Diploma Programme

Marine science guide (first assessment 2026)

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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.

Contents

Purpose of this document

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

This guide can be found on the subject page of the Programme Resource Centre, a password-protected International Baccalaureate (IB) website designed to support IB teachers. It can also be purchased from the IB store at store.ibo.org.

Additional resources

Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

Teachers are encouraged to check the Programme Resource Centre for additional resources created or used by other teachers. Teachers can provide details of useful resources, for example, websites, books, videos, journals or teaching ideas. This is particularly important in school-based syllabus (SBS) subjects, as schools are expected to support each other in the advancement of their subject.

Acknowledgement

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

First assessment 2026

The Diploma Programme

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

The Diploma Programme model

The course is presented as six academic areas enclosing a central core (see figure 1). It encourages the concurrent study of a broad range of academic areas. Students study two modern languages (or a modern language and a classical language), a humanities or social science subject, an experimental science, mathematics and one of the creative arts. It is this comprehensive range of subjects that makes the DP 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.

School-based syllabuses—regulations

The following conditions apply to the teaching of school-based syllabuses.

- School-based syllabuses are only available at SL.
- School-based syllabuses may only be offered by schools who have been 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.

The core of the Diploma Programme model

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

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

In TOK, students explore the means of producing knowledge within the core theme of "knowledge and the knower" as well as within various optional themes (knowledge and technology, knowledge and politics, knowledge and language, knowledge and religion, and knowledge and indigenous societies) and areas of knowledge (the arts, natural sciences, social sciences, history and mathematics). The course also encourages students to make comparisons between different areas of knowledge and reflect on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

Creativity, activity, service (CAS) is at the heart of the DP. 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 DP. The three strands of CAS are creativity (arts and other experiences that involve creative thinking), activity (physical exertion contributing to a healthy lifestyle) and service (an unpaid and voluntary exchange that has a learning benefit for the student). Possibly, more than any other component in the DP, CAS contributes to the IB's mission to create a better and more peaceful world through intercultural understanding and respect.

The extended essay (EE), including the world studies EE, 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 student's six DP subjects or, in the case of the interdisciplinary world studies essay, two subjects. The essay also acquaints students 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. 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 learning and approaches to teaching

Approaches to learning and approaches to teaching across the DP refers to deliberate strategies, skills and attitudes that permeate the learning and teaching environment. These approaches and tools, intrinsically linked with the learner profile attributes, enhance student learning and assist student preparation for the DP assessment and beyond. The aims of approaches to learning and approaches to teaching in the DP 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' DP 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 DP aims to develop in students the knowledge, skills and attitudes they will need to fulfil the aims of the IB, as expressed in the organization's mission statement and the learner profile. Learning and teaching in the DP represent the reality in daily practice of the organization's educational philosophy.

Academic integrity

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

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

For further information on academic integrity in the IB and the DP, please consult the IB publications *Academic integrity policy*, *Effective citing and referencing*, *Diploma Programme: From principles into practice* and the general regulations in *Diploma Programme Assessment procedures* (updated annually). Specific information regarding academic integrity as it pertains to external and internal assessment components of this DP 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.

DP candidates submit work for assessment in a variety of media that may include audiovisual 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, 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, candidates 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 audiovisual 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 *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning.*

The publications *Meeting student learning diversity in the classroom* and *The IB guide to inclusive education: a resource for whole school development* are available to support schools in the ongoing process of increasing access and engagement by removing barriers to learning.

Programme standards and practices

The programme standards and practices are a set of principles for schools to ensure quality and fidelity in the implementation of IB programmes. Learning and teaching are important markers of quality and effective practice in schools; thus, the expectations teachers and learners share across all IB programmes can be found in the programme standards and practices.

The programme standards and practices provide a framework to help teachers understand their rights and responsibilities in IB World Schools as they develop learning environments and experiences for their students. The IB recognizes that in order for effective teaching to take place, teachers must be supported in their understanding, well-being, environment and resources. Teachers use the core tenets of IB philosophy and pedagogy (approaches to learning, approaches to teaching, the learner profile and international-mindedness) to design learning experiences that prepare learners to fulfil the aims and objectives outlined in this guide.

To learn more about teachers' rights and responsibilities, please see the IB publication *Programme standards and practices* on the Programme Resource Centre.

Nature of science

What is nature of science?

Nature of science is an overarching theme in the biology, chemistry, physics and marine science courses that seeks to explore conceptual understandings related to the purpose, features and impact of scientific knowledge.

What do we want to know in science?

Nobel laureate and influential popularizer of science, Richard Feynman, once described the process of science using the analogy of watching an unknown board game being played: "… and you don't know the rules of the game, but you're allowed to look at the board from time to time. And from these observations, you try to figure out what the rules are of the game, [and] the rules of the pieces moving" (Feynman et al., 1963).

What is the scientific endeavour?

Classifying such observations and underlying patterns in the natural world is the essence of what scientists do, underpinned by the assumption that the universe exists as an external reality accessible to the human experience. The varied and often non-linear processes used in scientific methodologies have several key features in common to maximize the validity and reliability of knowledge produced. The development of falsifiable hypotheses, a requirement for replicable data, and the utilization of peer review may be among the most essential of these and help differentiate a scientific process from a pseudoscientific one. The communal and collaborative nature of this approach further strengthens the objectivity of science by ensuring the inclusion of diverse perspectives and shared responsibility for its outcomes.

What type of knowledge do we produce?

Formal scientific knowledge may encompass several categories including representative models, explanatory theories and descriptive laws. As the focus of each discipline of natural science differs, so too does the balance of their contributions to each category. What remains constant, however, is the acknowledgement of assumptions, exceptions and limitations of scientific knowledge to provide realistic parameters to our understanding of the natural world. Claims of certainty are treated with caution given the presence of paradigmatic shifts throughout the history of science.

What is the impact of scientific knowledge?

As well as the pursuit of knowledge for its own sake, it is useful to consider the interplay of science with other areas of society. Although advances in technology traditionally fuelled great leaps in scientific understanding, in recent times it may be more common to see science as a driver of technological development. In addition, the implications of science within environmental, political, social, cultural and economic domains can also be profound. These connections illustrate the importance of local, national and international scientific bodies that engage with the public understanding of science and heighten the responsibility of scientists to adhere to principles of academic integrity in their research.

Table 1

Aspects of nature of science

Aspects	How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions?
Observations	Scientists act as observers, looking at Earth and all other parts of the universe, to obtain data about natural phenomena. Observations can be made directly using human senses, or with the aid of instruments such as electronic sensors. Unexpected or unplanned observations can open up new research fields.
Patterns and trends	Scientists analyse their observations, looking for patterns or trends, and try to draw general conclusions by inductive reasoning. They also look for discrepancies. Scientists classify objects through pattern recognition. A trend may take the form of a positive or negative correlation between variables. Correlations may be based on a causal relationship, but correlation does not prove causation.
Hypotheses	Scientists make provisional explanations for the patterns that they have observed in natural phenomena. These hypotheses can be tested, with further observations or experiments, to obtain support for a hypothesis or show that it is false.
Experiments	Scientists design and perform experiments to obtain data, which can be used to test hypotheses. The quality of experimental evidence depends on careful control of variables and on the quantity of data generated. Progress in science often follows technological developments that allow new experimental techniques. Creativity and imagination play a role in experimental design, interpretation and conclusion.
Measurement	Quantitative measurements are more objective than qualitative observations, but all measurements are limited in precision and accuracy. Measurements are repeated to strengthen the reliability of data. Random errors in measurement due to unknown or unpredictable differences lead to imprecision and uncertainty, whereas systematic errors lead to inaccuracy.
Models	Scientists construct models as artificial representations of natural phenomena. They are useful when direct observation or experimentation is difficult. Models are simplifications of complex systems and can be physical representations, abstract diagrams, mathematical equations or algorithms. All models have limitations that need to be considered in their application.
Evidence	Scientists adopt a sceptical attitude to claims and evaluate them using evidence. Some claims cannot be tested using verifiable evidence, so cannot be falsified. They are therefore not scientific. Scientific knowledge must be supported by evidence.
Theories	Scientists develop general explanations that are widely applicable, based on observed patterns or tested hypotheses. Predictions can be generated from these theories by deductive reasoning. If these predictions are tested, they may corroborate a theory or show that it is false and should be rejected. Paradigm shifts take place when a new theory replaces an old one. The term “law” is sometimes used for statements that allow predictions to be made about natural phenomena without explaining them.
Falsification	Scientists can use evidence to falsify a claim formulated as a hypothesis, theory or model, but they cannot prove with certainty that such a claim is true. There is therefore inherent uncertainty in all scientific knowledge. Nonetheless, many theories in science are corroborated by strong evidence and allow for prediction and explanation. Scientists must remain open-minded with respect to new evidence.
Science as a shared endeavour	Scientists communicate and collaborate throughout the world. Agreed conventions and common terminology facilitate unambiguous communication. Peer review is

Aspects	How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions?
	essential to verify the research methods of knowledge claims prior to their publication in journals.
Global impact of science	Scientists have an obligation to assess the risks associated with their work and must aim to do no harm. Developments in science may have ethical, environmental, political, social, cultural and economic consequences that must be considered during decision-making. The pursuit of science may have unintended consequences. Research proposals are often filtered through ethics boards. Scientists have a responsibility to communicate their findings to the public with honesty and clarity.

How is nature of science different from theory of knowledge?

In contrast to the specificity of understanding of science, the TOK course encourages students to think critically about the concepts that underpin knowledge production. For example, peer review is used as a tool to support objectivity in scientific research. Through the study of TOK, students question the limitations of the peer review process and extend their thinking to an assessment of objectivity in other areas of knowledge.

Nature of marine science

What is the purpose of studying marine science?

The oceans constitute more than 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 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 their habitats, about essential interactions between the sea surface and the atmosphere, and about geological dynamics.

How is knowledge acquired in marine science?

Marine science is a multidisciplinary subject—several science disciplines are required to understand the World Ocean. These include the disciplines of biology, chemistry, physics, climatology and technology. The World Ocean is defined as the interconnected body of salty water filling Earth's basins and interacting with the lithosphere below and atmosphere above those basins, including associated life systems (Segar et al., 2019).

The study of marine science involves hands-on work. It is best carried out in a coastal location, where there will be many opportunities for practical work—both in the field and in the laboratory. Topics in physical marine science can be explored using ocean modelling and by analysing satellite imagery, which do not need to be done near the coast. The study of marine chemistry provides opportunities for practical laboratory work, which strengthens investigational skills.

What is the impact of marine science?

The El Niño phenomenon, fishing rights, global warming, coral bleaching, ocean pollution, storm and tsunami preparedness, oil exploration and mining are among many international issues concerning oceans worldwide. Science has a major role in informing decisions relating to these issues.

Oceans have fascinated and inspired humans for millennia and have been vital to their lives and livelihoods. Resources extracted from oceans, transport of goods across oceans and services provided by oceans have a huge impact on human population dynamics. Many coastal populations depend on the oceans for food. As stores of fossil fuels are depleted, interest in extracting energy from the oceans is increasing. Oceans and ocean life produce oxygen, absorb the greenhouse gas carbon dioxide and break down wastes, among other essential ecological processes. Ocean processes are also important in regulating climate. Because of our close connections with the ocean, it is essential to understand human–ocean interactions.

Many human activities are having a negative impact on the oceans. Overharvesting, pollution, acidification, habitat destruction, aquaculture, the introduction of alien species and urban development are altering marine ecosystems. An estimated 90% of global warming is occurring in oceans, which has far-reaching consequences for marine and terrestrial life (NASA, 2023). It is essential that global citizens understand their impact and reliance on the ocean. This is true regardless of where they live, due to the interconnectedness of the oceans and all other ecosystems of the biosphere.

How is the nature of marine science engaged with?

The DP marine science course supports teaching through:

- approaches to learning
- nature of science

- skills in the study of marine science.

The DP marine science course supports learning in several ways.

- A balanced experimental programme—Students are encouraged to become familiar with traditional experimentation techniques, as well as the application of technology where possible. These opportunities help them to develop their investigative skills and evaluate the impact of error in scientific inquiry.
- The scientific investigation—This places a specific emphasis on inquiry-based skills and the formal communication of scientific knowledge.
- The collaborative sciences project—This extends the development of scientific communication in a collaborative and interdisciplinary context, allowing students to work together beyond the confines of one specific syllabus.

Marine science and the core

Marine science and theory of knowledge

The TOK course plays a special role in the DP by providing opportunities for students to reflect on the nature, scope and limitations of knowledge and the process of knowing through an exploration of knowledge questions.

The areas of knowledge are specific branches of knowledge, each of which can be seen to have a distinct nature and sometimes use different methods of gaining knowledge. In TOK, students explore five compulsory areas of knowledge: history, the human sciences, the natural sciences, mathematics and the arts.

There are several different ways in which aspects of the marine science course can be connected to the exploration of knowledge. During the learning and teaching of the marine science course, teachers and students evaluate knowledge claims by exploring questions concerning their validity, reliability, credibility and certainty, as well as individual and cultural perspectives on them.

Exploration of the relationship between knowledge and TOK concepts can help students to deepen their understanding and make connections between disciplines. For example, while discussing the depletion of energy sources and the constant need for new energy resources to meet energy demands, students can explore the concepts of responsibility, power and justification.

Many aspects of the marine science course lend themselves to the exploration of knowledge questions. Some examples are provided in table 2.

Table 2

Examples of knowledge questions

Learning opportunities	Knowledge question
Origin of oceans (topic 1)	What is the role of imagination and intuition in the creation of hypotheses in natural sciences?
From a theory of permanence to plate tectonics (topic 1)	What role do paradigm shifts play in the progression of scientific knowledge?
Measuring salinity (topic 2)	Why is there so much discrepancy in measurements? What is the nature of uncertainty?
Thermodynamics of water (topic 2)	How do the tools that we use shape the knowledge that we produce?
Ecosystem health (topic 6)	To what extent do the systems that we use in the pursuit of knowledge affect the conclusions that we reach?

For more information, please refer to the *Theory of knowledge guide* and the *Theory of knowledge teacher support material*.

Marine science and the extended essay

Students are not permitted to complete an EE on a school-based subject. If a student is interested in topics related to marine science, it might be possible to explore them as part of another subject such as biology, environmental systems and societies or geography or as an interdisciplinary world studies EE.

Marine science and creativity, activity, service

The CAS component of the DP core provides many opportunities for students to link science concepts and topics to practical experiences. Teachers can highlight how knowledge and understanding developed through the course might inform meaningful experiences. Outside the classroom, CAS experiences might also ignite students' passion for addressing topics inside the marine science classroom.

Some examples of relevant CAS experiences are as follows.

- Organizing a science club for students in lower years
- Implementing environmental initiatives within the school or local community, such as recycling, composting and beach clean-ups
- Organizing or participating in a social media outreach or advocacy campaign, for example, on an environmental concern

CAS experiences can be a single event or may be an extended series of events. It is important that CAS experiences be distinct from and not submitted as part of a marine science assessment.

For more information, please refer to the *Creativity, activity, service guide* and the *Creativity, activity, service teacher support material*.

Marine science and international-mindedness

Science has been, and continues to be, a truly international endeavour. From the beginnings of seismology in China, through material science in Mesopotamia to astronomy in the Islamic Golden Age, the search for an objective understanding of the natural world transcends the limitations imposed by national boundaries. The scientific process, requiring curiosity, insight and an open-minded approach, benefits from the widest possible participation across genders and cultures through inclusivity and diversity.

Given the global nature of many scientific issues, international organizations often have a focus on the engagement of science with the public domain. The World Health Organization and the Intergovernmental Panel on Climate Change are two well-known examples that model a responsibility to inform nations of scientific progress on an equitable basis. Underlying this responsibility is the interest of promoting a peaceful and sustainable future.

Advancements in technology, along with the cost of modern research facilities, continue to reinforce the role of international collaborative work. The project between the Joint Institute of Nuclear Research in Russia and the Lawrence Livermore National Laboratory in the USA to provide evidence for the existence of element 118, oganesson, is a good example of international collaboration.

The importance of collaboration in contemporary science is reflected by the large number of international organizations tasked with collating and sharing data with the scientific community. Access to shared knowledge through websites and databases must be integrated into classroom teaching as it plays an important role in validating experimental work.

In addition to integrating technology and collaborative work, the collaborative sciences project provides an excellent opportunity for students to engage with global issues.

Marine science and the IB learner profile

Each box provides an example of how each learner profile attribute could be modelled by learners and teachers.

Example attribute
• Learners who best embody the attribute with reference to science. • Directing teachers with possible routes to develop the attribute in the classroom. • Practical ways in which learners demonstrate the attribute in the process of “doing” science.

Attributes of the IB learner profile

Inquirer
• Inquirers are curious; they actively use research skills, work independently and show enthusiasm about the world around them. • Teachers facilitate skill development and promote inquiry; they provide students with opportunities to ask questions, search for answers and experiment. • Learners use their inquiry skills to extend their scientific knowledge and engage with research.

Knowledgeable
• Learners explore concepts, ideas and issues related to science in order to broaden and deepen their understanding of factual and procedural knowledge. • Access to a variety of resources and opportunities provides learner agency to develop scientific knowledge and understanding. • Learners apply their knowledge to unfamiliar contexts and make connections between concepts and facts to illustrate their understanding of science.

Thinker
• Learners are eager to solve complex problems and reflect on their thinking strategies. • Teachers provide opportunities for learners to critically analyse their approaches and methods and deepen their understanding of science, allowing them to be creative in finding solutions to problems. • Learners practise reasoning and critical thinking by testing assumptions, formulating hypotheses, interpreting data and drawing conclusions from the evidence provided.

Communicator
• Learners collaborate effectively with others and use a variety of modes of communication to express their ideas and opinions. • Teachers facilitate group work and encourage open discussions and the use of the scientific language to provide models for successful communication. • Learners demonstrate effective communication skills as part of collaborative activities through listening to others and sharing ideas.

Principled
• Learners take responsibility for their work, promote shared values and act in an ethical manner. • Teachers can provide opportunities to model principled behaviour including acknowledging the work of others and citing sources. The collaborative sciences project provides opportunities for learners to take a principled stance. • Learners appreciate the importance of integrity in data collection and consider all data, even that which does not match their original hypothesis.

Open-minded
• Open-minded learners accept that different perspectives, models or hypotheses exist, and these can be used to enhance scientific understanding. • Teachers can provide models that were at the time supported by data or observations, but through reasoning, deduction or falsification may be rejected or refined. • Learners need to be prepared to have their perspectives and ideas challenged through the study of science.

Caring
• Learners act to protect the environment and to improve the lives of others. • Teachers can draw attention to how daily choices have consequences by challenging learners to adopt sustainable practice and providing support to help fellow learners. Reference should be made to the *IB sciences experimentation guidelines*. • Learners can connect curriculum content to global challenges such as healthcare, energy supply or food production. The collaborative sciences project provides an opportunity for learners to support each other to enable their group to achieve their goal successfully.

Risk-taker
• Risk-takers seek new opportunities to develop their learning and explore new approaches to solve problems. They actively thrive on challenges. • Teachers can provide support and guidance for learners, encouraging them to explore new techniques or methods of learning. This might include scaffolds for the use of language, the design of experiments and the analysis of data. As learners grow in confidence, these supports can be phased out, giving them more freedom to choose their own approach. • Learners should be prepared for the next set of experimental data to falsify their ideas as uncertainty is a feature of science. They understand that this is a step forward in their understanding.

Balanced
• Balanced learners look holistically at all aspects of their development and ensure that various tasks are given appropriate attention without focusing on one to the detriment of others. • Teachers should encourage learners to consider a balanced perspective on scientific issues without bias. • Learners need to organize their own time effectively, giving themselves sufficient time to complete all parts of their learning without negatively impacting on the emotional and social aspects of their lives.

Reflective
• Reflective learners consider why and how they achieve success, and also how they could change their approach when learning is difficult. • Teachers provide opportunities for learners to continually review strategies, methods, techniques and approaches to problem-solving in order to improve their conceptual understandings in science. Assessment criteria or checklists can help learners to consider the quality of their work in a guided way. • Learners develop skills and concepts throughout the course, networking their knowledge by continually reflecting on their understanding.

Approaches to the learning and teaching of marine science

The approaches to learning framework

What are approaches to learning skills and why do we teach them?

The approaches to learning framework seeks to develop in students affective, cognitive and metacognitive skills that will support their learning processes during and beyond their IB experience. The development of approaches to learning skills is closely connected with the IB learner profile attributes and therefore helps to advance the IB mission. The approaches to learning skills are an integral part of IB learning and teaching that should be developed across the whole programme—it is not expected that a single course should ever address all of them.

How are they organized?

The approaches to learning framework for IB programmes consists of five general skill categories: thinking skills, communication skills, social skills, research skills and self-management skills. Each of these categories covers a broad range, as shown by the examples presented in table 3. The approaches to learning skill categories are closely linked and interrelated, and therefore individual skills may be relevant to more than one category.

How do we teach them?

Approaches to learning skills can be learned and taught, improved with practice and developed incrementally. Table 3 illustrates, through a number of examples, how the marine science course can support approaches to learning skill development. The examples shown in the table are not exhaustive. Teachers are encouraged to adapt them for use in their school context and collaboratively identify further examples of approaches to learning skill development.

Further information on the approaches to learning framework and strategies for the development of the approaches to learning skills can be found on the *Diploma Programme Approaches to teaching and learning website*.

Table 3

Approaches to learning skills and development

Skill category	Examples of approaches to learning skill development in the classroom
Thinking skills	• Being curious about the natural world • Asking questions and framing hypotheses based upon sensible scientific rationale • Designing procedures and models • Reflecting on the credibility of results • Providing a reasoned argument to support conclusions • Evaluating and defending ethical positions • Combining different ideas in order to create new understandings • Applying key ideas and facts in new contexts • Engaging with, and designing, linking questions • Experimenting with new strategies for learning • Reflecting at all stages of the assessment and learning cycle

Skill category	Examples of approaches to learning skill development in the classroom
Communication skills	• Practising active listening skills • Evaluating extended writing in terms of relevance and structure • Applying interpretive techniques to different forms of media • Reflecting on the needs of the audience when creating engaging presentations • Clearly communicating complex ideas in response to open-ended questions • Using digital media for communicating information • Using terminology, symbols and communication conventions consistently and correctly • Presenting data appropriately • Delivering constructive criticism appropriately
Social skills	• Working collaboratively to achieve a common goal • Assigning and accepting specific roles during group activities • Appreciating the diverse talents and needs of others • Resolving conflicts during collaborative work • Actively seeking and considering the perspective of others • Reflecting on the impact of personal behaviour or comments on others • Constructively assessing the contribution of peers
Research skills	• Evaluating information sources for accuracy, bias, credibility and relevance • Explicitly discussing the importance of academic integrity and full acknowledgement of the ideas of others • Using a single, standard method of referencing and citation • Comparing, contrasting and validating information • Using search engines and libraries effectively
Self-management skills	• Breaking down major tasks into a sequence of stages • Being punctual and meeting deadlines • Taking risks and regarding setbacks as opportunities for growth • Avoiding unnecessary distractions • Drafting, revising and improving academic work • Setting learning goals and adjusting them in response to experience • Seeking and acting on feedback

Experimental programme

Integral to the student experience of a marine science course is the learning that takes place through scientific inquiry within the classroom, laboratory or in the field. Experimentation through a variety of forms can be used to introduce a topic, address a phenomenon or allow students to consider and examine authentic questions and curiosities.

A school's experimental programme should allow students to experience the full breadth and depth of the course, develop scientific skills and demonstrate safe, competent and methodical use of a range of tools, techniques and equipment. Students should therefore be encouraged to develop investigations to support their learning through open-ended inquiry with a focus on laboratory and fieldwork experiments, databases, simulations and modelling.

For more information, please see the full "Experimental programme" section.

Conceptual learning

Concept-based learning and teaching is encouraged across the continuum of IB programmes.

Concepts are mental representations of categories. They are constructed, modified and activated by the learner through learning experiences. Concepts do not exist in isolation but are interrelated. Conceptual understanding is always a work in progress—it is continually being developed and refined.

Conceptual understanding is therefore an outcome of a non-linear, ongoing process of evolving understandings, adapting previous understandings, and identifying and dispelling misconceptions. It consists of making connections between prior and new knowledge to construct and build an awareness of this network of knowledge.

Concepts vary in their level of abstraction and universality.

- They can involve organizing ideas that are applicable in many contexts and have relevance both within and across subject areas.
- They can provide a deep understanding of specific knowledge fields (or fields of knowledge) and help to organize knowledge further, as well as reveal connections between different areas of the subject.

For example, consider the following sequence.

interdependence > tectonic movements > tsunamis

Outcomes of a concept-based approach

Fostering critical thinking, the outcome of a concept-based approach is that students are able to:

- identify examples of a concept
- organize, reflect on, modify and expand their network of knowledge
- apply their concepts to existing and future knowledge
- apply their conceptual understanding as a scientific thinking tool for predicting outcomes, justifying conclusions and evaluating knowledge claims.

Structure of the syllabus and conceptual understanding

The four themes of the marine science course allow for a structured and holistic understanding of complex marine systems. They emphasize the complexity and interconnectedness of these systems.

Each theme synthesizes two key concepts.

- Structures and processes
- Interaction and interdependence
- Stability and change
- Transfer and transformation

The theme-based approach fosters enduring conceptual understanding and provides a broader context for learning the key concepts of the discipline. The linking questions, which are a feature of this syllabus, provide additional conceptual lenses.

Structures and processes

In the study of marine science, “structure” refers to the biological, chemical and physical characteristics of the oceans, and “process” refers to mechanisms of change and variability.

Biogeochemical and biological processes affect chemical composition and ecosystem structure. Physical processes such as currents, waves and tides can shape physical structures, and they are influenced by the motions of Earth’s atmosphere and/or movements of astronomical bodies in the solar system.

Both structures and processes have causes, measurable dimensions, modifying factors and descriptive terms.

- Biological processes include photosynthesis, respiration, food web dynamics, nutrient utilization, reproduction, life cycles, migration and the response of marine life to environmental changes.
- Chemical processes involve the transformation and transport of substances in the ocean. These include nutrient cycling, carbon dioxide absorption, photosynthesis, respiration, precipitation and dissolution of minerals.
- Physical processes include the circulation of ocean currents driven by wind and density differences. These processes influence heat transfer, mixing, upwelling and the distribution of heat, salinity and mineral nutrients in the ocean.

Structures influence processes, and processes can modify structures, so a feedback relationship exists.

The physical, chemical and biological characteristics of the oceans influence the rates, pathways and behaviours of processes occurring within them. For example, the distribution of nutrients or the availability of light can impact primary productivity, which subsequently affects the food web and other ecological processes.

Geological processes provide understanding of geological features of the deep ocean, vents and coastlines. These influence weather, tides, run-off, waves and currents, which determine the structures and processes of ecosystems. The development of a variety of substrates along coastlines dictates which organisms inhabit them.

Ocean currents, wind patterns, tides, waves and upwelling are significant in shaping the physical structure of oceans. The movement of water affects distributions of heat, salinity and density, which in turn impacts the distribution and transport of nutrients, heat and other components. Biogeochemical processes, including nutrient cycling, gas exchange, chemical reactions and the precipitation and dissolving of minerals, affect the chemical composition and structure of oceans. For example, the cycling of carbon, nitrogen, phosphorus and other elements influences the availability of these elements to marine organisms. Biological processes such as photosynthesis, respiration, nutrient utilization, reproduction and interactions among organisms contribute to the structure of marine ecosystems. The presence and activities of different species, trophic interactions and ecological relationships influence the biodiversity, distribution and community structure within the oceans.

Interaction and interdependence

Interactions are the ways in which different parts of a system affect each other. Interactions in marine systems occur in different ways, from physical processes such as waves, currents and tides, to chemical changes such as those of salinity and temperature, to shifts in biological relationships such as predator–prey dynamics and symbiosis. The ocean interacts with other Earth systems, including the atmosphere, cryosphere, lithosphere, upper mantle and biosphere.

Interdependence in marine science emphasizes that all components of the ocean system can impact other components. For example, wind patterns impact ocean currents while latitude and seasons impact temperature, which in turn impacts heat and nutrient distributions around the globe, thereby impacting weather patterns and marine life.

The concept of systems provides a framework for understanding these interactions and interdependencies within a larger context. Together, these concepts allow for a holistic understanding of the ocean, highlighting that changes to one part of the system can impact the whole system due to the intricate interactions and interdependencies among its components.

Due to the interaction and interdependence within oceans, human activities can have far-reaching impacts. Greenhouse gas emissions can lead to ocean warming and acidification, disrupting marine ecosystems and impacting human communities that depend on these systems. A comprehensive understanding of this interaction and interdependence contributes to sustainable human activities.

Stability and change

The overall consistency of ocean circulation patterns is an important contributor to ocean stability. A global "conveyor belt" of surface currents and deep currents, driven by differences in temperature and salinity, helps distribute heat around the planet. The oceans also act as a vast reservoir that absorbs and stores heat and carbon dioxide, providing a buffer against sudden changes in atmospheric conditions. Marine ecosystems also have a degree of stability, with communities of organisms adapted to specific temperature ranges, salinity levels and nutrient availability.

Oceans may be stable, but they are not static—they undergo both rapid and slow changes. Natural variability ranges from daily tides to decades-long oscillations in ocean temperature and salinity. Other periodic phenomena, such as El Niño and La Niña, lead to significant, though temporary, changes in weather patterns and marine life.

The tension between stability and change in the oceans is a subject of significant scientific research. Understanding how stable systems respond to change, particularly dramatic change, is crucial for predicting future conditions and managing marine resources. Resilience and tipping points are key concepts in this regard. Resilience refers to the ability of a system to "absorb" change and still retain its basic function and structure. Tipping points refer to thresholds beyond which a system undergoes a fundamental shift, often with dramatic and potentially irreversible consequences.

Climate change, driven by increasing concentrations of greenhouse gases in the atmosphere, is significantly altering oceans. Sea levels are rising due to the thermal expansion of seawater and melting polar ice. Ocean acidification, a result of the oceans absorbing more carbon dioxide, threatens the stability of marine ecosystems, particularly organisms with calcium carbonate shells or skeletons. Warming oceans also alter the range and abundance of marine species, disrupt the timing of biological processes and can contribute to more intense and frequent marine heatwaves.

Transfer and transformation

The concepts of transfer and transformation are significant in the discipline of marine science, particularly in relation to the movement and change of matter and energy in marine systems.

The relationship between transfer and transformation is evident in the global carbon cycle. Carbon dioxide is transferred from the atmosphere to the ocean through absorption. Within the ocean, it is transformed through biological processes, such as photosynthesis and respiration, and through chemical reactions, such as those that form carbonates. The interplay of transfer and transformation ultimately regulates the distribution and cycling of carbon on Earth, contributing to Earth's climate regulation.

In marine science, "transfer" can refer to the movement of matter and/or energy from one location to another. For example, ocean currents transfer heat and nutrients around the globe. This transfer affects regional climates and marine life distributions. The exchange of gases between the ocean and atmosphere is another crucial aspect of transfer. Oceans absorb approximately one quarter of anthropogenic carbon dioxide emissions, helping to mitigate climate change but also leading to ocean acidification.

Transformation in marine science can be a change in the form of energy or a chemical change involving matter. For example, light energy from the Sun is transformed into chemical energy by photosynthetic organisms such as phytoplankton. This energy is then transferred along food chains as one organism consumes another. Nutrient cycling involves the transformation of matter. Elements such as iron, nitrogen and phosphorus are transformed in various chemical processes, passing through different physical states and biological forms.

Guiding questions and linking questions

Each section starts with guiding questions. They are intended as signposts for inquiry into a topic and to help students view the content of the syllabus through a conceptual learning lens. These questions are, therefore, best answered after the associated understandings have been acquired.

Each section ends with linking questions, with the intention to strengthen students' understanding by making connections. They challenge students to think beyond the content in a single topic and apply concepts from one topic to another. The ideal outcome of the linking questions is networked knowledge.

Suggested activities

Each section includes suggested activities. These are possible activities for teachers and students. They are not prescriptive or exhaustive, and teachers are free to explore and develop alternative activities.

Teaching marine science in context

The study of marine science enables constructive engagement with topical scientific issues. By contextualizing marine science concepts, scientific knowledge claims can be evaluated more effectively, and informed choices on such issues as climate change and the environment can be made. Marine science research has brought innovation and benefit to many fields and continues to be at the heart of seeking effective solutions to many global challenges. It is therefore important to explore applications of marine science in our world while teaching the course to elicit interest, understanding and curiosity.

Teaching the content of the course in relation to specific contexts supports the pedagogical principle of teaching in local and global contexts as part of the approaches to teaching framework and offers a number of advantages. First, it helps students relate their learning to genuine applications of marine science, highlighting the relevance to global issues as well as the significance in students' own contexts. Second, it develops in students an appreciation for the interaction between scientific solutions and their implications, be it ethical, environmental or economic. Third, it helps to illustrate some of the nature of science aspects underpinning the course.

Engaging with sensitive topics

Students and teachers are encouraged to engage with exciting, stimulating and personally relevant topics and issues that may be, at times, sensitive or personally challenging. Teachers should be aware of this and provide guidance on how to engage with such topics in a responsible manner. Consideration should be given to the personal, political, cultural and spiritual values of others.

Prior learning

Past experience shows that students will be able to study marine science 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

The Middle Years Programme (MYP) sciences courses seek to promote skills and attitudes needed to apply scientific knowledge in theoretical, experimental and authentic contexts. A strong foundation is established for DP sciences in which learners will capitalize on—and continue advancing—their skills and attitudes to develop knowledge and understanding commensurate with pre-university-level science.

The MYP offers a framework for learning and teaching while maintaining flexibility with curriculum content. The content in MYP sciences courses can therefore vary greatly from one school to another. Content in DP sciences courses is more prescribed, and this is one of the main differences teachers will notice when comparing the two programmes.

A connected, conceptual curriculum where learning is inquiry-based and contextualized is the pedagogical principle that underpins both programmes and indeed the entire IB continuum (International Baccalaureate, 2019).

Conceptual learning focuses on organizing ideas and their interconnections. A conceptual approach is encouraged in IB programmes because it promotes deep learning and facilitates the construction of further knowledge. Conceptual understanding aids the application of knowledge in unfamiliar and novel contexts. This skill is reflected in the aims and assessment objectives of both programmes.

Broad concepts frame MYP learning and teaching with the purpose of unifying ideas across subject areas. Discipline-specific related concepts are intended to provide disciplinary depth (International Baccalaureate, 2014). Key and related concepts are not required in the DP, although some teachers may find that they wish to continue developing a curriculum around them. In DP sciences, overarching concepts are manifested in the course roadmaps and the nature of science. DP sciences seek to highlight the interconnectedness of the course understandings. The intention is to promote conceptual understanding and further the construction of learners' knowledge networks.

Both MYP and DP teaching involve inquiry-based approaches, which foster a high degree of student engagement, collaboration and interaction. The inquiry, design, experimental, analysis, evaluation and communication skills encouraged by criteria B and C will serve students well as they prepare to undertake the scientific investigation for the internal assessment (IA). In addition, MYP students will gain familiarity with criterion-related assessment and the use of assessment criteria, which will further support their understanding of the DP sciences IA criteria.

IB programmes encourage the exploration of scientific principles in connection to local and global contexts. Doing so helps students ground abstract concepts in more concrete local and global real-world situations as well as cultivating international-mindedness (see the "Approaches to teaching" section on the *Diploma Programme Approaches to teaching and learning website*). Teachers should therefore weave opportunities for contextualization into the curriculum. MYP sciences criterion D analyses the real-world application of science. In the DP, sciences teachers are encouraged to frequently anchor their teaching in real-world applications that are invoked throughout the course of the programme.

In addition to equipping students with scientific knowledge and skills, the MYP and DP sciences courses share similar guiding principles that seek to develop in students the learner profile attributes.

Links to the Career-related Programme

In the Career-related Programme (CP), students study at least two DP subjects, a core consisting of four components and a career-related study, which is determined by the local context and aligned with student needs. The CP has been designed to add value to the students' career-related studies. This provides the context for the choice of DP courses. The marine science course can assist CP students planning careers in a variety of professional fields where, for example, a sound understanding of science and mathematical skills are important. These include mariculture, technology, meteorology, navigation, engineering and habitat restoration. While marine science helps students understand the underlying science in the contemporary world, it also encourages the development of strong problem-solving, critical thinking and ethical approaches that will assist students in the global workplace.

Aims

The course enables students, through the overarching theme of the nature of science, to:

1. develop conceptual understanding that allows connections to be made between different areas of the subject, and to other DP sciences subjects
2. acquire and apply a body of knowledge, methods, tools and techniques that characterize science
3. develop the ability to analyse, evaluate and synthesize scientific information and claims
4. develop the ability to approach unfamiliar situations with creativity and resilience
5. design and model solutions to local and global problems in a scientific context
6. develop an appreciation of the possibilities and limitations of science
7. develop digital technology skills in a scientific context
8. develop the ability to communicate and collaborate effectively
9. develop awareness of the ethical, environmental, economic, cultural and social impact of science.

Assessment objectives

The assessment objectives for marine science reflect those parts of the aims that will be formally assessed either internally or externally. It is the intention of the course that students are able to fulfil the following assessment objectives.

1. Demonstrate knowledge of:
    a. terminology, facts and concepts
    b. skills, techniques and methodologies.
2. Understand and apply knowledge of:
    a. terminology and concepts
    b. skills, techniques and methodologies.
3. Analyse, evaluate and synthesize:
    a. experimental procedures
    b. primary and secondary data
    c. trends, patterns and predictions.
4. Demonstrate the application of skills necessary to carry out insightful and ethical investigations.

Assessment objectives in practice

Assessments align with the course's aims, objectives and conceptual approach; the nature of science and subject-specific skills are also assessed. This allows students to demonstrate learning effectively through varied tasks that are reliably and accurately marked or moderated by subject-area educators and experts.

Assessment objective (AO)	Which component addresses this assessment objective?	How is the assessment objective addressed?
AO1 Demonstrate knowledge	Paper 1 Paper 2 Scientific investigation	Students respond to a range of unseen short-answer and extended-response questions. Students investigate and answer a research question that is their own.
AO2 Understand and apply knowledge	Paper 1 Paper 2 Scientific investigation	Students respond to a range of unseen short-answer and extended-response questions. Students investigate and answer a research question that is their own.
AO3 Analyse, evaluate and synthesize	Paper 1 Paper 2 Scientific investigation	Students respond to a range of unseen short-answer, data-based and extended-response questions. Students investigate and answer a research question that is their own.
AO4 Demonstrate the application of skills necessary to carry out insightful and ethical investigations	Scientific investigation	Students investigate and answer a research question that is their own.

Component	Approximate weighting of assessment objectives (%)	
	AO1 + AO2	AO3
Paper 1	50	50
Paper 2	50	50
Internal assessment	Covers AO1, AO2, AO3 and AO4	

Syllabus outline

Syllabus component		Teaching hours
Syllabus content		**110**
Geological marine science	Topic 1: Formation, structure and dynamics of ocean basins	20
Chemical marine science	Topic 2: Physical and chemical properties of ocean water	15
Physical marine science	Topic 3: Patterns of water movement Topic 4: Oceans, atmosphere and climate	18 15
Biological marine science	Topic 5: Energy, productivity and marine life Topic 6: Marine ecosystems	12 30
Experimental programme		**40**
Practical work Collaborative sciences project Scientific investigation		20 10 10
Total teaching hours		**150**

The recommended teaching time is 150 hours to complete SL courses as stated in the general regulations (in *Diploma Programme Assessment procedures*).

Syllabus roadmap

The aim of the syllabus is to integrate concepts, topic content and the nature of science through inquiry. Students and teachers are encouraged to personalize their approach to the syllabus according to their circumstances and interests.

Table 4

Marine science syllabus roadmap

Geological marine science	Chemical marine science	Physical marine science	Biological marine science
Topic 1: Formation, structure and dynamics of ocean basins	**Topic 2: Physical and chemical properties of ocean water**	**Topic 3: Patterns of water movement**	**Topic 5: Energy, productivity and marine life**
1.1—Formation of oceans 1.2—Physical structure of ocean basins 1.3—Description of ocean basins 1.4—Plate tectonics and seismic activity 1.5—Coastal structure and dynamics 1.6—Human life at the dynamic coastline	2.1—Physical properties of water 2.2—Chemical properties of seawater 2.3—Ocean acidification 2.4—Ocean water profiles	3.1—Surface currents 3.2—Wind-generated waves 3.3—Tsunamis and wave hazards 3.4—Tides 3.5—Thermohaline circulation, upwelling and the ocean “conveyor belt”	5.1—Energy and productivity 5.2—The central role of plankton in marine life 5.3—Organisms of the benthic zone 5.4—Organisms of the pelagic zone
		Topic 4: Oceans, atmosphere and climate	**Topic 6: Marine ecosystems**
		4.1—Interactions between atmosphere and ocean 4.2—The water cycle 4.3—Ocean storms 4.4—Cryosphere and climate 4.5—Climate records and climate change	6.1—Plant and algae-based ecosystems 6.2—Intertidal ecosystems 6.3—Oceanic ecosystems

Download: *Marine science syllabus outline and roadmap* (PDF)

Syllabus format

Marine science is a standard level course. As such, it should be taught in approximately 150 classroom hours over a period of two years. The format of the syllabus is consistent for all content. Concepts, skills, tools and content will be assessed.

Syllabus format

Topic name

Theme of study

Subtopic name

The **guiding questions** frame the subtopic. Students will be able to give increasingly in-depth answers as they study the subtopic.

Each subtopic is divided into numbered **understandings**. These include a **content statement**.

The content statement may be followed by **guidance**. This clarifies the expectations for learning and assessment.

Some understandings include links to the **nature of science.** These are intended to promote thought about aspects of the scientific process.

Most subtopics contain **suggested activities**. These are examples of possible activities teachers and students may engage in. They are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

The **linking questions** signpost related concepts in other marine science topics or in the nature of science. They encourage problem-solving beyond the immediate content and promote networked knowledge. Teachers and students are encouraged to create their own linking questions.

The **recommended hours** should be sufficient to teach all the subtopics within this topic. They should also be sufficient for assessment of learning, and to cover material from "Skills in the study of marine science" and "Nature of science".

The time allocated to the experimental programme is in addition to these recommended teaching hours.

Topic 1: Formation, structure and dynamics of ocean basins

Geological marine science

20 hours

1.1—Formation of oceans

Guiding questions:

- How has Earth changed in the billions of years since its origin?
- What caused the formation of oceans?

1.1.1—The conditions of the early planet, including atmospheric composition and the origins of water

1.1.2—Alternative ideas about how oceans formed

Guidance: Limit to comets and outgassing.

Nature of science: The conditions of early Earth cannot be observed. However, hypothesis formation is possible as there are testable statements that can be proved to be false. The use of verifiable patterns provides evidence for analysis that must be examined without bias in order to be scientific in nature.

1.1.3—Evidence of past atmospheric conditions as found in ice cores and crustal cores

1.1.4—Changes occurring in oceans

Guidance: Include changes associated with climate change as well as changes due to coastal erosion and volcanic eruptions.

Suggested activity

These activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

1.1.3—Determine the history of a basin from core sample data of accumulated sediments and oozes.

Linking questions

- In what ways are humans having an impact on the oceans?
- How is the chemical composition of the oceans changing?
- What are examples of the diversity of methods that marine scientists use to justify knowledge claims?

Download: *Marine science syllabus format* (PDF)

Skills in the study of marine science

The skills and techniques students must experience through the course are encompassed within the tools. These support the application and development of the inquiry process in the delivery of the marine science course.

Tools

- **Tool 1:** Experimental techniques
- **Tool 2:** Technology
- **Tool 3:** Mathematics

Inquiry process

- **Inquiry 1:** Exploring and designing
- **Inquiry 2:** Collecting and processing data
- **Inquiry 3:** Concluding and evaluating

Teachers are encouraged to provide opportunities for students to encounter and practise the skills throughout the programme. Rather than being taught as stand-alone topics, they should be integrated into the teaching of the syllabus when they are relevant to the syllabus topics being covered. The skills in the study of marine science can be assessed through internal and external assessment.

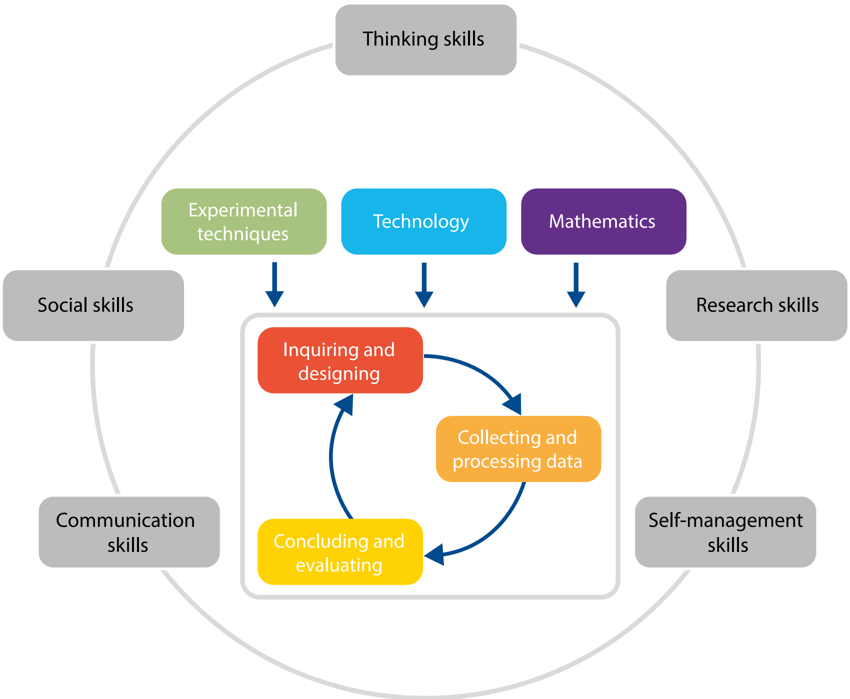
The approaches to learning provide the framework for the development of these skills.

By providing students with the opportunity for hands-on experimentation, they undertake some of the same processes as scientists. It is not enough for students to be able to follow directions and replicate a given experimental procedure; they must be provided with the opportunities for genuine inquiry. Developing scientific inquiry skills will give students the ability to construct an explanation based on reliable evidence and logical reasoning. Once developed, these higher-order thinking skills will enable students to be lifelong learners and scientifically literate.

This section of the syllabus lists specific tools, techniques and skills that students must experience throughout their study of marine science together with those covered in all science courses.

Figure 2

Skills for marine science



Tools

Tool 1: Experimental techniques

Skill	Description
Address safety of self, others and environment	Recognize and address relevant safety, ethical or environmental issues in an investigation.
Measuring variables	Understand how to accurately measure and communicate to an appropriate level of precision: • mass • volume • time • temperature • distance and length • density • pH • salinity • dissolved gases • velocity. Make careful observations of: • counts • scales of diagrams.

Skill	Description
	Use careful observation to: • draw annotated diagrams • make qualitative conclusions • recognize patterns • make classifications.
Controlling variables	Appreciate when and how to: • calibrate measuring apparatus, including sensors • maintain constant environmental conditions of reaction systems • choose representative random samples and minimize sampling errors.
Applying techniques	Show the ability to: • identify and classify organisms • use a variety of random and systematic sampling techniques, including quadrats, transect lines, core samples and plankton nets.
Tools specific to marine science	Demonstrate: • constructing and interpreting models • mapping, including contour mapping • using geographic coordinate systems • spatial understandings between spheres (3-D) and 2-D renderings • using vectors • drawing cycle and flow diagrams. Explain instrumentation and use data from: • magnetometers • bathythermographs • satellite altimeters • conductivity, temperature, depth (CTD) instruments • seismographs • Deep-ocean Assessment and Reporting of Tsunamis (DART) • Argo floats • the TAO/TRITON array • remotely operated vehicles (ROVs) • acoustic Doppler current profilers (ADCPs) • sonar (simple and multi-beam) • portable spectrophotometers. Additional tools can be found on the National Science Foundation website.

Tool 2: Technology

Skill	Description
Applying digital technology to collect data	• Use sensors, data loggers and apps. • Use cabled networks, for example, the Ocean Observatories Initiative (OOI).

Skill	Description
	• Identify and extract data from databases. • Generate data from models and simulations. • Use satellite imagery. Newer data collection tools may be found on the OOI website.
Applying digital technology to process data	• Represent data in a graphical form. • Use spreadsheets to manipulate data. • Create physical models. • Use computer modelling.

Tool 3: Mathematics

Skill	Description
Applying general mathematics	• Use basic arithmetic and algebraic calculations to solve problems. • Carry out calculations involving decimals, fractions, percentages, ratios, proportions, frequencies, densities, approximations and reciprocals. • Calculate measures of central tendency: mean, median and mode. • Calculate measures of dispersion: range, standard deviation (SD) and standard error (SE). • Use and interpret scientific notation (for example, 3.5×10^6). • Approximate and estimate. • Understand direct and inverse proportionality, as well as positive and negative correlations between variables. • Calculate and interpret percentage change and percentage difference. • Calculate rates of change from graphical or tabulated data. • Calculate rate, speed and celerity. • Apply the inverse Simpson's Diversity Index. • Calculate productivity. • Calculate abundance (density) of organisms.
Using units, symbols and numerical values	• Apply and use International System of Units (SI) prefixes and units or non-SI metric units, especially those used in marine studies. • Use a unit of measure to derive a formula. • Express quantities and uncertainties to an appropriate number of decimal places.
Processing uncertainties	• Understand the significance of uncertainties in raw and processed data. • Record uncertainties in measurements as a range (±) to an appropriate level of precision. • Express measurement and processed uncertainties to an appropriate number of decimal places. • Express ranges, degrees of precision, standard error (SE) or standard deviation (SD) as error bars. • Interpret values of the correlation coefficient and identify correlations as positive or negative.

Skill	Description
	• Apply the coefficient of determination (R^2) to evaluate the fit of a trend line. • Apply and interpret appropriate tests of statistical significance (for example, chi-squared test).
Graphing	• Sketch graphs, with labelled but unscaled axes, to qualitatively describe trends. • Construct and interpret tables, charts and graphs for raw and processed data including scatter plots, line graphs, logarithmic graphs, bar charts, histograms, pie charts, box-and-whisker charts and stacked bar charts. • Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes. • Draw lines or curves of best fit. • Distinguish between continuous and discrete variables. • Construct halocline, thermocline and pycnocline graphs. • Represent energy flow in the form of food chains, food webs and pyramids of energy.

Inquiry process

Inquiry 1: Exploring and designing

Skill	Description
Exploring	• Demonstrate independent thinking, initiative and insight. • Consult a variety of sources. • Select sufficient and relevant sources of information. • Formulate research questions and hypotheses. • State and explain predictions using scientific understanding.
Designing	• Demonstrate creativity in the designing, implementation and presentation of the investigation. • Develop investigations that involve hands-on laboratory experiments, databases, simulations, modelling and surveys. • Identify and justify the choice of dependent, independent and control variables. • Justify the range and quantity of measurements. • Design and explain a valid methodology. • Pilot methodologies.

Inquiry 2: Collecting and processing data

Skill	Description
Collecting data	• Identify and record relevant qualitative observations. • Collect and record sufficient relevant quantitative data. • Identify and address issues that arise during data collection.

Skill	Description
Processing data	• Carry out sufficient, relevant and accurate data processing.
Interpreting results	• Interpret qualitative and quantitative data. • Interpret diagrams, graphs and charts. • Identify, describe and explain patterns, trends and relationships. • Identify and justify the removal or inclusion of outliers in data (no mathematical processing is required). • Assess accuracy, precision, reliability and validity. • Critically analyse data.

Inquiry 3: Concluding and evaluating

Skill	Description
Concluding	• Interpret processed data and analysis to draw and justify conclusions. • Compare the outcome of an investigation to the accepted scientific context. • Discuss the impact of uncertainties on the conclusions.
Evaluating	• Evaluate hypotheses. • Identify and discuss sources and impacts of random and systematic errors. • Evaluate the implications of methodological weaknesses, limitations and assumptions on conclusions. • Explain realistic and relevant improvements to an investigation.

Syllabus content

Topic 1: Formation, structure and dynamics of ocean basins

Geological marine science

20 hours

1.1—Formation of oceans

Guiding questions

- How has Earth changed in the billions of years since its origin?
- What caused the formation of oceans?

1.1.1—Conditions of the early planet, including atmospheric composition and the origins of water

1.1.2—Alternative ideas about how oceans formed

Guidance: Limit to comets and outgassing.

Nature of science: The conditions of early Earth cannot be observed. However, hypothesis formation is possible as there are testable statements that can be proved to be false. The use of verifiable patterns provides evidence for analysis, which must be examined without bias in order to be scientific in nature.

1.1.3—Evidence of past atmospheric conditions as found in ice cores and crustal cores

1.1.4—Changes occurring in oceans

Guidance: Include the changes associated with climate change as well as changes due to coastal erosion and volcanic eruptions.

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**1.1.3**) Determine the history of a basin from core sample data of accumulated sediments and oozes.

Linking questions

- In what ways are humans having an impact on the oceans?
- How is the chemical composition of the oceans changing?
- What are examples of the different methods that marine scientists use to justify knowledge claims?

1.2—Physical structure of ocean basins

Guiding questions

- What criteria do we use to define the different regions of Earth's geosphere?
- How does the shape of coastlines determine the "boundaries" of named seas?

1.2.1—Oceans as water and ice as well as lithosphere beneath and atmosphere above

1.2.2—Three dimensions of the ocean system

1.2.3—Geographic coordinate system

1.2.4—Parallel lines of latitude and non-parallel lines of longitude as seen on a globe

1.2.5—Lines of latitude and longitude with special designations

Guidance: Limit to the equator, the prime meridian, the Arctic Circle, the Antarctic Circle, the international date line and the tropics of Cancer and Capricorn.

1.2.6—Importance of naming and locating the world's oceans and major seas

1.2.7—Characteristics of the cryosphere, lithosphere, atmosphere and hydrosphere

Guidance: Limit to the properties used to distinguish between them, such as composition, physical properties and relative positions on a cross-sectional representation of Earth.

Nature of science: Representations such as 2-D maps are useful, but such simplifications can lead to misconceptions. For example, because of the geometry of a sphere, the shortest flight path between Miami, USA, and Manila, the Philippines, would take an aircraft near Alaska.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**1.2.2**) Design a 3-D model to indicate the three dimensions of the ocean system.

Guidance: Students should demonstrate that oceans include two horizontal dimensions as well as vertical dimensions above and below sea level. This should be done both two-dimensionally and three-dimensionally using a sphere.

(**1.2.3**) Use the geographic coordinate system of latitude and longitude to describe locations.

(**1.2.6**) Locate and label the world's oceans and major seas using maps of different projections and a globe.

Linking questions

- How do the physical properties of water affect interactions between the atmosphere, cryosphere and hydrosphere?
- How does latitude affect tide patterns, water temperatures and ocean currents?
- In what ways does the hydrosphere interact with the atmosphere and the cryosphere?

1.3—Description of ocean basins

Guiding questions

- How do we determine the topography of the ocean floor and coastlines?
- What resources are mined from oceans and shores?

1.3.1—Uses of bathymetry

Guidance: Students should be able to explain how bathymetric data using echo soundings are obtained and can be used to make contour maps and ocean profiles.

Nature of science: The use of altimetry to verify bathymetry demonstrates the importance of ground truthing. When different methods yield results that support the same conclusion, this increases the confidence of conclusions.

1.3.2—Satellite altimetry

Guidance: Explain the principles of this technique and its resolution compared to bathymetry. Bathymetric data and altimetry data verify one another.

1.3.3—Locations of named seabed features as important sources of data

Guidance: Include the Mid-Atlantic Ridge, East Pacific Rise, Mariana Trench, Ring of Fire and Hawaiian–Emperor seamount chain.

1.3.4—Significance of coastline assets

Guidance: Include beaches, barrier islands, sandbars, barrier reefs, fringing reefs, cliffed headlands, estuaries, lagoons, bays, salt marshes and substrates.

1.3.5—Marginal (continental shelf, continental slope and continental rise) and oceanic ocean zones

Guidance: Include recognition of features such as seamounts, abyssal plains, trenches and submarine canyons. Include identification of abyssal plains, basins, canyons, continental margins, mid-ocean ridges, seamounts and trenches.

1.3.6—Mining of a basin floor for valuable minerals and resources, including oil and gas, metals and ocean floor deposits

Guidance: Include the changing demands on resources and the potential for environmental impact.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**1.3.1**) Use bathymetric data to construct a contour map with a profile of a transect through it.

(**1.3.2**) Use satellite altimetry data to map features of the ocean floor.

(**1.3.6**) Using a case study approach, discuss the value, risks and environmental impacts of oceanic mining of minerals required for electric vehicles.

Linking question

- How does topography affect the structure of biological communities?

1.4—Plate tectonics and seismic activity

Guiding questions

- How does the theory of plate tectonics explain the transformation of Earth's crust and oceans?
- How do data from several different types of instruments make it possible to construct an understanding of plate tectonics?

1.4.1—Tectonic boundaries and earthquake frequency

1.4.2—Mechanisms that have been proposed for the movement of plates

1.4.3—Mechanism that is forming the Emperor Seamounts and the Hawaiian Islands

1.4.4—Formation of ocean structures due to tectonic plate activity

Guidance: Include marine trenches, island arcs, rift valleys, seamounts and mid-ocean ridges.

1.4.5—Evidence of tectonics

Guidance: Include data collected by magnetometers, seismographs, bathythermographs and core samples. Understanding of the technology and the interpretation of the data generated is expected.

Nature of science: Models play an important role in scientific research and understanding but are incomplete representations of reality. The limitations of models should always be considered.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**1.4.1**) Using a map of earthquake epicentres, outline the tectonic plate boundaries. Label boundaries as divergent/seafloor spreading, convergent/subduction or transverse.

Guidance: Names of tectonic plates are not required.

(**1.4.2**) Create models of plate actions.

Guidance: Include subduction, seafloor spreading and mountain building. The model may be a 3-D structure, a diagram, an animation or a hand motion.

(**1.4.3**) Use data for the ages of Pacific volcanoes to measure the rate and direction of movements of the Pacific Plate.

(**1.4.5**) Analyse data sets collected by magnetometers, seismographs, bathythermographs and core samplings in support of the movement of tectonic plates.

Linking questions

- What are the challenges of life in seismically active areas?
- What are the effects of seismic activity on water movement?

1.5—Coastal structure and dynamics

Guiding questions

- What forces affect the stability and instability of coastal zones?
- What phenomena cause changes in coastal structure?

1.5.1—Natural processes that shape ocean coastlines

Guidance: Include the transport of sediments to and from beaches by waves, currents and storms, as well as weathering and erosion of rock by wind, water and ice.

1.5.2—Dynamic equilibrium of movement of sand on sandy shores from currents and wave action

Guidance: Include longshore currents and littoral drift that shift with the seasons.

1.5.3—Variety of substrate sediments, including sources, composition, texture, uniformity and size

1.5.4—Structures and practices to reduce coastal erosion, including the relative success of different measures

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**1.5.1**) Compare and contrast two different coastlines in relation to structure, substrate, currents and tides.

(**1.5.3**) Compare and contrast sediments from different beaches or for different seasons.

Linking questions

- What is the relationship between tides and definitions of a coastal zone?
- How do ocean currents affect the shape of a coastline?
- How does the shape of a coastline affect tide patterns?

1.6—Human life at the dynamic coastline

Guiding questions

- How do scientists contribute to solving problems associated with life at coastlines?
- What regular events and hazardous conditions cause coastal damage?

1.6.1—Damage due to tsunamis, storm surges and rising sea levels

1.6.2—Effects of shifting coastal conditions and human-made developments

1.6.3—Factors used to evaluate methods for protecting property

1.6.4—Adaptation and mitigation in response to regular coastal hazards

Guidance: Include how the detection devices, warnings and procedures for mitigation and adaptation work.

1.6.5—Limits to the effectiveness of adaptation solutions such as building seawalls and the artificial replacement of sand

1.6.6—Use of historic events to design future mitigation against hazards

1.6.7—Sea level rise due to climate change, and its impact on coastal communities

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**1.6.2**) Use an erosion table or computer model to investigate the effects of currents and/or waves on shore shape and the structures designed to maintain a shore.

(**1.6.6**) Study the effects of a named storm, seismic event or flooding event at a named coastal location and then evaluate the mitigation plans to protect against future disasters.

Linking questions

- How can mitigation and adaptation activities help to solve ecological problems?
- How do the dynamics of coastlines affect ecosystems?

Topic 2: Physical and chemical properties of ocean water

Chemical marine science

15 hours

2.1—Physical properties of water

Guiding questions

- What is the role of hydrogen bonding in determining the physical properties of water?
- How do the physical properties of water affect oceans?

2.1.1—Molecular structure of water, including its polarity

2.1.2—Cause and significance of hydrogen bonding in water

Guidance: Include diagrams showing covalent bonds within molecules and hydrogen bonds between molecules.

2.1.3—Physical properties of water resulting from hydrogen bonding: cohesion, surface tension, high melting and boiling points, high specific heat capacity and high latent heat

2.1.4—Maximum density of water at 4°C

Guidance: Include an explanation of water expansion on freezing as well as the significance to aquatic systems of having the highest density at 4°C.

2.1.5—Role of thermal expansion in rising sea levels

2.1.6—Effects of temperature, pressure and salinity on the density of seawater

2.1.7—Influence of density on the vertical structure of oceans

Guidance: Refer to thermohaline circulation and ocean stratification.

2.1.8—Importance of high specific heat capacity and latent heat of water in global heat regulation

Guidance: Include the greater absorption of heat without changing temperature as compared to other fluids.

2.1.9—Salt extrusion during freezing of seawater

Guidance: Include the importance of salt extrusion to deep-sea circulation.

2.1.10—Transmission of light, sound and heat energy through ocean water

Guidance: Include factors that change the transmission as well as impacts on other subsystems of the ocean.

2.1.11—Influence of ocean depth on spectra and intensity of light

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**2.1.6**) Determine the effects of temperature and/or salinity on the density of seawater.

Guidance: Include the understanding that temperature and salinity independently affect density.

(**2.1.8**) Collect temperature data while heating water from solid to vapour and construct an annotated time–temperature graph during the changes of state (fusion or vaporization) to demonstrate high latent heat.

Linking questions

- How do the thermal properties of water affect climate?
- How do differences in density affect deep ocean circulation and climate?
- How do changes in the quality of light affect producers?

2.2—Chemical properties of seawater

Guiding questions

- How does the tendency of water to dissociate into ions affect conditions in seawater?
- How does the pH buffering property of seawater help to maintain stable conditions?
- What aspects of ocean chemistry are affected by changes in temperature?

2.2.1—Solvent properties of water with solids, liquids and gases

2.2.2—Sources of salts and relative concentrations of ions

Guidance: Limit to general sources of salt and the fact that salts include other compounds in addition to NaCl.

2.2.3—Constancy of relative proportions of major ions in seawater with variation in salt concentration/absolute salinity

Nature of science: Measurement by different tools may result in different values for the same substance. Making decisions about how to reconcile these differences is an important process in science.

2.2.4—Sources of the dissolved gases nitrogen (N_2), oxygen (O_2) and carbon dioxide (CO_2)

2.2.5—Differences in relative concentrations of dissolved gases from 2.2.4 between the atmosphere (gaseous) and oceans (aqueous)

2.2.6—Effect of temperature on the concentration of dissolved gases from 2.2.4

2.2.7—pH buffering property of seawater

Guidance: Limit to the ability of seawater to maintain pH with small additions of H^+ and/or OH^- ions.

Nature of science: Making accurate quantitative measurements while understanding the limitations and sources of error of each technique is crucial to measurement.

2.2.8—Uses of inorganic nutrients (nitrate, phosphate, silicate, iron and calcium) by organisms

2.2.9—Seasonal fluctuation of nutrients

Guidance: Include the distinction between inorganic components and organic nutrients.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**2.2.3**) Measure salinity by at least two of the following methods: titration, conductivity, distillation, density.

(**2.2.6**) Measure concentrations of dissolved gases in water by chemical test or sensor. Include measurement of changes in concentration at different temperatures.

(**2.2.7**) Measure the pH of seawater by chemical indicator and pH sensor. Design and carry out an experimental procedure to show that seawater has buffering qualities different from the qualities of distilled water.

Linking questions

- How is climate change affecting the chemistry of water in oceans?
- What is the effect of upwelling on the composition of ocean water?

2.3—Ocean acidification

Guiding questions

- How has the concentration of carbon dioxide in the atmosphere changed over the past 100 years?
- How does the solubility of carbon dioxide at the ocean–atmosphere interface affect the pH of the ocean?
- What is the impact of rising carbon dioxide levels in the ocean on marine ecosystems?

2.3.1—The carbon cycle

2.3.2—Relative concentrations of carbon dioxide in water and air under standard conditions, and the role of carbon dioxide as a carbon sink

2.3.3—Effect of the dissolution of carbon dioxide on the pH of water

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

2.3.4—Acidification/decreasing pH of ocean water because of increasing carbon dioxide concentration in the atmosphere

Guidance: The pH scale is logarithmic, so a decrease of 0.1 pH units in seawater represents an approximately 30% increase in acidity.

2.3.5—Consequences of the acidification of oceans on marine life, including on shell formation, larval development and coral reefs

2.3.6—Strategies to mitigate the impact of ocean acidification

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**2.3.1**) Draw the carbon cycle, showing the form of carbon in each reservoir and relative residence times. Include CO_2(g), CO_2(aq), organic carbon and fossil forms.

(**2.3.3**) Measure change in the pH of water as carbon dioxide dissolves, for example, using a domestic soda maker.

(**2.3.5**) Analyse data on changes in ocean pH and its impact in a named marine ecosystem.

Linking questions

- How may changes in ocean temperature impact the pH of seawater?
- How may increasing carbon dioxide levels in the ocean affect marine productivity?
- How are organisms affected by changes in seawater pH?

2.4—Ocean water profiles

Guiding questions

- What causes the variation in properties of ocean water at different depths?
- What methods and equipment are used to collect data to investigate vertical patterns in ocean water?

2.4.1—Variation of physical and chemical characteristics of ocean water with depth

Guidance: Include dissolved oxygen, dissolved carbon dioxide, pressure, light, temperature, salinity and density.

2.4.2—Effect of increasing pressure on density of seawater

2.4.3—Tools and methods for measuring and monitoring surface and deep waters

Guidance: Include the use of Argo floats, conductivity, temperature, depth (CTD) devices, anchored buoys and drifting buoys measuring density, salinity, temperature and direction of water flow.

2.4.4—Thermoclines, haloclines and pycnoclines, and their variations in different locations

2.4.5—Influence of wind on ocean profiles by mixing and upwelling

2.4.6—Role of the deep-water "conveyor belt" in the chemical composition of oceans

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**2.4.1**) Measure the dissolved oxygen or the dissolved carbon dioxide content of water.

(**2.4.3/2.4.4**) Construct a temperature–depth profile and identify the thermocline, or construct a salinity–depth profile and identify the halocline, or construct a density–depth profile and identify the pycnocline.

Linking questions

- How does deep-ocean circulation affect climate?
- How does melting ice impact deep-water circulation?
- How do unstable water profiles contribute to vertical ocean currents?

Topic 3: Patterns of water movement

Physical marine science

18 hours

3.1—Surface currents

Guiding questions

- What are the dynamic interactions between the atmosphere and ocean?
- How does the rotation of Earth on its axis affect ocean currents?

3.1.1—Relationships between prevailing winds, land masses, Earth's rotation and velocity of surface currents in the ocean

3.1.2—Causes of land and sea breezes

Guidance: Include differential heating of land and water, changes in atmospheric pressure, resultant convection cell and resultant movement of water due to friction of wind at the surface of water.

3.1.3—Causes of monsoon events

3.1.4—The Coriolis effect

Guidance: Include the cause and effects on the direction of surface currents, Ekman's spiral and sea level, as well as the effect of latitude on the impact of the Coriolis effect.

3.1.5—Effects of the tilt of Earth relative to the Sun as Earth orbits the Sun

Guidance: Relate this variation in insolation to heat distribution and seasons.

3.1.6—Movement of water and heat by ocean currents

Guidance: Include the effect of transport of heat by the Gulf Stream and North Atlantic Drift.

3.1.7—Description of currents with reference to speed, direction, temperature and volume of water moved

3.1.8—Factors that modify currents: latitude, seasons, rotation of Earth on its axis, speed and direction of wind

3.1.9—Upwelling and downwelling

Guidance: Limit causes to prevailing winds and seasonal changes that affect these wind patterns.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**3.1.1**) Determine the velocity of a wind-driven surface current from the velocity of the wind.

(**3.1.6**) On a map, draw and annotate major gyres for the Pacific and Atlantic oceans. Predict and verify the locations of garbage patches.

(**3.1.7**) Draw a map showing patterns of surface currents and calculate average speed using data from shipping debris records.

Linking questions

- How are the actions of the Gulf Stream and North Pacific Drift related to climate change/stability?
- What effects do upwelling and downwelling have on marine ecosystems?
- How is the coupling of atmospheric events to sea-surface events related to the motion of ocean waters and climate stability/instability?

3.2—Wind-generated waves

Guiding questions

- By what means does wind affect water movement?
- What modifiers change the dimensions of waves?

3.2.1—Causes of surface waves

Guidance: Limit to the transfer of kinetic energy of wind to the ocean surface by friction.

3.2.2—Anatomy of waves

Guidance: Include drawing the basic shapes and variations.

3.2.3—Dimensions of waves

Guidance: Include height, length, period (time), frequency and calculations to determine celerity (speed) and steepness.

3.2.4—Modifiers of wave dimensions and shape

Guidance: Include depth of water, wind speed, wind duration and fetch.

3.2.5—Transfer of energy involved in waves

3.2.6—Wave train indicates the direction of energy movement

3.2.7—Forces that extinguish waves

Guidance: Include surface tension and gravity.

3.2.8—Types of waves

Guidance: Include deep-water waves, shallow-water waves, episodic (rogue) waves, internal waves, standing waves (seiches), swells and breakers.

3.2.9—Direction of refraction of waves

Guidance: Limit to the wave trains being refracted towards headlands and away from coves and bays.

3.2.10—Relationship between surface waves and beach drift

3.2.11—Coastal impacts of storm surges

Guidance: Include coastal destruction and flooding.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**3.2.3**) Describe waves by drawing a surface-wave profile and labelling the dimensions. Calculate steepness and celerity of the waves from given dimensions. Show changes in the wave profile as waves approach the shore.

(**3.2.4**) Use an actual or virtual wave tank to measure changes in equal-energy waves with increasing water depths. Determine at what depth a wave becomes a deep-water wave (not influenced by the bottom).

(**3.2.9**) Use vectors to show changes in the direction of a wave train as it hits a bay or a headland.

(**3.2.10**) Create a model to show the effects of wave energy on coastal erosion.

Linking questions

- What energy transformations occur between the atmosphere and the hydrosphere?
- To what extent are coastlines restructured by the energy of waves and currents?

3.3—Tsunamis and wave hazards

Guiding questions

- What are wave hazards? What kinds of damage do they cause?
- How do people adapt to recurring hazards?
- What mitigation techniques have been successful in dealing with wave hazards?

3.3.1—Tsunamis as surface/shallow-water waves

Guidance: Refer to the fact that the depth of water is less than the wavelength.

3.3.2—Causes of tsunamis

Guidance: Include subsidence earthquakes, submarine landslides, meteorites large enough to displace a large volume of water, volcanic eruptions and calving glaciers/ice shelves.

3.3.3—Detection of tsunamis by DART

Guidance: Include DART as the acronym for Deep-ocean Assessment and Reporting of Tsunamis, which uses tsunameters that communicate with surface buoys and satellites.

3.3.4—Global inequity of tsunami-warning systems and preparation for limiting damage

Guidance: Refer to the fact that warning systems are in place to predict the arrival time and magnitude of tsunamis around the world, yet some areas of the world are underserved by these systems.

Nature of science: Empirical evidence is data gathered through measurement and the senses. Intervention strategies against tsunamis are based on empirical data.

3.3.5—Rogue waves as hazards for ocean-going ships

Guidance: Include the definition, causes and navigation hazards of rogue waves.

Linking questions

- How do people mitigate or adapt to ocean-related natural disasters?
- How are plate movements related to tsunamis?

3.4—Tides

Guiding questions

- How do interacting forces result in tides?
- What causes tides to be variable on different coastlines?

3.4.1—Measurement of tides

Guidance: Include water level and time of day using tide stations and satellites.

3.4.2—Factors affecting the dimensions of tides

Guidance: Include landmasses, phase of the Moon (relative position of the Sun), shape of ocean basins, latitude, declination of the Moon and weather.

3.4.3—Prediction of tides

Guidance: Include the factors used to generate tide tables as well as those that are not used.

3.4.4—Variation in tidal patterns

Guidance: Include diurnal, semidiurnal, mixed, spring and neap tides. A tide can be described by more than one of these terms—for example, a pattern could be both a spring tide and semidiurnal tide.

3.4.5—Equilibrium tidal theory and dynamic tidal analysis

Guidance: Include astronomic relationships between the Sun, the Moon and Earth (orbits and rotations). Explore the tide-raising forces (gravity, momentum). Include the role of friction in the timing of tides. Dynamic tidal analysis involves summation of the waveforms that occur at a location.

3.4.6—Relationship between tides and tidal currents

3.4.7—Tidal power as a renewable energy source

Guidance: Include tidal power efficiency and requirements to produce tidal power. The mechanism of electricity production is not required.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**3.4.3**) Using a tide prediction table and a team-based approach, generate an annotated 28-day graph of the predicted tide pattern at a given tide station. Assigning tide stations from different parts of the world with different latitudes and coastal features can allow for a rich comparison of patterns and modifiers.

(**3.4.5**) Using vectors, draw an annotated diagram showing the forces involved in causing the tidal bulge at each main phase of the Moon.

Linking questions

- How are tides like waves?
- How do the tides affect coastal ecosystems and the distribution of organisms?
- How do winds, waves, tides and currents interact?

3.5—Thermohaline circulation, upwelling and the ocean "conveyor belt"

Guiding questions

- What is the importance of thermohaline circulation?
- How does the meridional overturning circulation (MOC) affect climate and climate change?

3.5.1—Effect of seawater density on floating and sinking

Guidance: Limit to the fact that denser water sinks whereas less dense water rises, resulting in thermohaline circulation.

3.5.2—Variables affecting salinity of seawater

Guidance: Include significant factors such as precipitation, run-off, evaporation, sea ice formation and wind shear.

3.5.3—Upwelling caused by winds

Guidance: Include the explanation that prevailing winds move surface water, which causes deep dense water to rise to the surface as it replaces water that has been moved.

3.5.4—Significance of the MOC (the ocean "conveyor belt")

3.5.5—Persistence of the MOC

Guidance: Include the mechanism for the persistent pattern, including the effects of evaporative winds in the North Atlantic Ocean. Changes in the MOC should be considered.

3.5.6—Seasonal patterns of upwelling and downwelling

Guidance: Include reasons for seasonality as well as implications for ecosystems.

Nature of science: A discrepant event is an unexpected or surprising phenomenon that contradicts existing knowledge or expectations, for example, high density water rising during upwelling.

3.5.7—Causes of El Niño and La Niña events

Guidance: Include recognition that the causes of these phenomena are not fully understood. Coupling of oceanic and atmospheric conditions must occur before an El Niño event can be declared.

3.5.8—Impacts of El Niño and La Niña events on ecosystems, climate and economies

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**3.5.5**) Examine a model of MOC to explain its effects on weather and climate.

(**3.5.6**) Track sea-surface temperatures over several months to predict whether or not an El Niño event is likely.

Linking question

- Which ocean patterns are seasonal?

Topic 4: Oceans, atmosphere and climate

Physical marine science

15 hours

4.1—Interactions between atmosphere and ocean

Guiding questions

- What are the effects of friction at the air–sea interface?
- What is the effect of variable density of air on the movement of the atmosphere and the hydrosphere?

4.1.1—Tricellular structure of the atmosphere

Guidance: Include reference to ocean-surface currents and the influence of Earth's rotation.

4.1.2—Global effect of prevailing winds and resulting surface-current patterns

4.1.3—Impact of the thermal properties of water on the oceans and on the atmosphere

Guidance: Include the transfer of heat from the ocean to the atmosphere.

4.1.4—Relationship between convection systems in the atmosphere that generate wind, causing waves and currents

4.1.5—Influence of ocean currents on climates of continents

4.1.6—Formation of a mixed layer in oceans, including vertical mixing caused by wind

Linking questions

- How can warm currents affect the climates of countries at high latitudes?
- In what ways does the heat of ocean currents affect the climate on land?

- What causes oceans to absorb more energy than the atmosphere?

4.2—The water cycle

Guiding question

- Why is the water cycle important to understanding the dynamics of oceans?

4.2.1—The water cycle and energy sources that drive it

Guidance: Include the movement of water and energy as well as changes in the states of water that store and release heat energy.

4.2.2—Water's presence as solid, liquid and gas for temperature and pressure conditions on Earth

4.2.3—Energy transformations associated with sublimation, evaporation, transpiration, condensation and deposition

4.2.4—Movement of water from one sink to another

Guidance: Include changes that may indicate climate change.

Nature of science: Using different frames of reference can yield a system-wide understanding of a process. For example, knowledge of the water cycle can be used to analyse water reservoirs, the thermodynamics of water or changes to the cycle as a result of climate change.

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**4.2.1**) Construct a diagram of the water cycle, indicating reservoirs, flows, phase changes and relative residence times.

Linking questions

- How does transfer of latent heat affect climate?
- What is the relationship between atmospheric greenhouse gases and the ocean?

4.3—Ocean storms

Guiding questions

- In what ways do ocean storms arise from the thermodynamic interactions between oceans and atmosphere?
- How do human societies adapt to and/or mitigate the effects of major ocean storms?

4.3.1—Occurrence of tropical cyclones, hurricanes and typhoons

Guidance: Include the use of these different terms according to the geographic origin of the storm.

4.3.2—Conditions for generating tropical cyclones, hurricanes and typhoons

Guidance: Include high sea-surface temperatures, adequate Coriolis effect and weak winds.

4.3.3—Energy sources for hurricanes and typhoons

Guidance: Include the roles of latent heat, evaporation and condensation.

4.3.4—Hazards from hurricanes and typhoons

Guidance: Include storm surges, flooding rains, strong winds and tornadoes.

4.3.5—Human responses to hurricanes and typhoons

Guidance: Include human adaptations in hurricane-affected areas as well as efforts to mitigate damage.

4.3.6—Oceanic heatwaves

Guidance: Include where they occur and the damage they cause to marine ecosystems.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**4.3.5**) Track an approaching hurricane from coordinate data and time.

(**4.3.6**) Collect data from oceans before and after a heatwave episode to determine the impact.

Linking questions

- To what extent do the properties of water affect hurricanes?
- How is increasing global heat content affecting marine storms and causing oceanic heatwaves?

4.4—Cryosphere and climate

Guiding questions

- How do the cryosphere, atmosphere and ocean affect climate equilibria?
- What is the difference between climate equilibria and climate change?

4.4.1—Factors that affect local climates

Guidance: Include latitude, proximity to large bodies of water (ocean), net incoming solar radiation, long-term average atmospheric circulation and prevailing ocean circulation.

4.4.2—Periodicity of climate

Guidance: Climate responds daily, seasonally, over decades and timescales of millions of years. Oceanic influences are similar in periodicity.

4.4.3—Cryosphere

Guidance: Include snow, land ice, ice caps, sea ice, glaciers and permafrost as well as the distinguishing characteristics and system-wide influences of each.

4.4.4—Antarctica, Arctic and sea ice impacts on Earth's climate

4.4.5—Melting glaciers and calving of shelf ice

Guidance: Relate these to impacts on rising sea levels.

4.4.6—Impact of rising sea levels on local flooding and on saltwater intrusion

Nature of science: The global climate system is vast, and making clear predictions is challenging. Models should consider the properties that emerge from the interaction of the individual parts of the climate system.

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**4.4.3**) Data-mine information about the extent and thickness/concentration of sea ice at either the Arctic or Antarctic over a period of time.

Linking questions

- What coastal features are at greatest risk of the effects of rising sea levels?
- How does formation of sea ice impact the ocean "conveyor belt"?

4.5—Climate records and climate change

Guiding question

- How can data be obtained to support hypotheses about climate change?

4.5.1—Evidence to examine past climate conditions

Guidance: Include evidence in rock, fossils, pollen, tree growth rings, deep-sea sediment cores and ice cores.

4.5.2—Characteristics of climate change

Guidance: Include the challenge of geographic variability in climate change and that it can involve changes in averages or changes in extremes.

4.5.3—Pace of climate change, including the abrupt nature of some changes

4.5.4—Natural and anthropogenic causes of climate change

Guidance: Include the climate-forcing mechanisms (climate drivers) of solar output variability (sunspots), Milankovitch cycles and volcanic eruptions. Include data on changes in atmospheric carbon dioxide, for example, from the Mauna Loa database, and its impact on oceans.

4.5.5—Use of computer models to predict climate change

Nature of science: Scientists contribute to the discussions and policies of international conventions. For example, the International Panel on Climate Change (IPCC) is an international organization that monitors climate change and its effects and periodically makes recommendations.

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**4.5.5**) Examine the inputs for two or more models and consider why predictions based on these climate models can be very different.

Linking questions

- How do interactions within the water cycle change with climate change?
- How is solubility of carbon dioxide in water related to global climate change?

Topic 5: Energy, productivity and marine life

Biological marine science

12 hours

5.1—Energy and productivity

Guiding questions

- How does the level of productivity affect ecosystems in oceans?
- What factors affect productivity?
- What is the key difference in the way energy and matter flow through an ecosystem?

5.1.1—Definition and measurement of productivity

5.1.2—Factors affecting primary productivity

Guidance: Limit to light, temperature and inorganic nutrients.

5.1.3—Phytoplankton, bacteria or algae/seaweeds as producers/autotrophs

Guidance: Limit to organisms with chlorophyll.

5.1.4—Role of chlorophyll in absorbing light energy for synthesis reactions during photosynthesis

Guidance: Only a simple treatment is expected. Limit coverage to molecular and energy inputs and organic products. Include conversion of the primary carbohydrate product into other organic products.

5.1.5—Energy and molecular transfer through biological communities

Guidance: Limit to food chains, food webs and trophic pyramids of energy.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**5.1.1**) Measure productivity.

(**5.1.5**) Draw and annotate marine food webs to illustrate energy flow and carbon cycling.

Linking questions

- How does the passage of light travelling through water affect photosynthesis?
- What is the effect of upwelling on plankton populations?
- How do the water cycle, carbon cycle and food webs interact?

5.2—The central role of plankton in marine life

Guiding questions

- What distinguishes plankton from other organisms?
- How is plankton central to marine life?
- How do variations among plankters affect their ways of life?

5.2.1—Characterization of plankton as diverse organisms that cannot move against winds and currents

Guidance: Include multicellular organisms, bacteria and viruses.

5.2.2—Roles of phytoplankton and zooplankton in food webs

5.2.3—Role of phytoplankton in the global carbon cycle

5.2.4—Survival adaptations of phytoplankton and zooplankton

5.2.5—Occurrence of phytoplankton blooms

Guidance: Include floating masses of *Sargassum* and harmful algal blooms.

5.2.6—Marine plankton as links among marine ecosystems

Guidance: Include their importance as producers, to coastal filter feeders, to fish populations and as marine snow for deep-water organisms.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**5.2.1**) Using a microscope, examine and sketch phytoplankton and zooplankton.

(**5.2.5**) Describe and evaluate two methods of sampling plankton. Include measurement of the abundance of plankton in a sample.

Linking questions

- What fluctuating environmental factors impact plankton populations?
- How do plankton help mitigate global heating and ocean acidification?

5.3—Organisms of the benthic zone

Guiding questions

- In what ways do benthic communities provide nurseries for oceanic communities?
- What structural and behavioural adaptations characterize benthic organisms?
- In what ways do benthic organisms compete?

5.3.1—Benthic zone substrates

5.3.2—Benthic organisms live on the ocean bottom or within sediment deposits throughout the ocean

5.3.3—Sessile and motile lifestyles of benthic organisms

5.3.4—Producers in the benthic zone

Guidance: Limit to kelp, other seaweeds and grasses.

5.3.5—Adaptations of organisms that live in the benthic zone for all or part of their lives

Guidance: Include adaptations of each taxonomic group: Mollusca, Crustacea, Echinodermata, Annelida, Porifera and Osteichthyes. Taxonomic hierarchy is not required.

5.3.6—Species-specific tolerance and optimal conditions of temperature, salinity, concentration and pH ranges in the benthic zone

5.3.7—Adaptations of species for living outside their optimal conditions or within their tolerance ranges in the benthic zone

Guidance: Include anatomical as well as behavioural adaptations.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**5.3.2**) Collect data on the substrate, available oxygen, mineral composition, temperature variations, pH, salinity and organisms of a benthic community.

(**5.3.6**) Using an available organism, investigate optimal conditions of temperature and salinity for that organism.

Linking questions

- To what extent do benthic organisms provide protection to coastlines?
- To what advantage do organisms have life cycles split between planktonic and benthic existence?

5.4—Organisms of the pelagic zone

Guiding questions

- How are organisms adapted to live within their tolerance ranges?
- To what extent does overharvesting of pelagic species endanger their ecosystems?
- How are the anatomical forms of nekton similar?

5.4.1—Pelagic organisms live in the open ocean in the water column away from shore

5.4.2—Characterization of nekton as organisms that are able to swim independently of winds and currents

5.4.3—Characteristics of nekton

Guidance: Study lifestyles and adaptations of one named example of each taxonomic group: Osteichthyes, Chondrichthyes, Mammalia, Cephalopoda and Reptilia.

5.4.4—Tolerance range and optimal conditions of salinity, temperature and water depth for three named organisms in the pelagic zone

Guidance: Scientific names are not required.

5.4.5—Adaptations of species for living outside their optimal conditions or within their tolerance ranges in the pelagic zone

Guidance: Include anatomical as well as behavioural adaptations.

5.4.6—Interactions among species

Guidance: Include competition, predator–prey, parasitism and mutualism, with examples.

5.4.7—Effect of harvesting of fish populations by humans.

Guidance: Include overharvesting, habitat destruction, pollution, fishing regulation, fish farming, fish hatcheries, marine sanctuaries and marine conservation districts.

Nature of science: Use of precise terminology is essential for communication in science. Terms such as “population”, “species” and “community” have specific meanings in their biological contexts.

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**5.4.7**) Using landings data, construct a chart to show the variation in time of a fish population.

Linking questions

- How is climate change affecting the populations of pelagic species?
- How do pelagic mammals use the sound properties of water?
- Who are the stakeholders in conservation of fish populations?

Topic 6: Marine ecosystems

Biological marine science

30 hours

6.1—Plant and algae-based ecosystems

Guiding questions

- How do abiotic conditions affect the community of an ecosystem?
- By what criteria can we determine the health of an ecosystem?

6.1.1—Distinct characteristics of the following plant and algae-based ecosystems:

- kelp forests
- seagrass beds
- salt marshes
- mangrove forests

Guidance: Include temperature, salinity, light, nutrients, oxygen, substrate and energy.

6.1.2—Factors that affect the ecosystem types in 6.1.1

Guidance: Include topography, latitude and substrate, as well as tides, waves, currents and upwelling.

6.1.3—Water qualities and dynamics that characterize each of the ecosystems in 6.1.1

Guidance: Limit to salinity, pH, temperature, inorganic nutrients, light, oxygen and tides.

6.1.4—Adaptations of organisms for the ecosystems in 6.1.1

Guidance: Include named organisms for each adaptation. Include the characteristics of kelp as the dominant species in kelp forests.

6.1.5—Roles of detritus in the ecosystems in 6.1.1

Guidance: Include the role of detritivores in grass-dominated ecosystems.

6.1.6—Communities in each ecosystem in 6.1.1

Guidance: Limit to typical species, including index species and keystone species.

6.1.7—Threats to the ecosystems in 6.1.1 and ecosystem decline

Guidance: Include shrimp farming for mangrove forests and imbalances in the ecosystems.

6.1.8—Impact of climate change on the ecosystems in 6.1.1

Guidance: Consider both the effect of climate change on each ecosystem and the influence of each ecosystem on the rate of climate change.

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**6.1.6**) Construct a food web with eight types of organisms, including producers and detritivores, for each ecosystem.

Linking questions

- How do algae and plants affect water qualities?
- In what ways does human activity interrupt the natural interactions of plant- and algae-based ecosystems?

6.2—Intertidal ecosystems

Guiding questions

- What are the challenges to organisms living in intertidal ecosystems?
- How do human activities impact the life of intertidal organisms?

6.2.1—Distinct characteristics of the following intertidal ecosystems:

- rocky shore
- sediment-covered ecosystem—sandy beaches, mudflats and dunes
- estuary

Guidance: Include substrate characteristics and biotic stratification due to tides.

6.2.2—Water qualities and dynamics that characterize intertidal ecosystems

Guidance: Include daily changes in salinity, pH, temperature, inorganic nutrients, light and dissolved oxygen due to tides and weather.

6.2.3—Adaptations of organisms to tidal zones

Guidance: Include adaptations against desiccation, protection from wave action, changing salinity, changing temperature, predation and competition. Include adaptations of tide-pool organisms.

6.2.4—Adaptations of organisms to diurnal and seasonal conditions in sediment-dominated ecosystems

Guidance: Include feeding mechanisms and protection from desiccation, predation and competition.

6.2.5—Zonation in rocky-shore ecosystems and sandy shores

6.2.6—Importance of sandy beaches to reproduction of some organisms

Guidance: Include sea turtles and species of fish that time their egg-laying with the tides.

6.2.7—Effects of tides on distributions of molluscs and crustaceans

Guidance: Include the regulation of harvestable organisms of sediment-dominated ecosystems.

6.2.8—Effects of estuary water-flow patterns

Guidance: Include types of estuaries based on water-flow patterns.

6.2.9—Estuaries as buffers against storm surges and as a human food resource

Guidance: Include threats to estuaries from dredging and overharvesting.

6.2.10—Community of organisms within an estuary

Guidance: Limit to typical organisms, with attention to index species and keystone species.

6.2.11—Formation and characteristics of tropical coral reefs

6.2.12—Community of organisms in tropical coral-reef ecosystems

Guidance: Limit to typical organisms, with attention to index species and keystone species.

6.2.13—Coral reef bleaching

Guidance: Include causes, effects, recovery conditions and mitigation.

6.2.14—Human impact on coral-reef systems

Guidance: Include harvesting, pollution, recreation, habitat destruction and mitigation efforts, including Indigenous knowledge.

Suggested activities

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**6.2.5**) Select tools and design a study of intertidal zonation from the low-tide zone to the splash zone of a rocky shore. Include measurements of abiotic factors. Identify index species for the mid-tide zone. Include transect and quadrat data, and kite diagrams.

(**6.2.10**) Construct a representative food web for an estuary with eight types of organisms, including a producer and detritus.

(**6.2.12**) Construct a representative food web for a coral reef with eight types of organisms.

Linking questions

- How do the geological characteristics of an area affect the type of ecosystem that develops?
- What tools and technologies are used to research changes in ecosystems?

6.3—Oceanic ecosystems

Guiding questions

- What makes oceanic ecosystems difficult to study?
- How are organisms adapted to survive the challenges of oceanic ecosystems?
- What causes the extreme conditions that exist in oceanic ecosystems?

6.3.1—Characteristics of the open oceans

Guidance: Include their unique characteristics, locations and importance.

6.3.2—Water qualities and dynamics that characterize open oceans

Guidance: Limit to salinity, temperature, inorganic nutrients, light, effects of seasons and effects of latitude.

6.3.3—Communities of open-ocean ecosystems

Guidance: Limit to typical organisms, with attention to index species and keystone species.

6.3.4—Effects of climate change on open-ocean populations of organisms

6.3.5—Importance of monitoring population sizes for conservation and regulatory purposes

Guidance: Include techniques for monitoring fish, mammals and locally important populations.

6.3.6—Characteristics of polar-ocean ecosystems

Guidance: Include seasonal temperature variations and the impact of ice and the ice formation–melting cycle.

6.3.7—Water qualities of the Arctic and Antarctic oceans

Guidance: Include salinity, temperature, inorganic nutrients, light and the effect of winds on salinity and ice formation.

6.3.8—Communities of organisms of polar oceans

Guidance: Limit to typical organisms, with attention to index species and keystone species. Include differences between Arctic and Antarctic species.

6.3.9—Adaptations of organisms to extreme cold

6.3.10—Threats to polar populations

Guidance: Include resource exploitation, mining, overfishing, tourism, pollution, climate change and the loss of sea ice.

6.3.11—Characteristics of deep-sea ecosystems and vent ecosystems

Guidance: Include temperature, salinity, light, nutrients, oxygen, substrate and energy.

6.3.12—Adaptations of organisms to extreme pressure in deep-sea ecosystems

Guidance: Adaptations may include examples of animals with collapsible lungs, changes in metabolism, enhanced myoglobin and haemoglobin, slowed heart rate or gelatinous body composition.

6.3.13—Adaptations to extreme temperatures in hydrothermal-vent ecosystems

6.3.14—Importance of marine snow to organisms on the deep-ocean floor

Suggested activity

Suggested activities are not prescriptive or exhaustive, and teachers are free to explore and develop alternative learning activities.

(**6.3.5**) Evaluate methods of estimating the sizes of fish populations.

Linking questions

- How does the stability of open oceans provide stability to coastal ecosystems?
- How have organisms adapted to volcanic activity at hydrothermal vents?
- What interdependence exists between extreme ecosystems and more moderate systems?

Experimental programme

Practical work

20 hours

Practical work includes laboratory, field and data-based work carried out by students to enhance understanding of subject matter and to develop skills described in "Topic 1: Formation, structure and dynamics of ocean basins" and "Topic 2: Physical and chemical properties of ocean water". Practical work may be carried out individually and/or in groups. Teachers can prepare students for the IA by means of practical work.

While working on practical work, teachers should coach students on their participation as members of a team by recognizing attributes of good teamwork as they occur.

- Planning as a team
- Mutual respect for each person's contributions
- Workload equally shared among team members
- Individual accountability

For more information, please see the "Teaching and developing authentic group work" appendix.

The range of practical work carried out should reflect the breadth and depth of the subject syllabus, but it is not necessary to carry out an investigation for every syllabus topic. It is essential to introduce students to the skills outlined.

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

The practical plan allows 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 involving questionnaires, user trials or surveys
- data-analysis exercises
- fieldwork.

Collaborative sciences project

10 hours

The collaborative sciences project is an interdisciplinary sciences project, providing a worthwhile challenge to DP and CP students, addressing real-world problems that can be explored through the sciences. The nature of the challenge should allow students to integrate factual, procedural and conceptual knowledge developed through the study of their disciplines.

Through the identification and research of complex issues, students can develop an understanding of how interrelated systems, mechanisms and processes impact a problem. Students will then apply their collective understanding to develop solution-focused strategies that address the issue. With a critical lens, they will evaluate and reflect on the inherent complexity of solving real-world problems.

Students will develop an understanding of the extent of global interconnectedness between regional, national and local communities, which will empower them to become active and engaged citizens of the world. While addressing local and global issues, students will appreciate that the issues of today exist across national boundaries and can only be solved through collective action and international cooperation.

The collaborative sciences project supports the development of students' approaches to learning skills, including team building, negotiation and leadership. It facilitates an appreciation of the environment, and the social and ethical implications of science and technology.

Full details of the requirements are in the *Collaborative sciences project guide*.

Scientific investigation

10 hours

The scientific investigation constitutes the IA for marine science.

For more information, please see the "Internal assessment details" section.

Assessment in the Diploma Programme and Career-related Programme

General

Assessment is an integral part of learning and teaching. The most important aims of assessment in the Diploma Programme (DP) and Career-related Programme (CP) are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the DP and CP. 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 learning and teaching. 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 (0404-01).
- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement at, or towards the end of, the course of study (0404-04).

A comprehensive assessment policy is viewed as being integral with learning, teaching 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 DP, please refer to the publication *Assessment: principles and practice—Quality assessments in a digital age*.

To support teachers in the planning, delivery and assessment of the DP and CP courses, a variety of resources can be found on the Programme Resource Centre or purchased from the IB store (store.ibo.org). Additional publications such as specimen papers and markschemes, teacher support materials (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes 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 access arrangements

Inclusive access arrangements are available for candidates with access requirements. Standard assessment conditions may put candidates with assessment access requirements at a disadvantage by preventing them from demonstrating their attainment level. Inclusive access arrangements enable candidates to demonstrate their ability under assessment conditions that are as fair as possible.

The IB document *Access and inclusion policy* provides details on all the inclusive access arrangements available to candidates. The IB document *Learning diversity and inclusion in IB programmes: Removing barriers to learning* 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 publication *Diploma Programme Assessment procedures* (updated annually), which includes the general regulations, provides 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 *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning*.

Assessment outline

First assessment 2026

Assessment component	Weighting
External assessment (3 hours)	**80%**
Paper 1 (1 hour 30 minutes) Section A—short-answer questions based on syllabus content (25 marks) Section B—data-based questions related to syllabus topics and experimental work (25 marks) (Total 50 marks)	**40%**
Paper 2 (1 hour 30 minutes) Section A—multi-part, data-based question and short-answer questions based on syllabus content and skills (34 marks) Section B—multi-part, extended-response question combining concepts, intervention strategies and/or syllabus topics (16 marks) (Total 50 marks)	**40%**
Internal assessment (10 hours)	**20%**
The IA consists of one task: the scientific investigation. This component is internally assessed by the teacher and externally moderated by the IB at the end of the course. (Total 24 marks)	

External assessment

Detailed markschemes specific to each examination paper (paper 1 and paper 2) are used to assess students.

Examinations may require a general understanding and application of the nature of science.

External assessment details

Paper 1

Duration: 1 hour 30 minutes

Weighting: 40%

Marks: 50

Section A—25 marks

- Short-answer questions based on syllabus content
- **All** questions to be attempted by candidates

Section B—25 marks

- Data-based questions centred on different syllabus topics
- Based on experimental work identified in the syllabus
- **All** questions to be attempted by candidates

Section A and Section B are to be completed together without interruptions.

The questions on paper 1 test assessment objectives 1, 2 and 3.

No marks are deducted for incorrect answers.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* (updated yearly) on the Programme Resource Centre.

Paper 2

Duration: 1 hour 30 minutes

Weighting: 40%

Marks: 50

Section A—34 marks

- Multi-part, data-based question
- Short-answer questions based on syllabus content and skills
- **All** questions to be attempted by candidates

Section B—16 marks

- Multi-part, extended-response questions combining concepts, intervention strategies and syllabus topics
- **One** of two extended-response questions to be attempted by candidates

Section A and Section B are to be completed together without interruptions.

The questions on paper 2 test assessment objectives 1, 2 and 3.

No marks are deducted for incorrect answers.

The use of calculators is permitted. See the *Calculators guidance for examinations* booklet (updated yearly) on the Programme Resource Centre.

Internal assessment

Purpose of internal assessment

Internal assessment is an integral part of the course and is compulsory for all 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 IA 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 scientific investigation submitted for the IA 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 IA 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 sciences experimentation guidelines* publication
- 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 integrity, 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 malpractice. Each student must confirm that the work is their 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 publications *Academic integrity policy*, *The Diploma Programme: From principles into practice* and the relevant general regulations (in *Diploma Programme Assessment procedures*).

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

- The student's initial proposal
- The first draft of the written work
- The references cited
- The style of writing compared with work known to be that of the student

- The analysis of the work by a web-based plagiarism detection service such as www.turnitin.com

The same piece of work cannot be submitted to meet the requirements of both the IA and the EE.

Time allocation

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

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

- time for the teacher to explain to students the requirements of the IA
- class time for students to work on the IA 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

It is the responsibility of everyone involved in science education to make an ongoing commitment to safe and healthy practical work.

The working practices and protocols should be effective in safeguarding students and protecting the environment. Schools are responsible for following national or local guidelines, which differ from country to country.

Using assessment criteria for internal assessment

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

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

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

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

Internal assessment details

The scientific investigation

Duration: 10 hours

Weighting: 20%

The IA requirement is the same for biology, chemistry, physics and marine science. The IA, worth 20% of the final assessment, consists of one task—the scientific investigation.

The scientific investigation is an open-ended task in which the student gathers and analyses data in order to answer their own formulated research question. The outcome of the scientific investigation will be assessed through the form of a written report. The maximum overall word count for the report is 3000 words.

The following are not included in the word count.

- Charts and diagrams
- Data tables
- Equations, formulas and calculations
- Citations/references (whether parenthetical, numbered, footnotes or endnotes)
- Bibliography
- Header

The following details should be stated at the start of the report.

- Title of the investigation
- Candidate's personal code (alphanumeric, for example, xyz123)
- All group members' personal codes (if applicable)
- Number of words

There is no requirement to include a cover page or a contents page.

Facilitating the scientific investigation

The research question should be of interest to the student, but it is not necessary that it encompasses concepts beyond those described by the understandings within the guide.

The scientific investigation undertaken must have sufficient extent and depth to allow for all the descriptors of the assessment criteria to be meaningfully addressed.

The investigation of the research question must involve the collection and analysis of quantitative data that should be supported by qualitative observations where appropriate.

The scientific investigation allows a wide range of techniques for data gathering and analysis to be employed. The approaches that could be used in isolation or in conjunction with each other are as follows.

- Hands-on practical laboratory work
- Fieldwork
- Use of a spreadsheet for analysis and modelling
- Extraction and analysis of data from a database
- Use of a simulation

Teachers must:

- ensure that students are familiar with the assessment criteria
- ensure that students are able to investigate their individual research question
- counsel the students on whether their proposed methodology is feasible in consideration of available time and resources
- ensure that students have given appropriate consideration to safety, ethical and environmental factors before undertaking the action phase
- remind students of the requirements for academic integrity and the consequences of academic malpractice. The difference between collaboration and collusion must be made clear.

Developing the research question

Each student is expected to formulate, investigate and answer a unique research question, seeking advice from their teacher.

A student must not present the same set of raw data as another student.

Methodology for individual work

Each student develops their own methodology to answer their individual research question. The student investigates by:

- manipulating an independent variable

or

- selecting variables during fieldwork

or

- selecting different data from external databases.

The student might seek support from peers when collecting data.

Methodology for collaborative work

Collaborative work is optional and where it is facilitated the groups formed must be no larger than three students. Students may organize their own groups. The teacher must provide guidance to ensure that all students are fully engaged in the collaborative activity. Students must clearly understand the requirement to conduct an individual investigation.

The methodology developed to answer their individual research question may be in part the outcome of collaborative activity. A student within the group investigates their individual research question by manipulating:

- a different independent variable from those selected by other group members

or

- the same independent variable with a different dependent variable from those selected by other group members

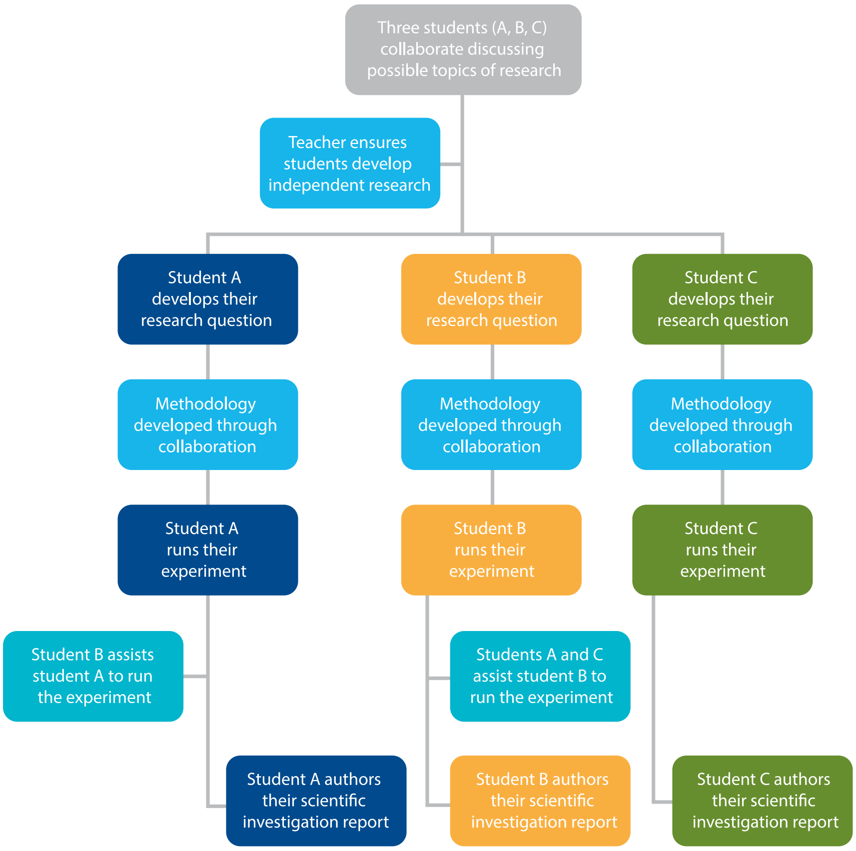
or

- different data from those selected by other group members from within a larger communally acquired data set.

In this context, collaborative work is permitted under the understanding that the final report presented for assessment is that of the individual student. A report by the group is not permitted. All authoring, including the description of the methodology, must be done individually. This diagram illustrates a possible route through the IA process where students collaborate.

Figure 3

A possible route through collaborative work



Class collaboration to set up a database

A school may take part in a large-scale activity collecting data to generate a database using standardized protocols. If a student decides to utilize this database in order to answer their research question, then the investigation must be treated as a database investigation. In such a case, the methodology should be focused on the way the data is filtered and sampled from the whole database in the same way as if the data was wholly acquired from an external source.

Assessing the scientific investigation

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

The four assessment criteria are as follows.

- Research design
- Data analysis
- Conclusion
- Evaluation

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 using the level descriptors and aided by the clarifications. The criteria must be applied systematically using a best-fit approach—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. The highest-level descriptors do not imply faultless performance.

Where there are two or more marks available within a level, teachers should award the upper mark if the student's work largely satisfies the qualities described; 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 must be recorded; partial marks (fractions and decimals) are not acceptable.

The criteria should be considered independently. 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.

Where command terms are used in the level descriptors, they are to be interpreted as indicated in the "Glossary of command terms" section of this guide. These command terms indicate the depth of treatment required. Command terms used within the descriptors are provided in the following table.

Assessment objective (AO)	Command term	Descriptor
AO1	State	Give a specific name, value or other brief answer without explanation or calculation.
AO2	Identify	Provide an answer from a number of possibilities.
AO2	Outline	Give a brief account or summary.
AO2	Describe	Give a detailed account.
AO3	Explain	Give a detailed account including reasons or causes.
AO3	Justify	Give valid reasons or evidence to support an answer or conclusion.

Referencing and academic integrity

Appropriate referencing to sourced information used in the report of the scientific investigation is expected. Omitted or improper referencing will be considered to be academic malpractice.

Students must ensure their assessment work adheres to the IB's academic integrity policy and that all sources are appropriately referenced. A student's failure to appropriately 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. See the "Academic integrity" section of this guide for full details.

Internal assessment criteria

Download: *Internal assessment criteria* (PDF)

There are four IA criteria for the scientific investigation. The marks and weightings are as follows.

Criterion	Maximum number of marks available	Weighting (%)
Research design	6	25
Data analysis	6	25
Conclusion	6	25
Evaluation	6	25

Criterion	Maximum number of marks available	Weighting (%)
Total	**24**	**100**

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Marks	Level descriptor
0	The work does not reach a standard described by the descriptors below.
1–2	• The research question is stated without context. • Methodological considerations associated with collecting data relevant to the research question are stated. • The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced.
3–4	• The research question is outlined within a broad context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions.
5–6	• The research question is described within a specific and appropriate context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced.

Clarifications for research design
A research question with context should contain reference to the dependent and independent variables or two correlated variables, include a concise description of the system in which the research question is embedded, and include background theory of direct relevance. Methodological considerations include: • the selection of the methods for measuring the dependent and independent variables • the selection of the databases or model and the sampling of data • the decisions regarding the scope, quantity and quality of measurements (e.g. the range, interval or frequency of the independent variable, repetition and precision of measurements) • the identification of control variables and the choice of method of their control • the recognition of any safety, ethical or environmental issues that needed to be taken into account. The description of the methodology refers to presenting sufficiently detailed information (such as specific materials used and precise procedural steps) while avoiding unnecessary or repetitive information, so that the reader may readily understand how the methodology was implemented and could in principle repeat the investigation.

Data analysis

This criterion assesses the extent to which the student's report provides evidence that the student has recorded, processed and presented the data in ways that are relevant to the research question.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• The recording and processing of the data is communicated but is neither clear nor precise. • The recording and processing of data shows limited evidence of the consideration of uncertainties. • Some processing of data relevant to the addressing research question is carried out but with major omissions, inaccuracies or inconsistencies.
3–4	• The communication of the recording and processing of the data is either clear or precise. • The recording and processing of data shows evidence of a consideration of uncertainties but with some significant omissions or inaccuracies. • The processing of data relevant to the addressing research question is carried out but with some significant omissions, inaccuracies or inconsistencies.
5–6	• The communication of the recording and processing of the data is both clear and precise. • The recording and processing of data shows evidence of an appropriate consideration of uncertainties. • The processing of data relevant to addressing the research question is carried out appropriately and accurately.

Clarifications for data analysis
Data refers to quantitative data or a combination of both quantitative and qualitative data. **Communication** • Clear communication means that the method of processing can be understood easily. • Precise communication refers to following conventions correctly, such as those relating to the annotation of graphs and tables or the use of units, decimal places and significant figures. Major omissions, inaccuracies or inconsistencies impede the possibility of drawing a valid conclusion that addresses the research question. Significant omissions, inaccuracies or inconsistencies allow the possibility of drawing a conclusion that addresses the research question but with some limit to its validity or detail.

Conclusion

This criterion assesses the extent to which the student successfully answers their research question with regard to their analysis and the accepted scientific context.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• A conclusion is stated that is relevant to the research question but is not supported by the analysis presented. • The conclusion makes superficial comparison to the accepted scientific context.
3–4	• A conclusion is described that is relevant to the research question but is not fully consistent with the analysis presented. • A conclusion is described that makes some relevant comparison to the accepted scientific context.
5–6	• A conclusion is justified that is relevant to the research question and fully consistent with the analysis presented. • A conclusion is justified through relevant comparison to the accepted scientific context.

Clarifications for conclusion
A conclusion that is fully consistent requires the interpretation of processed data including associated uncertainties. Scientific context refers to information that could come from published material (paper or online), published values, course notes, textbooks or other outside sources. The citation of published materials must be sufficiently detailed to allow these sources to be traceable.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation methodology and suggested improvements.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• The report identifies generic methodological weaknesses or limitations. • Realistic improvements to the investigation are stated.
3–4	• The report identifies specific methodological weaknesses or limitations. • Realistic improvements to the investigation that are relevant to the identified weakness are described.
5–6	• The report explains the relative impact of specific methodological weaknesses or limitations. • Realistic improvements to the investigation that are relevant to the identified weakness or limitations are explained.

Clarifications for evaluation
Generic means general to many methodologies and not specifically relevant to the methodology of the investigation being evaluated. *Methodological* refers to the overall approach to the investigation of the research question as well as procedural steps. *Weaknesses* could relate to issues regarding the control of variables, the precision of measurement or the variation in the data. *Limitations* could refer to how the conclusion is limited in scope by the range of the data collected, the confines of the system or the applicability of assumptions made.

Glossary of command terms

Command terms for marine science

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

Assessment objective 1

Command term	Definition
Define	Give the precise meaning of a word, phrase, concept or physical quantity.
Draw	Represent by means of a labelled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve.
Label	Add labels to a diagram.
List	Give a sequence of brief answers with no explanation.
State	Give a specific name, value or other brief answer without explanation or calculation.

Assessment objective 2

Command term	Definition
Annotate	Add brief notes to a diagram or graph.
Calculate	Obtain a numerical answer showing the relevant stages in the working.
Describe	Give a detailed account.
Distinguish	Make clear the differences between two or more concepts or items.
Estimate	Obtain an approximate value.
Identify	Provide an answer from a number of possibilities.
Outline	Give a brief account or summary.

Assessment objective 3

Command term	Definition
Analyse	Break down in order to bring out the essential elements or structure.
Comment	Give a judgement based on a given statement or result of a calculation.
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.

Command term	Definition
Contrast	Give an account of differences between two (or more) items or situations, referring to both (all) of them throughout.
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 (labelled 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.

Teaching and developing authentic group work

Research on cooperative learning and collaborative skills by Johnson et al. (1994) as well as many others, has enhanced classroom teaching, enabling development of the skills expected in the learning experiences of IB students. This research has developed techniques and delineated activities for teachers to incorporate into their classrooms.

Cooperative learning

In cooperative learning, students work together in small groups on common tasks that are best handled through group work. Such tasks are sufficiently complex to require a team to accomplish them. Students are individually accountable for their work, and the work of the group as a whole is also assessed. Cooperative groups work face to face and learn to work as a team. Individual accountability, when emphasized by the group or the teacher, can increase student understanding of personal authenticity and integrity.

Major elements of cooperative learning

- Positive interdependence
- Individual accountability
- Face-to-face interaction
- Interpersonal skills
- Group processing

Role of the teacher, sometimes with student input

- Setting the task
- Choosing the element of cooperation to be observed
- Providing feedback to the individual groups, especially positive observations
- Providing feedback to the whole class about individual group successes

Benefits of cooperative learning

- Leadership and decision-making skills
- Conflict management skills
- Increased student engagement with their work
- Enhanced communication skills
- Developed personal responsibility
- Increased confidence
- Increased positive attitude towards peers

Collaborative skills

In a classroom, collaborative skills can be taught in two to three minutes at the beginning of a class, followed by a two- to three-minute process observation at the end of the class.

Teaching collaborative skills

One way of teaching a skill is to name the skill to be addressed for a particular class or task, then list what that skill looks and sounds like. Make the list visible while students work. At the end of the class or task, ask students for examples of when someone in their group applied the skill. The teacher, who has been observing the students working together, describes when they saw or heard the skill demonstrated.

For example, if the skill is "supporting others", the list may look like the one in table 5.

Table 5

What "supporting others" looks and sounds like

Looks like	Sounds like (calm voices)
Giving a helping hand	"That's it."
Smiling	"You can do it."
Facing each other	"How can I help you?"
Reading someone's work	"What do you need?"

Process observation

- "I saw Joe pat Sam on the back for getting the equipment lined up correctly."
- "When Maria had her hands full, Sara steadied the thermometer so that it didn't fall."
- "While group 2 planned their experiment, they were all huddled together, actively showing interest in each other's ideas."

Alternative process observation

The teacher can ask each team to write down one example of support that occurred during their work. Teams can also write about a challenging moment when support was needed and to describe how the support could have been given. Teams give their written responses to the teacher at the end of the class or task.

Further guidance

When beginning the process of teaching collaborative skills, reward responsible teamwork over results. Over the course of a year, emphasis can be moved from group accountability to individual accountability as equal to group accountability.

Authentic work standards can be developed when students give credit to other students on their team by acknowledging the individuals in written work. In this way, students treat one another as authentic scientists, giving credit where credit is due. After students do this for a few written assignments, they understand the importance of citations in their work.

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.

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Updates to the publication

This section outlines the updates made to this publication over the past two years. The changes are ordered from the most recent to the oldest updates. Minor spelling and typographical corrections are not listed.

Changes for March 2024

Assessment > Internal assessment

"Internal assessment details"

Correction of error in the previous version.

In the "The scientific investigation" section about details that should be stated at the start of the report, the term "IB candidate code" was amended to "candidate's personal code".