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Diploma Programme

Astronomy guide
School based syllabus

First assessment 2017

Diploma Programme

Astronomy (school based syllabus) guide

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Purpose of this document

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

Additional resources

Teachers should contact IB Answers to enquire about additional resources such as past examination papers and markschemes, student sample work and grade descriptors. Some of these items will eventually be made available on the OCC or the Basecamp group.

Teachers are encouraged to share resources with other teachers, for example: websites, books, videos, journals or teaching ideas. This is particularly important in school-based syllabus subjects, as teachers are expected to support each other in the teaching and development of their subject: teachers will be contacted inviting them to join a Basecamp group, to facilitate this collaboration.

Acknowledgment

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

First assessment 2017

The Diploma Programme

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

The Diploma Programme model

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

Figure 1

Diploma Programme model

Choosing the right combination

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

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

The core of the Diploma Programme model

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

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

Creativity, Activity, Service (CAS) is at the heart of the Diploma Programme. CAS enables students to live out the IB learner profile in real and practical ways, to grow as unique individuals and to recognise their role in relation to others. Students develop skills, attitudes and dispositions through a variety of individual and group experiences that provides students opportunities to explore their interests and express their passions, personalities and perspectives. CAS complements a challenging academic programme in a holistic way, providing opportunities for self-determination, collaboration, accomplishment and enjoyment.

The three strands of CAS are:

Creativity - exploring and extending ideas leading to an original or interpretive product or performance

Activity - physical exertion contributing to a healthy lifestyle

Service - collaborative and reciprocal engagement with the community in response to an authentic need

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

Approaches to teaching and approaches to learning

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

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

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

The IB mission statement and the IB learner profile

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

Academic honesty

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

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

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

Learning diversity and learning support requirements

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

Nature of science

The Nature of science (NOS) is an overarching theme in the group 4 science courses. This section, titled Nature of science, is in the group 4 subject guides to support teachers in their understanding of what is meant by the nature of science. The “Nature of science” section of the guide provides a comprehensive account of the nature of science in the 21st century. It will not be possible to cover in this document all the themes in detail in the three science courses, either for teaching or assessment.

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

Technology

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2. The understanding of science

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

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

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

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

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

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

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

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

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

3. The objectivity of science

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

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

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

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

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

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

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

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

4. The human face of science

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

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

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

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

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

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

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

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

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

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

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

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

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

5. Scientific literacy and the public understanding of science

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

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

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

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

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

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

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

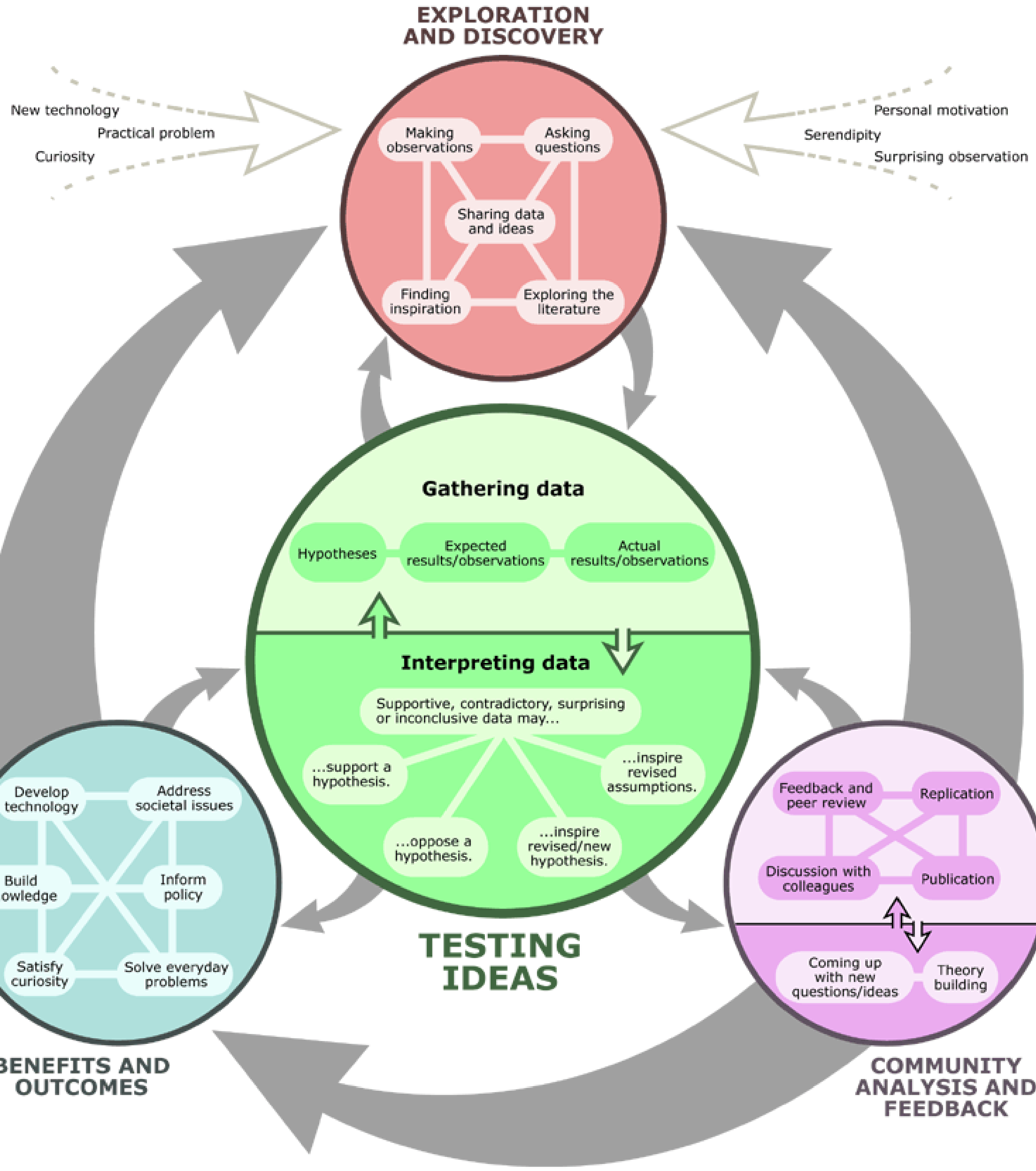

Figure 2

Pathways to scientific discovery

Nature of astronomy

Astronomy is arguably a unique branch of the sciences in being an area of study that many non-scientists consider as their hobby. In this sense, it is a discipline which is open to all. Further, the astronomer's playground (i.e., the sky at night) belongs to everyone and everyone can make discoveries – and there are so many to be made!

The subject's popularity is a result of many combining factors:

Romance – Astronomy is the stuff of legend. In times past, when religion and superstition were intimately linked to heavenly phenomena, the unexpected was often greeted with grave concern. By observing the motions and properties of objects in the sky, it was possible to understand more about the universe.

Wonder – Astronomy has been a breeding ground for many science fiction films and programs such as Star Trek and Star Wars. This has resulted in amazing images of star filled panoramas, prominences of the Sun and supernova explosions being brought into everyone's living room.

The search for the ultimate truth – Everyone can look up into the night sky and dream. Are there other planets like us? Is there life out there? Astronomy promises to explain how we got here and where the universe is going – questions which touch every human on the planet.

The above are just three of the reasons why Astronomy is considered as a glamour science. Beyond this, it is a rich and fertile area for scientific research and human endeavour, bringing together areas as diverse as Physics, Biology, Chemistry, Mathematics, Geography, Earth Science, History, Economics and Religion. Astronomy pulls together the very limits of our understanding of the world we live in, from the experimental observations of Tycho Brae, through Newton's law of Gravitation, Einstein's theories of relativity and Quantum Mechanics. Astronomy has been the driving force and the universe the natural laboratory for many of the greatest advances in science.

Teaching approach

There are a variety of approaches to the teaching of astronomy. By its very nature, astronomy lends itself to an experimental approach, and it is expected that this will be reflected throughout the course. The order in which the syllabus is arranged is **not** the order in which it should be taught, and it is up to individual teachers to decide on an arrangement that suits their circumstances.

Science and the international dimension

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

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

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

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

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

Prior learning

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

Links to the Middle Years Programme

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

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

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

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

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

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

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

Science and theory of knowledge

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

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

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

- How do we distinguish science from pseudoscience?
- When performing experiments, what is the relationship between a scientist’s expectation and their perception?

- How does scientific knowledge progress?
- What is the role of imagination and intuition in the sciences?
- What are the similarities and differences in methods in the natural sciences and the human sciences?

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

Group 4 aims

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

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

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

Assessment objectives

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

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

Syllabus outline

Syllabus component	Recommended teaching hours
Core content	**110**
1. Stars	32
2. The planets	32
3. Galaxies	26
4. Cosmology	20
Practical scheme of work	**40**
Practical activities	20
Individual investigation (internal assessment–IA)	10
Group 4 project	10
Total teaching hours	**150**

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

Format of the syllabus

This new structure gives prominence and focus to the teaching and learning aspects.

Topics

Topics are numbered, for example, “Topic 4: Cosmology”.

Sub-topics

Sub-topics are numbered as follows, “4.1: The birth, life and death of the universe”.

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

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

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

Format of the guide

Topic 1: <Title>

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

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

Group 4 experimental skills

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

Confucius

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

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

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

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

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

Mathematical requirements

All Diploma Programme astronomy students should be able to:

- perform the basic arithmetic functions: addition, subtraction, multiplication and division
- carry out calculations involving means, decimals, fractions, percentages, ratios, approximations and reciprocals
- carry out manipulations with trigonometric functions
- carry out manipulations with logarithmic and exponential functions
- carry out manipulations involving the volume and surface area of a sphere
- use standard notation (for example, 3.6×10^6)
- use direct and inverse proportion
- solve simple algebraic equations
- solve linear simultaneous equations
- plot graphs (with suitable scales and axes) including two variables that show linear and non-linear relationships
- interpret graphs, including the significance of gradients, changes in gradients, intercepts and areas
- draw lines (either curves or linear) of best fit on a scatter plot graph
- on a best-fit linear graph, construct linear lines of maximum and minimum gradients with relative accuracy (by eye) taking into account all uncertainty bars
- interpret data presented in various forms (for example, bar charts, histograms and pie charts)
- represent arithmetic mean using x-bar notation (for example, $\bar{x}$)
- express the answer to a calculation using an appropriate number of significant figures, with justification
- express uncertainties to one or two significant figures, with justification.

Use of information communication technology

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

Planning your course

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

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

The IB learner profile

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

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

Syllabus content

	Recommended teaching hours
Core	**110 hours**
Topic 1: The stars	**32**
1.1 The Sun	13
1.2 Measuring stars	10
1.3 The birth, life and death of stars	9
Topic 2: The planets	**32**
2.1 The origin of the planets	14
2.2 Life on Earth	9
2.3 The search for extra-terrestrial life	9
Topic 3: Galaxies	**26**
3.1 The Milky Way	14
3.2 Measuring galaxies	5
3.3 Active galaxies	7
Topic 4: Cosmology	**20**
4.1 The birth, life and death of the universe	9
4.2 Large scale structures in the universe	4
4.3 The shape of spacetime	7

Topic 1: The stars 32 hours

Essential idea: In considering the properties of stars and the basic processes happening within them, it is obvious that we should be using the Sun (*our* star) as the starting point to our understanding. It is relatively close to us, easily accessible to observation and we are able to situate orbiters to give us a constant stream of information.

1.1 The Sun

Nature of science:

Curiosity: Humans have had a long term fascination with the objects visible in the sky and have developed many ideas to help explain the observations they were able to make. (1.5)

Understandings:

- Historical development of the layout of the solar system
- Eclipses
- Newton's Law of gravitation
- Kepler's Laws
- Mass-distribution curve for the solar system
- Luminosity
- Black-body radiation and Wien's Law
- Limb darkening
- Sunspots
- Granulation of Sun's surface
- Chromosphere and corona
- The interior of the Sun

International-mindedness:

- The historical development of ideas about the Sun has involved scientists from many different countries, using a common language for the structure of the Sun and the different planets in orbit

Theory of knowledge:

- Knowledge about the Sun has come from remote observations. How can we be certain of the processes taking place inside the Sun without direct measurements

Utilization:

- Physics (gravitation, astrophysics option, nuclear physics)

Aims:

- **Aim 2:** this topic allows for student to develop skills in data processing and analysis
- **Aim 7:** modelling using a spreadsheet can be used to explore the motion of objects around a star

1.1 The Sun	
• Nuclear fusion • Proton-proton chain • Gamma radiation travels from the stellar core to the Earth **Applications and skills:** • Solving problems involving planetary orbits including Newton's law of gravitation, gravitational field strength, gravitational potential energy and kinetic energy and speed • Describing the relationship between gravitational force and centripetal force • Applying Newton's law of gravitation to the motion of an object in circular orbit around a point mass • Solving problems involving gravitational force, gravitational field strength, orbital speed and orbital period • Determining the resultant gravitational field strength due to two bodies • Deriving Kepler's 3^{rd} law • Solving problems involving black body radiation • Applying nuclear reactions to the processes taking place in stars • Describing the composition, temperature and energy transport mechanisms of the interior of the Sun • Explaining that for fusion to occur high temperatures are required to overcome the electrostatic repulsion between like charges **Guidance:** • Students should know about planets, asteroids comets, the Kuiper belt and Oort cloud, and that gravity holds it together with the Sun at the centre (due to its huge mass), providing the centripetal force.	

1.1 The Sun	
• Understand that the Sun's output covers a wide range of the electromagnetic spectrum • The Sun's output approximates to a black body output • Sunspots indicate an 11/22 year cycle and that they come in pairs • Know that sunspot activity indicates the differential rotation of the photosphere • The chromosphere and corona may be defined by the temperature profile of the Sun's atmosphere and can be observed using an eclipse method e.g. using a coronagraph • Understand that the atmosphere can be viewed using restricted wavelength images (e.g., $H_{\propto}$ views) • Knowledge of solar features will include plages, filaments, and prominences • Appreciate the role of fusion in supporting the star, defining the size of the stellar core and changing the overall composition of the star • Understand the random walk through the Sun (requiring local thermodynamic equilibrium), the production of 'black-body' output and the relatively fast travel to the Earth through space • Know about the evidence for the solar interior based on neutrino detection and solar oscillations	

Essential idea: Science and in particular physics, has shown that one of the best ways of describing the universe around us is to use mathematics as a language. In order to extend our knowledge of stars beyond the qualitative and into the quantitative, it is crucial that we are able to make actual measurements of the properties of stars. Without such information, our understanding of the birth, life and death of stars and in fact, of the universe itself, would be severely restricted.

1.2 Measuring stars

Nature of science:

Reality: The systematic measurement of distances and brightness of stars and galaxies has led to an understanding of the universe on a scale that is difficult to imagine and comprehend. (1.1)

Understandings:

- Constellations
- Light pollution
- Movement of stars
- Astronomical distances
- Methods of measuring, size, surface temperature, composition and luminosity of stars
- The electromagnetic spectrum
- Stellar spectra
- Stellar parallax and its limitations
- Luminosity and apparent brightness
- Harvard Spectral Classification
- Stefan's law
- Hertzsprung-Russell (HR) diagram

Applications and skills:

- Using the astronomical unit (AU), light year (ly) and parsec (pc)

Theory of knowledge:

- The information revealed through spectra needs to be interpreted by a trained mind. What is the role of interpretation in gaining knowledge in the natural sciences? How does this differ from the role of interpretation in other areas of knowledge?
- Observing the universe using detectors capable of "seeing" gamma rays or radio waves has vastly increased our understanding of the universe. In which ways do advancements in technology allow our understanding to continue to grow?

Utilization:

- Similar parallax techniques can be used to accurately measure distances here on Earth

Aims:

- **Aim 1:** creativity is required to analyse objects that are such vast distances from us
- **Aim 4:** analysis of star spectra provides many opportunities for evaluation and synthesis
- **Aim 6:** local amateur or professional astronomical organizations can be useful for arranging viewing evenings
- **Aim 6:** software-based analysis is available for students to participate in astrophysics research

• Describing the method to determine distance to stars through stellar parallax • Solving problems involving luminosity, apparent brightness and distance • Explaining how surface temperature may be obtained from a star’s spectrum • Relate the colour of light to the frequency of the radiation emitted • Describe the different regions of the electromagnetic spectrum • Describing emission and absorption spectra to explain how the chemical composition of a star may be determined from the star’s spectrum • Sketching and interpreting HR diagrams • Identifying the main regions of the HR diagram and describing the main properties of stars in these regions **Guidance:** • Students should be able to use a Planisphere (not examinable) • Stars move with a transverse and radial velocity • Understand how to measure the luminosity of a star based on a measurement of flux density • HR diagrams will be used as a way of organising stars and to show their evolution • HR graphs labelling will be limited to luminosity vs temperature or luminosity vs spectral class • Students are expected to have an awareness of the vast changes in distance scale from planetary systems through to super clusters of galaxies and the universe as a whole • Regions of the HR diagram are restricted to the main sequence, white dwarfs, red giants, super giants and the instability strip (variable stars) • The mass-luminosity relation is not required	• **Aim 8:** be aware that light pollution seriously compromises observational astronomy and may often represent a significant waste of energy • **Aim 9:** as we are able to observe further into the universe, we reach the limits of our current technology’s capacity to make accurate measurements

Essential idea: One of the primary concerns in astrophysics is how the universe started, how it is developing and how it will end. It is clear that the development of the universe will have a primary influence on how it will end and the way to understand this, and explain where the elements we see around us have come from, we need to study the birth, life and death of stars – this is the key into understanding many of the processes we see occurring in the wider universe.

<table>
<tr><td colspan="2">1.3 The birth, life and death of stars</td></tr>
<tr><td colspan="2">Nature of science:

Evidence: Our understanding of the processes taking place in stars has come about through the observation of many stars using telescopes and deducing the nature of stars based on this. (1.8)</td></tr>
<tr><td>Understandings:
• Star formation from a nebula
• Jeans criteria
• Star clusters
• Protostars
• T-Tauri phase
• The nature of stars
• Proton-proton chain reactions and the CNO cycle
• Brown dwarfs
• Death of a star
• Electron and neutron degeneracy pressure
• Triple alpha process ($3\propto$) to produce beryllium
• Secondary fusion to produce elements up to iron
• r-process to produce elements heavier than iron
• Stellar evolution on HR diagrams
• Black holes and escape velocity</td><td>International-mindedness:
• Due to the increasing costs involved in observing stars and galaxies, using telescopes placed into orbit around the Earth, funding is the result of the collaboration from a number of countries.
Theory of knowledge:
• How certain can we be about our understanding of the life cycle of the Sun, based around observations of distant stars?
Utilization:
• An understanding of how similar stars to our Sun have aged and evolved assists in our predictions of our fate on Earth
Aims:
• Aim 10: analysis of nucleosynthesis involves the work of chemists</td></tr>
</table>

Applications and skills: • Applying the Jeans criterion to star formation • Sketching and interpreting evolutionary paths of stars on an HR diagram • Describing the evolution of stars off the main sequence • Describing the formation of elements in stars that are heavier than iron including the required increases in temperature • Understanding the instability strip for a protostar and be able to describe how this affects the luminosity • Describing the s and r processes for neutron capture qualitatively **Guidance:** • Limited to main sequence stars • Understand the physics behind the collapse of a gas cloud into a star: - gravitation initiates the collapse - gravitational potential energy reducing - conservation of total energy leading to an increase in kinetic energy - rising kinetic energy relating to a rise in temperature - rising nebula density producing reduced radiation loss from the nebula - greater temperature finally producing a plasma - greater kinetic energy resulting in fusion (against the electrostatic repulsion) • Know how the condensing nebula produces a protostar and how this is seen on the Hertzsprung-Russell diagram (Hayashi tracks) • Understand that main sequence stars are defined by the fusion occurring in the core	

• Appreciate that the rate of fusion in the core strongly depends on the temperature of the core (equations are not needed) • Know that the main sequence lifetime is reduced for larger stars • Understand why there is a lower limit and upper limit for star size: - Lower limit due to a requirement to trigger fusion - Upper limit due to increased stellar wind • Be aware that the larger a star, the shorter the lifetime and the smaller their abundance • The death of stars will be limited to the formation of a white dwarf, neutron star or black hole • Students should know about hydrogen burning and the changes taking place when hydrogen burning stops • Be aware that secondary fusion reactions occur with greater temperatures up to the creation of iron • For this course, objects in the universe include planets, comets, stars (single only), planetary systems, constellations, star clusters, nebulae, galaxies, clusters of galaxies, white dwarf, neutron star, black hole, supernova remnant, red giant, supergiant, pulsar • Appreciate the importance of the solar abundances and the implication that the Sun is not a first generation star. Also appreciate the fact that the elements of life on Earth must also have been created in a previous supernova explosion • Only an elementary application of the Jeans criterion is required, i.e. collapse of an interstellar cloud may begin if $M>M_J$	

Topic 2: The planets — 32 hours

Essential idea: If we are to understand our place in the universe, we need to be able to explain where the Earth came from and whether its location is preordained or due to random chance, and how this impacts on the wider question of the possibility of other life existing in the universe.

2.1 The origin of the planets

Nature of science:

Scientific ideas: Many theories have been developed to try to explain where the Earth came from but those which are based more on scientific understanding have a greater credibility. (2.6)

Understandings:

- Theories of the origin of the planets including reference to inferior and superior planets
- Solar nebula model
- Condensation and coagulation
- Significance of the Sun's T-Tauri phase for the composition of the planets
- Origin of the asteroids based on the gravitational influence of Jupiter
- Oort Cloud
- Origin of the Moon
- Planetary differentiation
- Forms of heating within a planet
- Creation of the Earth's magnetic field
- Terrestrial planets (ignoring Mercury) and gas giants
- Details of magnetic field configuration – type and possible origin

Theory of knowledge:

A number of theories exist to explain the origin of the Moon. What causes one theory to become more accepted than others in the scientific community? Is this the same in other areas of knowledge?

Aims:

Aim 4: evaluation of the different theories of the origin of the planets allows for students to understand the scientific method

Aim 9: although the current models help to explain the origin of the planets scientists continue to collect data to improve their understanding

2.1 The origin of the planets	
Applications and skills: • Identifying the main phases of planetary formation • Explaining the different models for the origin of the planets • Describing homogeneous and heterogeneous accretion and their dependence on the planet's growth rate compared with the nebulas cooling rate **Guidance:** • Models for the origin of the planets will be limited to - Nebular theories - Accretion theories - Tidal theories - Turbulence theories • Know that an original theory needs to explain the following: - planetary orbits are close to the plane of the Earth's orbit - planetary orbits are largely circular - all planets rotate in the same sense around the Sun - Only 2% of the solar system's angular momentum is contained in the Sun (Jupiter $\approx$ 65%) • Appreciate how planetary growth was affected by the distance from the Sun • Appreciate the significance of the gravitational and electrical forces in creating the planets • To aid planetary differentiation be aware of the following forms of heating - accretional heating - radiogenic heating - core formation heating - tidal heating	

2.1 The origin of the planets	
• Differentiation requires enough heat and material mobility • In the study of planets students should be aware of - internal structure - differentiated or not - details of satellites - volcanic activity – active or not, and why • Be aware of the evidence that the Earth is a differentiated planet (including magnetism and average density)	

Essential idea: The creation of a habitable planet within which our kind of life can flourish is a prime requirement if the universe is to sustain and allow for the development of carbon-based life. Understanding how this habitable space was created is vital if mankind is to have a future in the long term, a future that may require us to explore and colonise other planets. This knowledge will also be important in allowing us to survive and evolve on the Earth without degrading the biosphere to a point where life is not viable.

2.2 Life on Earth

Nature of science:

Public understanding: There is a great deal of conflicting information on climate change available and the public doesn't always understand the science involved and scientists had a key role in ensuring this information is shared in a way which can be easily accessible. (5.1)

Understandings:

- Original atmosphere of terrestrial planets
- Development of atmospheres of Venus, Earth and Mars
- Solar radiation and planetary weather
- Greenhouse effect and CFCs
- Upper and lower temperatures for life
- Effect of asteroids and asteroid impact on the production of life on Earth
- Evidence of impactors

Applications and skills:

- Knowing that the T-Tauri phase removed the original planet's atmosphere
- Understanding how the effects of global warming could compromise life on Earth
- Analysing data related to the greenhouse effect

Guidance:

- Appreciate the differences that have produced Earth's life-supporting atmosphere

International-mindedness:

- International organisations such as the IPCC have a great deal of responsibility in shaping governmental policies on an international scale to limit and reduce the effects of global warming

Theory of knowledge:

- Scientific understanding suggests that life on Earth began around 3.8 billion years ago. How does this fit with other ways of thinking?

Utilization:

- Biology, Chemistry, Environmental systems and societies

Aims:

- **Aim 4:** there exists a great deal of information on the greenhouse gases and their effect on life on Earth with can be critically evaluated
- **Aim 7:** databases should be accessed in order to analyse data on climate change
- **Aim 8:** there is scope for studying the environmental implications of scientific advancement

• Know the importance of the 'escape velocity' for a planet in discussing which gases can be held in the atmosphere and which cannot • Be aware of the general effect of solar radiation on a planet's weather including generation of Hadley cells within the atmospheric structure, comparing Venus, Earth and Jupiter • Students should be aware that lower temperatures do not provide enough energy for biochemical reactions, and that higher temperatures result in the denaturing of proteins • Students should be aware of the evidence for impactors on the Earth (Meteor Crater, Tunguska, various parts of Africa) and on the surface of the Moon • Be aware that it is thought that life on Earth has been compromised a number of times in the past (e.g. Permian mass extinction, Cretaceous-Tertiary mass extinction)	

Essential idea: It is an important question to ask *Are we alone in the universe?* The answer to this question touches upon so many different aspects of life, from the scientific probability for the creation of life in the universe to non-scientific questions about the *point* of life and the concept of a *god*. The implications for society of the answer to this question cannot be understated.

2.3 The search for extra-terrestrial life

Nature of science:

Economic: Is there a justification for spending vast amounts of money on looking for extra-terrestrial life when funds could be used instead to develop projects that are likely to have a more immediate, positive, impact on life on Earth? (4.7)

Understandings:

- Fermi paradox
- The search for extra-terrestrial life
- The Drake equation for the probability of life

Applications and skills:

- Calculations involving the Drake equation

Guidance:

- Be aware of at least two initiatives carried out since the late 1950s to further the search for extra-terrestrial life. Examples include 'Suitcase SETI', 'Project Sentinel', 'Project META', 'The internet SETI project', 'Project Phoenix'
- Be aware of the significance of radio astronomy in the search for life and in particular, radio frequencies between 18 and 21 cm
- Be aware of how the discovery of the Pulsar was thought to have been a possible signal from extra-terrestrials
- Know the details of at least one probe within the solar system which was designed to look for life (e.g. Pathfinder mission, Mars explorer, Spirit and Odyssey)

International-mindedness:

- As in many areas of science, international funding is required in the search for extra-terrestrial life

Theory of knowledge:

- Our knowledge of living things is based entirely on what can be observed on Earth. Is it possible to imagine other forms of life which may exist outside of our planet?

Aims:

- **Aim 8:** students should be able to discuss economic implications resulting from the search for extra-terrestrial life

• Know and understand that the major candidates for life within the solar system outside Earth are presently thought to be Mars and Europa • $N = R_* . f_p . n_e . f_l . f_i . f_c . L$	

Topic 3: Galaxies 26 hours

Essential idea: Galaxies are the units that form the large scale structure of the visible universe and as such, are important areas of study. The Milky Way is *our* galaxy and as we are part of it, provides an ideal example from which to identify the structure and discuss the properties of such structures.

3.1 The Milky Way

Nature of science:

Forming a hypothesis: Although dark matter cannot be directly observed it can be inferred due to gravitational effects on the Milky Way. (2.5)

Understandings:

- Structure and constituents of the Milky Way
- Electromagnetic radiation
- Neutrinos
- Rotation curve for the Milky Way and the evidence for dark matter
- Mass distribution curve
- Dark matter
- Spiral arms
- Winding dilemma

Applications and skills:

- Describing rotation curves as evidence for dark matter
- Interpreting rotation and mass distribution curves

Guidance:

- Know where the Sun lies in the Milky Way

Theory of knowledge:

- Observations of the rotation of the Milky Way lead to the inference of dark matter. How valid a way of knowing is this?

Utilization:

- Physics: waves (physics sub-topic 7.2) nuclear physics (Topic 7)

3.1 The Milky Way	
• The Sun's oscillations may produce a disturbance of the Oort cloud which may then produce comet motion through the solar system • Know that it is thought that there is a supermassive black hole at the centre of each galaxy that is surrounded by a ring of molecular clouds • Students should know about the basic size and structure of the Milky Way including the disc, halo and nuclear bulge. In addition, the constituents are: - stars (population I and II stars, metallicity, age, and orbits) - gas (75% hydrogen and 25% helium, the form depends on temperature, around $10^{10} M_{\odot}$) - dust ($0.1 - 1 \mu m$ particles, around $10^{8}\ M_{\odot}$, restricts our ability to make optical measurements in the disc) - cosmic rays (85% protons, 12% helium, 2% electrons and 1% heavy nuclei) - magnetic field mainly aligned with the disc - electromagnetic radiation - neutrinos • Mass distribution and rotation curves beyond those for the Milky Way, will only be used for galaxies with a central mass and a uniform density • The spiral arms are centres of light output not stellar density	

Essential idea: It is crucial to be able to measure the properties of the different types of galaxy so that we are able to thereby discuss the properties of the universe itself, including its evolution through time. Such studies have also concluded that the vast majority of the universe is hidden to us and not visible as normal matter but rather, has a form referred to as *dark*.

3.2 Measuring galaxies

Nature of science:

Classification: Using the vast amount of data collected through observing galaxies, scientists have been classifying types of galaxies based on observed features. (3.1)

Understandings:

- The Hubble classification for naming galaxies
- Features of elliptical, lenticular and spiral galaxies
- Irregular galaxies
- Formation of galaxies as a result of density fluctuations in expanding gas produced by the Big Bang
- Cosmic distance ladder
  - Trigonometric parallax
  - Cepheid variables: period-luminosity relationship
  - Type Ia Supernovae: maximum luminosity is a constant

Applications and skills:

- Describing the reason for the variation in the luminosity of Cepheid variables
- Determining the distance of galaxies using data on Cepheid variables

Guidance:

- Ellipticals
  - Elliptical outline
  - Featureless appearance
  - Flattening factor

Theory of knowledge:

- Large parts of scientific understanding have been based around understanding the properties of matter. How did the postulate of the presence of dark matter in the 1960s change our understanding of matter?

Aims:

- **Aim 3:** classification is a highly effective scientific technique in the analysis of vast amounts of data

3.2 Measuring galaxies	
• Lenticulars - Lens shaped - Disc and bulge but no spiral arms - May be barred • Spirals - Disc, bulge and spiral arms - May be barred • Flattening factor, *f*, (with the degree of ellipticity of the galaxies given by $10 \times f$)	

Essential idea: Active galaxies provide evidence for the ongoing development and evolution of a galaxy and in turn, allow us to investigate the way the mechanisms which occur within a galaxy affect its properties.

3.3 Active galaxies	
Nature of science: Observing: Technology has allowed for the collection of large amounts of data on galaxies which has enabled scientists to classify them according to specific properties (1.8)	
Understandings: • Spectral peculiarity • Active Galactic Nucleus (AGN) • Starburst galaxies • Quasars • Radio galaxies **Applications and skills:** • Explaining the power sources for different types of active galaxies • Describing the methods used to observe different types of galaxies **Guidance:** • AGN has at least four times the luminosity of the rest of the galaxy • Be aware of the typical schematic of an AGN with a surrounding dust cloud, producing two radio lobes	**Theory of knowledge:** How do you know that what we observe is real? Will we ever be able to travel so far? **Aims:** **Aim 6**: Databases and web-based images can be used to analysis information on different types of active galaxies

Topic 4: Cosmology 20 hours

Essential idea: The modern field of cosmology uses advanced experimental and observational techniques to collect data with an unprecedented degree of precision and as a result very surprising and detailed conclusions about the structure of the universe have been reached.

4.1 The birth, life and death of the universe

Nature of science:

Occam's Razor: The Big Bang model was purely speculative until it was confirmed by the discovery of the cosmic microwave background radiation. The model, while correctly describing many aspects of the universe as we observe it today, still cannot explain what happened at time zero. (2.7)

Understandings:

- The Big Bang model
- Cosmic microwave background (CMB) radiation
- Cosmological redshift
- Hubble's law
- Hubble's constant and the age of the universe
- The cosmological principle
- Olbers' paradox

Applications and skills:

- Describing both space and time as originating with the Big Bang
- Explaining how redshift data indicates the universe is expanding and how this leads to the idea of the Big Bang
- Describing the characteristics of the CMB radiation
- Explaining how the CMB radiation is evidence for a Hot Big Bang

International-mindedness:

There have been a variety of ideas and models for the origin of the universe and still many questions unanswered. It is clearly a question that cosmologists are vitally interested in across the globe and touches on non-scientific questions such as the existence of a god. The comments and research are hugely international since the thirst for answers touches virtually every human being.

Theory of knowledge:

Experimental data seems to show that the expansion of the universe is accelerating yet no one understands why. Will the experiments carried out on Earth (e.g. at CERN) ever completely explain all the questions?

Utilization:

- Physics, mathematics

Aims:

- **Aim 2:** unlike how it was just a few decades ago, the field of cosmology has now developed so much that cosmology has become a very exact science on the same level as the rest of physics

4.1 The birth, life and death of the universe	
• Solving problems involving Hubble's law • Estimating the age of the universe by assuming a constant expansion rate **Guidance:** • Be aware of the elements considered to have been created in the Big Bang (H to Li) • Be aware of how the elemental abundance is changing over time through the birth, life and death of stars and the importance of these heavier elements to the creation of life	• **Aim 10:** it is quite extraordinary that to settle the issue of the fate of the universe, cosmology, the physics of the very large, required the help of particle physics, the physics of the very small

Essential idea: Galaxies are formed within the universe and seem to be randomly generated, forming large scale structures which are observable.

4.2 Large scale structures in the universe

Nature of science:

Observation: As the amount of data increases as a result of more detailed observations our understanding of the universe also increases. (1.8)

Understandings:

- Galactic distribution
- Galactic clusters
- Local groups
- Superclusters
- Walls of galaxies, including the Great Wall
- The galactic arrangement in the universe

Applications and skills:

Explaining the distribution of galaxies within the universe to include rich and poor clusters

Guidance:

International-mindedness:

As the discussion about the structure of the universe moves to larger and larger scales, the experiments that are needed in order to obtain more and more information become more expensive. As such, beyond the research teams themselves being international, there is a need for more countries to invest in the research to cover the cost–hence the large financial support from across the globe.

Theory of knowledge:

It is important to always question the basis upon which our ideas are founded. The large scale distances within the universe are based upon the *galactic ladder* of measurements and any flaw in any of them, would disrupt the stability of the knowledge base – as such, it is vitally important to always question our understanding and never try to obscure the problems that exists.

Essential idea: The density of the universe determines the geometry of spacetime which in turn, determines the eventual fate of the universe.

4.3 The shape of spacetime

Nature of science:

Paradigm shift**:** Over time there have been a number of different theories of gravitation and some of these have led to a major change in our understanding of the world around us. (2.3)

Understandings:

- The ancient Greeks
- Galileo Galilei and falling objects
- Isaac Newton and the universal law of gravitation
- Albert Einstein and General Relativity
- The effect of gravity is equivalent to the acceleration of an object
- Relativistic ideas about time and space can be reconciled by describing these things together as four-dimensional *spacetime*
- Geometries for spacetime
- Know that the Big Bang theory of cosmology raises questions
- Inflation

Applications and skills:

- Understanding the development of ideas of gravitational forces
- Understanding the consequences of the possible geometries of spacetime

Guidance:

- Students should be aware of the properties of different possible geometries for spacetime

International-mindedness:

Over time our understanding of the universe around us has changed, moving from the varying ideas of a relatively small number of societies (e.g., the ancient Greeks, the ancient Egyptians, etc) to the development of a more *invested* set of ideas, fundamentally based on the fact that the transfer of knowledge around the world became easier. This has led to the global nature of this area of human endeavour.

Theory of knowledge:

This area of astrophysics has wonderful examples where our understanding has been somewhat limited because of preconceived ideas whch have been forced upon the scientific community by other vested interested (largely based around religion). The movement from a geocentric model of the solar system to a heliocentric one was a huge move forward and a great example for TOK. Further, the empirical understanding that Kepler had was put on a more-theoretical basis by Newton's theory of Gravitation.

4.3 The shape of spacetime	
- Flat (flat plane) o Straight lines extend to infinity o Parallel straight lines do not intersect o Internal angles of a triangle add up to 180° o Circumference of a circle = $2\pi r$ - Spherical (sphere) o Straight lines come back to the same point. o Parallel straight lines do intersect (e.g. at the poles) o Internal angles of a triangle > 180° o Circumference of a circle < $2\pi r$ - Hyperbolic (saddle shaped) o Straight lines continue to infinity o Parallel lines diverge o Internal angles of a triangle < 180° o Circumference of a circle > $2\pi r$	

Assessment in the Diploma Programme

General

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

There are two types of assessment identified by the IB.

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

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

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

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

To support teachers in the planning, delivery and assessment of the SBS Astronomy course a Basecamp group has been set up. This aims to facilitate the sharing of resources and discussion between teachers involved in the delivery of the course. Past examination papers as well as markschemes are also available. The physics teacher support material may also provide some useful information about different approaches to the individual investigation.

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.

Responsibilities of the school

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

Acknowledging the ideas or work of another person

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

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

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

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

Inclusive assessment arrangements

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

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

Assessment outline

First assessment 2017

Assessment component	Weighting
External assessment (2¼ hours)	**80%**
Paper 1 (¾ hour)	**30%**
Short-answer questions (30 marks)	
Paper 2 (1½ hours)	**50%**
Section A: Short-answer and extended response questions (around 40 marks) Section B: One data-based question (around 20 marks) Total 60 marks	
Internal assessment (10 hours) This component is internally assessed by the teacher and externally moderated by the IB at the end of the course.	**20%**

External assessment

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

External assessment details

Paper 1

Duration: ¾ hour

Weighting: 30%

- **Short-answer questions.**
- **The questions on paper 1 test assessment objectives 1, 2 and 3.**
- **The use of calculators is permitted. (See calculator section on the OCC.)**
- **An astronomy data sheet is provided inside the examination question paper.**

Paper 2

Duration: 1½ hours

Weighting: 50%

- **Section A: short-answer and extended-response questions.**
- **Section B: one data-based question.**
- **The questions on paper 2 test assessment objectives 1, 2 and 3.**
- **The use of calculators is permitted. (See calculator section on the OCC.)**
- **An astronomy data sheet is provided inside the examination question paper.**

Purpose of internal assessment

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

Time allocation

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

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

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

Guidance and authenticity

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

- the requirements of the type of work to be internally assessed
- the assessment criteria; students must understand that the work submitted for assessment must address these criteria effectively.

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

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

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

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.

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

Group work

Group work may not be undertaken by students as part of the individual investigation (IA). Each investigation is an individual piece of work based on different data collected or measurements generated. Ideally, students should work on their own when collecting data.

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

Group work is encouraged for all other practical work.

Safety requirements and recommendations

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

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

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

40 suggestions for a safer lab

Steps Requiring Minimal Expense

1. Have a written health, safety and environmental affairs (HS&E) policy statement.
2. Organize a departmental HS&E committee of employees, management, faculty, staff and students that will meet regularly to discuss HS&E issues.
3. Develop an HS&E orientation for all new employees and students.
4. Encourage employees and students to care about their health and safety and that of others.

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

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

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

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

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

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

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

    - What are the hazards?

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

    - How will I deal with them?

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

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

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

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

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

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

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

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

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

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

21. Require good housekeeping practices in all work areas.

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

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

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

25. Use warning signs to designate particular hazards.

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

Steps Requiring Moderate Expense

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

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

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

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

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

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

33. Provide fireproof cabinets for storage of flammable chemicals.

34. Maintain a centrally located departmental safety library:

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

    (All are available from LSI.)

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

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

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

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

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

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

Using assessment criteria for internal assessment

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

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

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

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

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

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

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

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

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

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

Practical work and internal assessment

General introduction

The internal assessment, worth 20% of the final assessment, consists of one scientific investigation. The individual investigation should cover a topic that is commensurate with the level of the course of study.

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

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

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

The practical investigation, with generic criteria, will allow a wide range of practical activities satisfying the varying needs of group 4 subjects. The investigation addresses many of the learner profile attributes well. See section on "Approaches to teaching and learning" for further links.

The task produced should be complex and commensurate with the level of the course. It should require a purposeful research question and the scientific rationale for it. The marked exemplar material in the teacher support material will demonstrate that the assessment will be rigorous and of the same standard as the assessment in the previous courses.

Some of the possible tasks include:

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

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

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

The task will have the same assessment criteria for SL and HL. The five assessment criteria are personal engagement, exploration, analysis, evaluation and communication.

Internal assessment details

Internal assessment component

Duration: 10 hours

Weighting: 20%

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

Internal assessment criteria

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

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

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

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

Personal engagement

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

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

Exploration

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

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

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

Analysis

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

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

Evaluation

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

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

Communication

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

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

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

Rationale for practical work

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

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

Practical scheme of work

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

Syllabus coverage

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

Planning your practical scheme of work

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

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

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

Teachers are encouraged to share ideas about possible practical activities. A Basecamp group with a discussion forum will be created for astronomy teachers, where resources can also be uploaded for others to view. It is to be hoped that teachers will take advantage of this resource.

Flexibility

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

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

Practical work documentation

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

Time allocation for practical work

The recommended teaching times for all Diploma Programme courses are 150 hours at SL and 240 hours at HL. Students at SL are required to spend 40 hours, and students at HL 60 hours, on practical activities (excluding time spent writing up work). These times include 10 hours for the group 4 project and 10 hours for the internal assessment investigation. (Only 2–3 hours of investigative work can be carried out after the deadline for submitting work to the moderator and still be counted in the total number of hours for the practical scheme of work.)

The group 4 project

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

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

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

Summary of the group 4 project

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

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

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

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

Project stages

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

Planning

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

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

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

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

Action

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

- Students should investigate the topic in mixed-subject groups or single subject groups.

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

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

Evaluation

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

- One solution is to devote a morning, afternoon or evening to a symposium where all the students, as individuals or as groups, give brief presentations.

- Alternatively, the presentation could be more informal and take the form of a science fair where students circulate around displays summarizing the activities of each group.

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

Addressing aims 7 and 8

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

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

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

Addressing the international dimension

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

Types of project

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

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

Logistical strategies

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

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

Model A: mixed-subject groups and one topic

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

Model B: mixed-subject groups adopting more than one topic

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

Model C: single-subject groups

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

Model D: collaboration with another school

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

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

Timing

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

Year 1

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

Year 1–Year 2

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

Year 2

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

Combined SL and HL

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

Selecting a topic

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

Student selection

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

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

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

Glossary of command terms

Command terms for astronomy

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

Objective 1

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

Objective 2

Command term	Definition
Annotate	Add brief notes to a diagram or graph.
Apply	Use an idea, equation, principle, theory or law in relation to a given problem or issue.
Calculate	Obtain a numerical answer showing the relevant stages in the working.
Describe	Give a detailed account.
Distinguish	Make clear the differences between two or more concepts or items.
Estimate	Obtain an approximate value.
Formulate	Express precisely and systematically the relevant concept(s) or argument(s).

Identify	Provide an answer from a number of possibilities.
Outline	Give a brief account or summary.
Plot	Mark the position of points on a diagram.

Objective 3

Command term	Definition
Analyse	Break down in order to bring out the essential elements or structure.
Comment	Give a judgment based on a given statement or result of a calculation.
Compare	Give an account of the similarities between two (or more) items or situations, referring to both (all) of them throughout.
Compare and contrast	Give an account of similarities and differences between two (or more) items or situations, referring to both (all) of them throughout.
Construct	Display information in a diagrammatic or logical form.
Deduce	Reach a conclusion from the information given.
Demonstrate	Make clear by reasoning or evidence, illustrating with examples or practical application.
Derive	Manipulate a mathematical relationship to give a new equation or relationship.
Design	Produce a plan, simulation or model.
Determine	Obtain the only possible answer.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Examine	Consider an argument or concept in a way that uncovers the assumptions and interrelationships of the issue.
Explain	Give a detailed account including reasons or causes.
Hence	Use the preceding work to obtain the required result.
Hence or otherwise	It is suggested that the preceding work is used, but other methods could also receive credit.

Justify	Give valid reasons or evidence to support an answer or conclusion.
Predict	Give an expected result.
Show	Give the steps in a calculation or derivation.
Show that	Obtain the required result (possibly using information given) without the formality of proof. “Show that” questions do not generally require the use of a calculator.
Sketch	Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Solve	Obtain the answer(s) using algebraic and/or numerical and/or graphical methods.
Suggest	Propose a solution, hypothesis or other possible answer.

Bibliography

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

Resource materials and bibliography

All documentation for this course was originally written by Dr John Chilton (Oakham School). The revised document was produced with Dr John Chilton and Simon Davis (St. Clare's, Oxford) along with the Curriculum Manager for physics.

The following resources are recommended as support materials

- Planisphere
- Universe (7th Edition), Freedman and Kaufmann, W H Freeman, ISBN: 0-71676-995-6
- The Sun and Stars, Green and Jones, The Open University, ISBN: 0-7492-56680
- Planetary Landscapes (2nd Edition), Greeley, Chapman and Hall, ISBN: 0-412-05181-8
- Astronomy – The Evolving Universe (7th Edition), Zeilik, Wiley, ISBN: 0-471-59739-2
- Space – Our Final Frontier, Gribbin, BBC, ISBN:0-563-53713-2