical understanding, are developed to explain processes that may not be observable. Computer-based mathematical models are used to make testable predictions, which can be especially useful when experimentation is not possible. [1.10]</td></tr>
<tr><td>
Understandings:

climate models consist of equations used to predict positive and negative temperature and precipitation anomalies
Numerical models are used to predict El Niño/La Niña events (the empirical model uses past occurrences, whereas the dynamical model uses equations that simulate ocean/atmosphere coupling.

Applications and skills:

application: examining the inputs for two or more models and discussing why climate models are so variable in their conclusions
skill: Modeling climate changes using a computer simulation.
application: discussion of the impact of increased atmospheric carbon dioxide on oceans, greenhouse effect, ocean acidification and climate.

Guidance:
Models for examining climate change are available so that students can manipulate variables and get predictions. More complex models may be studied by examining inputs and outputs from published papers.
</td><td>
International-mindedness:
International meetings are held to evaluate various models of climate change

Theory of Knowledge:
How can models build knowledge? How can we know which model is most like reality?

Utilization:
Topic 4.3 (carbon cycle)
Topic 4.3

Aims:

Aim 9 Develop an appreciation of the possibilities and limitations of modeling technology with regard to climate change.

</td></tr>
</table>

Essential idea: Understanding natural oceanic disasters, allows for better intervention strategies.

B.5 Science to mitigate coastal disasters.

Nature of science: Scientists work to assist with disaster preparedness by creating models to solve problems and improve man's lot. [4.8]

Understandings:

- storm surges are large waves that bring coastal destruction and flooding
- rising sea level due to global warming causes local flooding as well as salt intrusion
- disasters are measured, risks analysed, interventions are made
- steps used in some communities to limit damage may form a basis for modeling mitigation designs
- structures such as dikes, sea walls, special building construction have limits to their effectiveness.

Applications and skills:

skill: developing testable models to alleviate components of coastal disasters.

application: Choose a place with damage from a storm surge or hurricane and describe what was done to prepare for the disaster, what relief was provided, and what plans have been made for the future.

Guidance:

Many communities have emergency managers who could be asked to work with students on this topic.

International-mindedness:

Many nations contribute to relief efforts when a disaster hits a coast and there are losses of life, infrastructure, property, etc.

Theory of Knowledge:

- Sudden disasters illicit emotional responses that lead to generous actions. Is this response ethically justified when so many less glamorous needs go unmet on a daily basis? What other ways of knowing could lead to more equitable distribution of resources?

Utilization:

Geography Option D

Aims:

- **Aim 10** Develop an understanding of the relationship between ocean and atmospheric science as well as engineering in service to communities and emergency planners.

Option C: Geology of ocean basins (15 hours)

Essential idea: In the coastal zone, ocean, atmosphere, biosphere (including humans), geosphere and cryosphere interact creating an exceptionally dynamic environment.

<table>
<tr><th colspan="2">C.1 Coastal dynamics</th></tr>
<tr><td colspan="2">Nature of science: Scientists use observed and measured patterns to form explanations and make predictions. [2.2]</td></tr>
<tr><td>
Understandings:

the coastal zone has different definitions
physical factors that affect the coast zone are the substrate, topography, wind, waves, longshore currents and littoral drift that shift with the seasons
Beaches, barrier islands, sandbars, barrier reefs, fringing reefs, cliffed headlands, estuaries, lagoons, bays, and salt marshes are coastal features
tide zones describe coasts
coastlines of the Pacific Rim are affected by tectonic activities
sediment formation, erosion, transport and deposition are active process of apparently static beaches
sea waves are refracted toward headlands and away from coves and bays
waves approaching at an angle produce beach drift

Applications and skills:

skill: Drawing and annotating a generalized topographic profile of a coastal zone.

Guidance:
Coastal zone may be defined as the farthest inland extent of storm waves or as mean high water level.
Terminology: shore, shoreline, intertidal, littoral.
</td><td>
International-mindedness:

Theory of Knowledge:
Does the way that we define the coastal zone affect our knowledge about it? What are reliable references for definitions?

Utilization:
option A.2,
topics 2.1, 2.3

Aims:
Aim 2/3 Acquire and apply a body of knowledge, methods and techniques to study coastal dynamics.
</td></tr>
</table>

Essential idea: Sediments that accumulate on the sea floor differ in source, composition, size and rate at which they accumulate, thus, providing useful information.

<table>
<tr><th colspan="2">C.2 Sediments and oozes</th></tr>
<tr><td colspan="2">Nature of science: Looking for patterns, trends and discrepancies [3.1]
Scientists use classification systems to develop observations leading to generalizations</td></tr>
<tr><td>Understandings:
▪ terminology that describes sources, composition, and sizes of sediments
▪ characterize biogenous, lithogenous, hydrogenous and cosmogenous sediments as well as calcareous and siliceous oozes
▪ rates of accumulation vary
▪ accumulated sediments and oozes provide a history of the basin
▪ coastal sediments shift in response to currents, waves and storms seasonally and sporadically
▪ deep sea core sampling verifies seismic profiling
▪ commercial importance of neritic and pelagic sediments

Applications and skills:
▪ skill: examining sediments as to composition
▪ skill: measuring sediments and apply Wentworth scale
▪ skill: comparing sand samples from different beaches

Guidance:
Further terminology includes the following: aeolian, deltaic, oceanic, glacial, and terms on the Wentworth Scale.
Qualities that distinguish one sediment sample from another should be explored. No recognition of specific sand samples expected.</td><td>International-mindedness:
United Nations has been working on international policies concerning exploitation of seabed resources.

Theory of Knowledge:
In what ways has commercial interest shaped our knowledge of the sea floor.

Utilization:
links to topic 2 and option B

Aims:
▪ Aim 3 Apply and use body of knowledge and techniques with regard to seismic profiling and core sampling

• Aim 10 Scientific study of sediment distributions and profiles contributes to economic and national boundary claims in the Arctic Ocean.</td></tr>
</table>

Essential idea: Mineral resources of value to human endeavour are available in the ocean floor.

C.3 Mining the ocean floor

Nature of science: Scientists analyse data and look for patterns, trends and discrepancies, attempting to discover relationships and establish causal links. [3.1]

Understandings:

- seismic profiling and deep-sea core sampling have identified mineral resources worth mining on the ocean floor.
- among the resources identified are oil, natural gas, sulfide deposits, placer deposits of iron, tin, platinum, gold and diamonds
- gravel, shells and sand are mined to build roads
- ocean mining is hazardous and expensive

Applications and skills:

skill: Examining a seismic profile and/or core sample to find evidence of exploitable resources

application: Oil pollution in the Gulf of Mexico

application: the oil spill by the Exxon Valdez in the Gulf of Alaska

Guidance:

Any study could be done such that chemical, physical and biological principles as well as environmental, economic, mitigation costs and benefits are considered and aligned with ethical principles.

International-mindedness:

The United Nations convention on the Law of the Sea (1994) sets environmental protections and financial obligations on exploitation of mineral from the ocean floor.

Theory of Knowledge:

What knowledge claims are used to build up knowledge of ocean floor resources in order to make a reasoned decision about exploitation?

Utilization:

topic 2.3

geography option B.3

Aims:

- **Aim 8** Become aware as a global citizen of the ethical implications of using information gained during scientific investigations into resources on the ocean floor and the ethics of their exploitation.

Essential idea: There are serious consequences when oceanic processes intersect with human activity.

C.4 Human activity and marine disasters

Nature of science: Investigating the relationship between human activities to mitigate marine hazards, has taken the form of trial and error. [2.9]

Understandings:

- There is increasing human development along coastlines including docks, ports, resorts, recreational facilities, growing cities, roads, etc.
- Forces of nature that are in conflict with human activity include storm surges, oceanic storms, rising sea level, and littoral drift
- Human activity has removed natural coastal features such as dunes, wetlands, mangrove forests, as well stabilizing river deltas and straightening rivers so that the original natural safeguards from ocean hazards have been removed.
- Shipping, fishing, mining and travel across oceans have lead to disasters especially during storms.
- building of levees, dikes, jetties, groins, breakwaters, dams and sea walls has had variable success.
- Artificial replacement of beach sand is a short term solution.

Applications and skills:

- skill: designing and testing models to explore the effectiveness of a structure to prevent beach erosion, survive an earthquake or a flooding event on a coast.
- application: chart the movement of debris from the Japanese tsunamis of 2011 (shipping accidents or other event) and its arrival on the west coast of North America. Consider the consequences of this information.

Guidance:

Reports are available on the effectiveness of various techniques designed to mitigate coastal hazards.

The rebuilding of Japan after the tsunami of 2011, the rebuilding of the Jersey Shore, or New Orleans after hurricanes provide case studies of human persistence in the face of hazards.

International-mindedness:

- The tsunami in Indonesia in 2004 was not detected by a warning system. Consideration of the reasons for this situation can stimulate better international responsibility.

Theory of Knowledge:

Human attempts to protect mankind from disasters has lead to trial and error approaches to build up our knowledge. How can science use this body of knowledge to facilitate practical solutions?

Utilization:

Topic 2.3

Mangrove forests have been removed from many coastlines. How has this changed the responsiveness of the coast to storm surges and tsunamis damage?

Aims:

- **Aim 10** Develop an understanding of the relationship between ocean and atmospheric science as well as engineering in service to communities and emergency planners.

Essential idea: Understanding oceanic processes, allows for scientifically sound intervention strategies.

<table>
<tr><td colspan="2">C.5 Using science to understand marine catastrophes</td></tr>
<tr><td colspan="2">Nature of science: Scientists work to assist with disaster preparedness by creating models to solve problems and improve man's lot. [4.8]</td></tr>
<tr><td>
Understandings:
• In coastal communities likely to be affected by tsunamis, procedures are in place to avoid loss of life and property.
• warning systems are in place to predict the arrival time and magnitude of tsunamis yet some areas of the world are under-served by these systems.
• steps to prepare for or limit damage vary from community to community
• disasters are measured, risks analysed, interventions are made
• structures such as sea walls have limits to their effectiveness.

Applications and skills:
skill: developing testable models to alleviate components of coastal disasters.
application: Choose a place with tsunami damage and describe the nature of the tsunami event(s), what was done to prepare for the disaster, what relief was provided, and what plans have been made for the future.

Guidance:
Many communities have emergency managers who could be asked to work with students on this topic.
</td><td>
International-mindedness:
• Many nations contribute to relief efforts when a disaster hits a coast and there are losses of life, infrastructure, property, etc.

Theory of Knowledge:
• Sudden disasters elicit emotional responses that lead to generous actions. Is this response ethically justified when so many less glamorous needs go unmet on a daily basis? What other ways of knowing could lead to more equitable distribution of resources?

Utilization:
Topic 2.3
Geography Option D

Aims:
• Aim 10 Develop an understanding of the relationship between ocean and atmospheric science as well as engineering in service to communities and emergency planners.
</td></tr>
</table>

Assessment in the Diploma Programme

General

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

There are two types of assessment identified by the IB.

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

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

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

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

To support teachers in the planning, delivery and assessment of the Diploma Programme courses, a variety of resources can be found on the OCC or purchased from the IB store (http://store.ibo.org). Teacher support materials, subject reports, internal assessment guidance, grade descriptors, as well as resources from other teachers, can be found on the OCC. Past examination papers as well as mark schemes can be purchased from the IB store.

Methods of assessment

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

Assessment criteria

Assessment criteria are used when the assessment task is open-ended. Each criterion concentrates on a particular skill that students are expected to demonstrate. An assessment objective describes what students should be able to do, and assessment criteria describe how well they should be able to do it. Using assessment criteria allows discrimination between different answers and encourages a variety of responses.

Each criterion comprises a set of hierarchically ordered level descriptors. Each level descriptor is worth one or more marks. Each criterion is applied independently using a best-fit model. The maximum marks for each criterion may differ according to the criterion's importance. The marks awarded for each criterion are added together to give the total mark for the piece of work.

Markbands

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

Analytic markschemes

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

Marking notes

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

Inclusive assessment arrangements

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

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

Responsibilities of the school

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

Assessment outline

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1 + 2	3	
Paper 1	50	25	25	1¾
Paper 2	30	15	15	1¼
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

External assessment

Detailed markschemes specific to each examination paper are used to assess students.

External assessment details

Paper 1

Duration: 1¾ hours
Weighting: 50%
Marks: 65

- Section A: short-answer and data-based questions on core material. All questions to be attempted by candidates.
- Section B: extended-response questions on core material. Two out of three multi-part questions to be attempted by candidates.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted (see calculator section on the OCC).

Paper 2

Duration: 1¼ hours
Weighting: 30%
Marks: 35

- This paper will have questions on core and option material.
- Section A: two to three short-answer questions based on experimental skills and techniques, analysis and evaluation, using unseen data linked to the core material. All questions to be attempted by candidates.
- Section B: short-answer and extended-response questions from the three options. All questions on one option to be attempted by candidates.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted (see calculator section on the OCC).

Internal assessment

Purpose of internal assessment

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

Guidance and authenticity

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

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

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

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

All work submitted to the IB for moderation or assessment must be authenticated by a teacher, and must not include any known instances of suspected or confirmed academic misconduct. Each student must confirm that the work is his or her authentic work and constitutes the final version of that work. Once a student has officially submitted the final version of the work it cannot be retracted. The requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that will be submitted to the IB for the purpose of moderation. For further details refer to the IB publication *Academic honesty* (2011), *The Diploma Programme: From principles into practice* (2009) and the relevant articles in *General regulations: Diploma Programme* (2012).

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

- the student's initial proposal
- the first draft of the written work
- the references cited
- the style of writing compared with work known to be that of the student
- the analysis of the work by a web-based plagiarism detection service such as http://www.turnitin.com.

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

Group work

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

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

Time allocation

Internal assessment is an integral part of the course, contributing 20% to the final assessment in the SL courses. This weighting should be reflected in the time that is allocated to teaching the knowledge, skills and understanding required to undertake the work, as well as the total time allocated to carry out the work.

It is recommended that a total of approximately 10 hours of teaching time for SL should be allocated to the work. This should include:

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

Safety requirements and recommendations

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

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

The Laboratory Safety Institute's Laboratory Safety Guidelines...

40 suggestions for a safer lab

Steps Requiring Minimal Expense

1. Have a written health, safety and environmental affairs (HS&E) policy statement.
2. Organize a departmental HS&E committee of employees, management, faculty, staff and students that will meet regularly to discuss HS&E issues.
3. Develop an HS&E orientation for all new employees and students.
4. Encourage employees and students to care about their health and safety and that of others.
5. Involve every employee and student in some aspect of the safety program and give each specific responsibilities.
6. Provide incentives to employees and students for safety performance.
7. Require all employees to read the appropriate safety manual. Require students to read the institution's laboratory safety rules. Have both groups sign a statement that they have done so, understand the contents, and agree to follow the procedures and practices. Keep these statements on file in the department office
8. Conduct periodic, unannounced laboratory inspections to identify and correct hazardous conditions and unsafe practices. Involve students and employees in simulated OSHA inspections.
9. Make learning how to be safe an integral and important part of science education, your work, and your life.
10. Schedule regular departmental safety meetings for all students and employees to discuss the results of inspections and aspects of laboratory safety.
11. When conducting experiments with hazards or potential hazards, ask yourself these questions:
    – What are the hazards?

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

    – How will I deal with them?

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

12. Require that all accidents (incidents) be reported, evaluated by the departmental safety committee, and discussed at departmental safety meetings.
13. Require every pre-lab/pre-experiment discussion to include consideration of the health and safety aspects.
14. Don't allow experiments to run unattended unless they are failsafe.
15. Forbid working alone in any laboratory and working without prior knowledge of a staff member.
16. Extend the safety program beyond the laboratory to the automobile and the home.
17. Allow only minimum amounts of flammable liquids in each laboratory.
18. Forbid smoking, eating and drinking in the laboratory.
19. Do not allow food to be stored in chemical refrigerators.
20. Develop plans and conduct drills for dealing with emergencies such as fire, explosion, poisoning, chemical spill or vapour release, electric shock, bleeding and personal contamination.
21. Require good housekeeping practices in all work areas.
22. Display the phone numbers of the fire department, police department, and local ambulance either on or immediately next to every phone.
23. Store acids and bases separately. Store fuels and oxidizers separately.

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

25. Use warning signs to designate particular hazards.

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

Steps Requiring Moderate Expense

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

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

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

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

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

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

33. Provide fireproof cabinets for storage of flammable chemicals.

34. Maintain a centrally located departmental safety library:

    – “Safety in School Science Labs”, Clair Wood, 1994, Kaufman & Associates, 101 Oak Street, Wellesley, MA 02482

    – “The Laboratory Safety Pocket Guide”, 1996, Genium Publisher, One Genium Plaza, Schnectady, NY

    – “Safety in Academic Chemistry Laboratories”, ACS, 1155 Sixteenth Street NW, Washington, DC 20036

    – “Manual of Safety and Health Hazards in The School Science Laboratory”, “Safety in the School Science Laboratory”, “School Science Laboratories: A guide to Some Hazardous Substances” Council of State Science Supervisors (now available only from LSI.)

    – “Handbook of Laboratory Safety”, 4th Edition, CRC Press, 2000 Corporate Boulevard NW, Boca Raton, FL 33431

    – “Fire Protection Guide on Hazardous Materials”, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269

    – “Prudent Practices in the Laboratory: Handling and Disposal of Hazardous Chemicals”, 2nd Edition, 1995

    – “Biosafety in the Laboratory”, National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418

    – “Learning By Accident”, Volumes 1-3, 1997-2000, The Laboratory Safety Institute, Natick, MA 01760

    (All are available from LSI.)

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

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

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

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

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

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

The Laboratory Safety Institute

Using assessment criteria for internal assessment

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

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

- The aim is to find, for each criterion, the descriptor that conveys most accurately the level attained by the student, using the best-fit model. A best-fit approach means that compensation should be made when a piece of work matches different aspects of a criterion at different levels. The mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded.
- When assessing a student’s work, teachers should read the level descriptors for each criterion until they reach a descriptor that most appropriately describes the level of the work being assessed. If a piece of work seems to fall between two descriptors, both descriptors should be read again and the one that more appropriately describes the student's work should be chosen.
- Where there are two or more marks available within a level, teachers should award the upper marks if the student's work demonstrates the qualities described to a great extent; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student’s work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.
- Only whole numbers should be recorded; partial marks (fractions and decimals) are not acceptable.
- Teachers should not think in terms of a pass or fail boundary, but should concentrate on identifying the appropriate descriptor for each assessment criterion.
- The highest level descriptors do not imply faultless performance but should be achievable by a student. Teachers should not hesitate to use the extremes if they are appropriate descriptions of the work being assessed.
- A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.
- It is recommended that the assessment criteria be made available to students.

Practical work and internal assessment

General introduction

The internal assessment requirements are the same for biology, chemistry, physics and marine science. The internal assessment, worth 20% of the final assessment, consists of one scientific investigation. The individual investigation should cover a topic that is commensurate with the level of the course of study.

Student work is internally assessed by the teacher and externally moderated by the IB. The performance in internal assessment is marked against common assessment criteria, with a total mark out of 24.

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

The internal assessment task will be one scientific investigation taking about 10 hours and the write-up should be about 6 to 12 pages long. Investigations exceeding this length will be penalized in the communication criterion as lacking in conciseness.

The practical investigation, with generic criteria, will allow a wide range of practical activities satisfying the varying needs of biology, chemistry, physics and marine science. The investigation addresses many of the learner profile attributes well. See section on “Approaches to teaching and learning” for further links.

The task produced should be complex and commensurate with the level of the course. It should require a purposeful research question and the scientific rationale for it.

Some of the possible tasks include:

- a hands-on laboratory investigation
- using a spreadsheet for analysis and modeling
- extracting data from a database and analysing it graphically
- producing a hybrid of spreadsheet/database work with a traditional hands-on investigation
- using a simulation provided it is interactive and open-ended

Some tasks may consist of relevant and appropriate qualitative work combined with quantitative work.

The tasks include the traditional hands-on practical investigations as in the previous course. The depth of treatment required for hands-on practical investigations is unchanged from the previous internal assessment. In addition, detailed assessment of specific aspects of hands-on practical work will be assessed in the written papers as detailed in the relevant topic(s) in the "Syllabus Content" section of the guide.

The five assessment criteria are personal engagement, exploration, analysis, insight and communication,

Internal assessment details

Internal assessment component

Duration: 10 hours

Weighting: 20%

- Individual investigation
- This investigation covers assessment objectives 1, 2, 3 and 4.

Internal assessment criteria

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

Personal engagement	Exploration	Analysis	Evaluation	Communication	Total
2 (8%)	6 (25%)	6 (25%)	6 (25%)	4 (17%)	24 (100%)

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

Teachers should read the guidance on using mark bands shown above in the section called “Using assessment criteria for internal assessment” before starting to mark. The precise meaning of the command terms used in the criteria can be found in the glossary of the subject guides.

Personal engagement

This criterion assesses the extent to which the student engages with the exploration and makes it their own. Personal engagement may be recognized in different attributes and skills. These could include addressing personal interests or showing evidence of independent thinking, creativity or initiative in the designing, implementation or presentation of the investigation.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1	**The evidence of personal engagement with the exploration is limited with little independent thinking, initiative or insight.** The justification given for choosing the research question and/or the topic under investigation does not demonstrate **personal significance, interest or curiosity**. There is little evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.
2	**The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or insight.** The justification given for choosing the research question and/or the topic under investigation demonstrates **personal significance, interest or curiosity.** There is evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.

Exploration

This criterion assesses the extent to which the student establishes the scientific context for the work, states a clear and focused research question and uses concepts and techniques appropriate to the Diploma Programme level. Where appropriate, this criterion also assesses awareness of safety, environmental, and ethical considerations.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	The topic of the investigation is identified and a research question of some relevance is **stated but it is not focused.** The background information provided for the investigation is **superficial** or of limited relevance and does not aid the understanding of the context of the investigation. The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of limited awareness of the significant **safety**, ethical or environmental issues that are **relevant to the methodology of the investigation***.
3-4	The topic of the investigation is identified and a relevant but not fully focused research question is described. The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation. The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of some awareness of the significant **safety**, ethical or environmental issues that are **relevant to the methodology of the investigation***.
5-6	The topic of the investigation is identified and a relevant and fully focused research question is clearly described. The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation. The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of full awareness of the significant **safety**, ethical or environmental issues that are **relevant to the methodology of the investigation*.**

*This indicator should only be applied when appropriate to the investigation.

Analysis

This criterion assesses the extent to which the student's report provides evidence that the student has selected, recorded, processed and **interpreted** the data in ways that are relevant to the research question and can support a conclusion.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	The report includes **insufficient relevant** raw data to support a valid conclusion to the research question. Some **basic** data processing is carried out but is either too **inaccurate or too insufficient to lead to a valid** conclusion. The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis. The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.
3-4	The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question. Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing. The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis. The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.
5-6	The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question. Appropriate and sufficient data processing is carried out with **the accuracy** required to enable a conclusion to the research question to be drawn that is fully **consistent** with the experimental data. The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis. The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation and the results with regard to the research question and the accepted scientific context.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	A conclusion is **outlined** which is not relevant to the research question or is not supported by the data presented. The conclusion makes superficial comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **outlined** but are restricted to an **account** of **the practical** or **procedural issues** faced. The student has **outlined** very few realistic and relevant suggestions for the improvement and extension of the investigation.
3-4	A conclusion is **described** which is relevant to the research question and supported by the data presented. A conclusion is described which makes some relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **described** and provide evidence of some awareness of the **methodological issues*** involved in establishing the conclusion. The student has **described** some realistic and relevant suggestions for the improvement and extension of the investigation.
5-6	A detailed conclusion is **described and justified** which is entirely relevant to the research question and fully supported by the data presented. A conclusion is correctly **described and justified** through relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **discussed** and provide evidence of a clear understanding of the **methodological issues*** involved in establishing the conclusion. The student has discussed realistic and relevant suggestions for the improvement and extension of the investigation.

Communication

This criterion assesses whether the investigation is presented and reported in a way that supports effective communication of the focus, process and outcomes.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	**The presentation of the investigation is unclear, making it difficult to understand the focus, process and outcomes.** The report is not well structured and is unclear: the necessary information on focus, process and outcomes is missing or is presented in an incoherent or disorganized way. The understanding of the focus, process and outcomes of the investigation is obscured by the presence of inappropriate or irrelevant information. There are many errors in the use of subject-specific terminology and conventions*.
3-4	**The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes.** The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way. The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation. The use of subject-specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding.

*For example, incorrect/missing labeling of graphs, tables, images; use of units, decimal places. For issues of referencing and citations refer to the "Academic honesty" section.

Rationale for practical work

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

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

Practical scheme of work

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

Syllabus coverage

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

Planning your practical scheme of work

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

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

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

Flexibility

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

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

Practical work documentation

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

Time allocation for practical work

The recommended teaching times for all Diploma Programme courses are 150 hours at SL Students at SL are required to spend 40 hours on practical activities (excluding time spent writing up work). These times include 10 hours for the group 4 project and 10 hours for the internal assessment investigation. (Only 2–3 hours of investigative work can be carried out after the deadline for submitting work to the moderator and still be counted in the total number of hours for the practical scheme of work.)

The group 4 project

The group 4 project is an interdisciplinary activity in which all Diploma Programme science students must participate. The intention is that students from the different group 4 subjects analyse a common topic or problem. The exercise should be a collaborative experience where the emphasis is on the **processes** involved in, rather than the **products of such an activity.**

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

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

Summary of the group 4 project

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

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

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

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

Project stages

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

Planning

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

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

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

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

Action

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

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

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

Evaluation

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

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

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

Addressing aims 7 and 8

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

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

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

Addressing the international dimension

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

Types of project

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

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

Logistical strategies

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

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

Model A: mixed subject groups and one topic

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

Model B: mixed subject groups adopting more than one topic

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

Model C: single subject groups

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

Model D: collaboration with another school

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

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

Timing

The 10 hours that the IB recommends 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/most other school work is suspended.

Year 1
In the first year, students' experience and skills may be limited and it would be inadvisable to start the project too soon in the course. However, doing the project in the final part of the first year may have the advantage of reducing pressure on students later on. This strategy provides time for solving unexpected problems.

Year 1–Year 2
The planning stage could start, the topic could be decided upon, and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation time to think about how they are going to tackle the project and would be ready to start work early in the second year.

Year 2
Delaying the start of the project until some point in the second year, particularly if left too late, increases pressure on students in many ways: the schedule for finishing the work is much tighter than for the other options; the illness of any student or unexpected problems will present extra difficulties. Nevertheless, this choice does mean students know one another and their teachers by this time, have probably become accustomed to working in a team and will be more experienced in the relevant fields than in the first year.

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

Selecting a topic

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

Student selection

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

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

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

Glossary of command terms

Command terms with definitions

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

These command terms indicate the depth of treatment required.

Assessment objective 1

Define Give the precise meaning of a word, phrase, concept or physical quantity.

Draw Represent by means of a labeled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve.

Label Add labels to a diagram.

List Give a sequence of brief answers with no explanation.

Measure Obtain a value for a quantity.

State Give a specific name, value or other brief answer without explanation or calculation.

Assessment objective 2

Annotate Add brief notes to a diagram or graph.

Calculate Obtain a numerical answer showing the relevant stages in the working (unless instructed not to do so).

Describe Give a detailed account.

Distinguish Make clear the differences between two or more concepts or items.

Estimate Obtain an approximate value.

Identify Provide an answer from a number of possibilities.

Outline Give a brief account or summary.

Assessment objective 3

Analyse	Break down in order to bring out the essential elements or structure.
Comment	Give a judgment based on a given statement or result of a calculation.
Compare	Give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout.
Compare and contrast	Give an account of similarities and differences between two (or more) items or situations, referring to both (all) of them throughout.
Construct	Display information in a diagrammatic or logical form.
Deduce	Reach a conclusion from the information given.
Design	Produce a plan, simulation or model.
Determine	Obtain the only possible answer.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Explain	Give a detailed account including reasons or causes.
Predict	Give an expected result.
Sketch	Represent by means of a diagram or graph (labeled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Suggest	Propose a solution, hypothesis or other possible answer.

Bibliography

This bibliography lists the principal works used to inform the curriculum review. It is not an exhaustive list and does not include all the literature available: judicious selection was made in order to better advise and guide teachers. This bibliography is not a list of recommended text books. Please see the *Resource Materials and Bibliography for Marine Science* appendix that follows for information specific to that subject.

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