The Sciences: An introduction

An extended essay (EE) in the sciences gives students an opportunity to apply a range of skills while researching a topic of personal interest in the field. Students working on a science EE must demonstrate an in-depth analysis of the subject matter studied, be it biology, chemistry, computer science, design technology, physics or sports, exercise and health science. This understanding must be shown in the form of a research paper involving a well-formulated research question.

Students should be advised that while there is overlap between the subjects, their study should reflect one specific science area. For example:

- biology—dealing with living organisms and life processes
- chemistry—dealing with the composition, characterization and transformation of substances
- computer science—exploring advances in hardware and software development, network systems and computer control systems.

The nature of the topic under investigation should be different for each subject area and students should be careful if they undertake essays that may blur the boundaries between two science subjects. For example, when studying the pH of a body of water, students may investigate the chemicals responsible for the observed pH (chemistry), or the effect of the pH on the biota (biology).

A critical stage in preparing for the EE is the formulation of a logical and coherent rationale for selecting a particular topic. Students need to identify a topic that offers enough scope for the essay. They also require a research question that allows them to either generate data or examine existing data in order to support or refute their argument.

The outcome of the research should be a coherent and structured piece of writing that effectively addresses the research question and arrives at a particular objective conclusion based on the evidence presented. In addition, students are expected to think critically about their methodology, especially when the data may not support their initial thoughts. Students should consider a range of factors that may have contributed to this.

The process of topic selection

Students should initially identify the broad area of inquiry they are interested in within one of the science subjects: biology, chemistry, computer science, design technology, physics or sports, exercise and health science. If interested in a topic that falls between two sciences, students must be reminded that their essay will be graded on a specific subject content. For example, an EE in an interdisciplinary area such as materials science will, if registered as a physics EE, be judged on its physics content, not its chemical content. In other words, students must align their research to one subject area.

The topic may relate to an area of the Diploma Programme science courses, but this is not a requirement and other areas of the subject may be explored. Crucially, the topic should reflect the student's particular interest and enthusiasm within the subject area. The student must be personally involved with the subject matter and not simply be an informant.

Students need to narrow down the topic by dividing the area into more specific and detailed subtopics. The chosen topic should enable students to discuss conflicting ideas and theories, and to produce an in-depth analysis within the 4,000-word limit.

Students should avoid research topics that go beyond the boundaries of conventional science into areas that are more related to pseudo-science.

If students choose a topic that is already well documented they should try to apply their understanding in a different way. For example, a student may use a standard technique in a novel situation, thus demonstrating personal input or intellectual initiative.

Some topics may be inappropriate for investigation due to safety issues. Experiments involving dangerous or carcinogenic substances, radioactive materials, toxic substances, ionizing radiation, loud sounds or heavy equipment should be avoided unless adequate safety apparatus and qualified supervision are available. Students must check and understand all IB policies related to carrying out experiments with animal or human subjects, including both safety issues and those of an ethical nature. Before embarking on any practical experiment students should undertake a risk assessment and discuss this with their supervisor.

Often their previous experiences help students to decide on their topic.

It is strongly recommended that students choose a topic within a subject area they are currently studying within the Diploma Programme. This will ensure they already have the basic knowledge to complete the task. For some, a topic that extends beyond work already undertaken as part of the course might be a great source of research ideas. This is usually the case when students are pursuing topics in literature-based EEs.

Students undertaking an experimental science EE are not permitted to use the same investigations covered in the science courses. A student may, however, undertake research in a related area, or use the same techniques in a different scenario.

Students should discuss the appropriateness of their topic with their supervisor in the early stages of the research process.

Literature review—demonstrating knowledge and understanding in context

Literature-based research is an essential element of the EE. Students should review the existing literature on the topic to inform the construction of their own research question and design. In many instances, they will conduct their review in the early stages of the research process.

Once they have discussed their choice of topic with their supervisor, a student can begin to outline main points to be discussed in their essay. Their research plan should be flexible enough to allow the student to explore the topic in a creative manner.

Students should not be afraid to take risks throughout the research process: originality is encouraged, as is the use of a number of different research models.

A comprehensive literature review will help to guide and improve the students' own work as it will enable them to contextualize their findings. Students should be recommended to use statistics or data that they are able to demonstrate are linked to their research question. They should not necessarily ignore anomalies or even eliminate them from their data set on the basis that they are not reliable, but instead should discuss them critically.

Students should consult a range of appropriate sources. They must take particular care to ensure that all sources of information consulted are up to date and relevant to the research question posed.

Research question

When working on the research question, students should be guided by the rationale that their piece of writing is important and that it fills a gap in personal curiosity.

Thus, their research question should be non-trivial and follow from the existing body of literature on the topic. A well-constructed research question needs to:

- be specific and sharply focused on the particular aspect and/or area of subject matter being explored

- be stated clearly on the title page and in the introduction of the essay
- fit into one of the science subjects
- offer an alternative perspective compared to previous research findings
- be formulated as an actual question.

Students need to avoid researching a question that is too narrow or too obvious as this will limit their ability to formulate reasoned arguments and engage in critical thinking.

The question must give an appropriate context and encourage an investigative approach. It should be centred on science and not on peripheral issues such as the history of a subject or social implications of discoveries in a subject.

Research methods

The emphasis of the EE should always be on:

- written analysis
- interpretation of data
- evaluation
- construction and development of a reasoned argument.

Therefore, it is vital that the chosen methodology and experimental work of the essay is tailored to the research question and allows for an in-depth exploration.

In experimental essays, students should choose feasible experiments that do not require extensive lengths of time for the construction of apparatus or apparatus that is beyond the resources of their school.

Students should be guided by content analysis of primary and secondary sources in conducting research. Every science EE will involve some research into the background or theory of the topic selected. Therefore, students may choose any of the following approaches:

- experimental—design and implementation of an experiment, then personal collection and analysis of the data
- data-based—location and extraction of raw or processed data, which is then further refined and analysed
- theoretical—development of a quantitative or semi-quantitative description of the phenomenon, development or construction of a model, predictions about its behaviour and limitations.

Students working on an EE in computer science may choose data for analysis from a program written by themselves.

In biology essays this data may come through experimentation, microscopic observations, fieldwork or some other appropriate scientific approach.

In design technology it might be appropriate to include surveys, user observations and structured interviews with users or experts.

A secondary source of information refers to the collection of books, academic journals, newspaper and magazine articles, textbooks, reviews and websites that may be used to collect data as the focus of the student's research.

All students should consult secondary sources even if their EE is experimental.

Students who choose to undertake a literature-based EE must ensure that the range of sources used clearly relate to their chosen topic and are discussed critically.

For essays that are based on data taken from written sources, the student should explain clearly how the data has been selected in order to comment on its reliability.

For experimental work, sufficient information on the methodology should be provided to allow the work to be repeated by an independent researcher.

Students must carry out the research for the essay solely under the direction of the school supervisor. Students must provide evidence in the essay of their personal contribution to the research approach and to the selection of the methods used.

In the rare circumstances that a student undertakes their research outside the school, they must do so with the permission of the DP/EE coordinator and adhering to the requirements outlined in the important note on external mentors.

Supervisors also need to ensure that students are aware of their responsibility to properly cite the resources used and check their work for plagiarism. Citations should adhere to the requirements of the IB and be consistently applied throughout the EE.

Framework for the EE in the sciences

Introduction	An EE in the sciences is intended for students who are interested in undertaking research in an area of biology, chemistry, computer science, design technology, physics or sports, exercise and health science. Qualitative and quantitative methods are used.
Methods most relevant to subjects in this group	Primary methods involve analysis of original scientific publications, experiments, analysis of data, use of databases, modelling, written computer programs, surveys, questionnaires, observations, personal communications and interviews. Secondary sources include the collection of information from books, academic journals, newspaper and magazine articles, textbooks, reviews and websites.
Suggestions for possible sources	Use of peer-reviewed journals, newspaper articles, books, e-resources and publications online, specialized academic research engines, unpublished conference papers and previously published essays. Where relevant and possible, students may wish to consult practitioners and professionals to stimulate original ideas, provide models of disciplined, structured and informed approaches and encourage direct and personal involvement with the essay topic.
Particular things to be aware of	Students need to be aware that their work will be checked in terms of the IB's academic honesty policy and so all students must ensure that they are familiar with this document. When collecting data and conducting experimental procedures with human subjects (especially in biology and sports, exercise and health science), students must gain informed consent from the research participants. Research participants should be informed of the purpose, procedures and potential risks involved in a study. Investigations that are based on experiments likely to inflict pain on, or cause unnecessary stress to, living organisms are inadmissible. For greater clarification all students and supervisors are advised to read the IB Animal experimentation policy. It is recommended that all test subjects complete a physical activity readiness questionnaire (PAR-Q) or similar readiness questionnaire prior to partaking in

	rigorous exercise to ensure that they are suitable candidates for the investigation. Experiments involving bodily fluids must not be performed under any circumstances due to the risk of the transmission of pathogens. Experiments involving dangerous or carcinogenic substances, radioactive materials, toxic chemicals, ionizing radiation, loud sounds or heavy equipment should be avoided unless adequate safety apparatus and qualified supervision are available.
Summary	Undertaking an EE is a challenge and so planning is crucial. Students need to start writing their papers early and discuss any emerging difficulties with their supervisor, especially those that relate to experimental work that needs to be undertaken over a period of time, as with, for example, experiments with plants. Supervisors, practitioners and professionals in the field are a great source of information, advice and support for students. Students writing a science EE should search for primary and secondary sources of information prior to initiating the writing process. The framing of a good research question that is well structured and thought through will aid students in establishing a reasoned argument.
The EE and internal assessments	The EE is not an extension of the internal assessment, or any other assessment component, and students must ensure that they do not use material submitted for any other assessment component as part of the EE submission. In the sciences this explicitly means that data collected for experiments undertaken as part of science lessons or the internal assessment task cannot be used as the basis of the EE in that subject.

Overview

An extended essay (EE) in biology provides students with an opportunity to apply a range of skills while researching a topic of personal interest in the field of biology.

Biology is the science that deals with living organisms and life processes. A biology EE should incorporate biological theory and emphasize the essential nature of this subject

Choice of topic

The topic must allow an approach that relates specifically to biology. Where a topic can be approached from different viewpoints, the treatment of the material must be clearly biological. For example, an EE in an interdisciplinary area such as biochemistry will, if registered under the subject of biology, be judged solely on its biological content.

Essays that deal with human diseases can often be dealt with from a number of perspectives, such as biological, medical, social or economic. Such essays should focus on biological aspects of the disease rather than on medical diagnosis and treatment.

Similarly, essays that deal with sports physiology and physical fitness must have a clear biological emphasis. They must explore the issues from a biological viewpoint and provide biological explanations for the results.

Inappropriate topics

Some topics may be inadmissible because their means of investigation are unethical. For example, investigations that:

- are based on experiments likely to inflict pain on, or cause stress to, living organisms
- are likely to have a harmful effect on health, eg culturing micro-organisms at or near body temperature (37°C)
- involve access to, or publication of, confidential medical information.

In all cases where human subjects are used as the basis for an investigation, clear evidence of informed consent must be provided in accordance with the IB guidelines.

Some topics may be unsuitable because of safety issues. Adequate safety apparatus and qualified supervision is required for experiments involving dangerous substances such as:

- toxic or dangerous chemicals
- carcinogenic substances
- radioactive materials.

Other topics may be unsuitable because the outcome is already well known and documented in standard textbooks.

Examples of topics

These examples are just for guidance. Students must ensure their choice of topic is focused (left-hand column) rather than broad (right-hand column).

Focused topics	Broad topics
The effect of detergent toxicity on soil bacteria	Detergents in the environment
A study of malnourished children in Indonesia and the extent of their recovery after a period of supervised improved nutrition	Malnutrition in children
A study of the effect of differing pH levels on the growth of *Phaseolus vulgaris*	The effect of acidity on plant growth
The competitive and evolutionary nature of the symbiotic relationship in *Paramecium bursaria*	Symbiosis
The effect of banana peel on seed germination	Factors that affect the germination of seeds
Gel electrophoresis: The construction of an apparatus and the separation of proteins in heat-treated cow's milk	Uses of the gel electrophoresis technique

Treatment of the topic

Students should explain early in the essay how they arrived at their research question and narrowed it down, by briefly outlining aspects they are not considering in the essay.

Students should be encouraged to formulate one or more hypotheses based on the research question. A single well-formulated question may give rise to a small number of precise hypotheses.

Primary research

Essays in biology may be based on data collected by the student through:

- experimentation
- survey
- microscopic observations
- biological drawing
- fieldwork
- or some other appropriate biological approach.

Essays that involve practical work carried out in the laboratory, or fieldwork, should include a clear and concise description of the experimental procedure.

Students taking an experimental approach must also consult secondary sources.

Secondary research

Alternatively, students can base their essays on data or information obtained from literature. Ideally they can use the data and manipulate or analyse it in an original way. Essays that simply restate facts or data taken directly from the sources are of little value.

Whichever approach is chosen, the student must ensure that they have access to sufficient data or information to research the topic effectively.

Students should attempt to specify how the research approach and methodology were decided, and show any approaches that were considered and rejected.

Supervision

Ideally, students should carry out the research for the essay solely under the direction of a school supervisor. Some of the IB's best essays have been written by students investigating relatively simple phenomena using standard school apparatus and this approach is to be encouraged.

All students must provide evidence in the essay of their personal contribution to the research approach and to the selection of the methods used.

Essays based on research carried out by the student at a research institute or university, under the guidance of an external supervisor, must be accompanied by a covering letter outlining the nature of the supervision and the level of guidance provided.

Writing the essay

Generating and presenting data should not be an end in itself; analysis using appropriate scientific techniques is essential.

The main body of the essay should consist of an argument or evaluation based on the data or information presented. Here, the student should point out the significance of any graphs, tables or diagrams.

Students should ensure that the main body of the essay is well structured and has an obvious logical progression. They can use numbered and headed paragraphs to impose a clear structure. Their evaluation should show they understand the results and their significance in the context of wider academic reading on the topic.

Students should provide some explanation of anomalies or unexpected outcomes as well as explore alternative explanations for their findings. If necessary, they should propose modifications to hypotheses presented earlier in the essay and suggest a research approach for testing these.

Students must be encouraged to undertake a critical evaluation of the work they have done. In their analysis, they should describe and explain the limitations imposed on the research by factors such as:

- the suitability and reliability of the sources accessed
- accuracy and precision of measuring equipment
- sample size
- validity and reliability of statistics.

They should also consider biological limitations such as:

- those arising from the problem of repeatability and control when using living material
- the difficulties of generalizing from research based on a single type of organism or environment.

Examples of topics, research questions and suggested approaches

Once students have identified their topic and written their research question, they can decide how to research their answer. They may find it helpful to write a statement outlining their broad approach. These examples are for guidance only.

Topic	**The effect of soil salinity on the distribution and abundance of a halophyte in a salt marsh community**
Research question	To what extent is the distribution and abundance of the sea aster (*Tripolium pannonicum*) dependent on soil salinity?
Approach	Survey of vegetation using ecological techniques such as quadrat sampling to measure distribution and abundance, and a conductivity meter to measure salinity in soil samples.

Topic	**Urease from soy beans**
Research question	How does the level of urease activity differ between dried and fresh soy beans?
Approach	The enzyme is extracted from dried and fresh soy beans. Urease activity is measured by monitoring the pH of the solution using a suitable approach such as a pH probe or indicator.

Topic	**Antibacterial effects of a plant extract**
Research question	What evidence is there for the antibacterial properties of commercially available mouthwash on *Streptococcus mutans* (or other safe/approved strain) grown at 20°C?
Approach	Cultures of *S.mutans* are grown on agar plates with a suitable growth medium. Filter paper discs soaked in various concentrations of mouthwash are placed on inoculated plates and zones of inhibition are measured after a period of incubation.

An important note on "double-dipping"

Students must ensure that their EE does not duplicate other work they are submitting for the Diploma Programme. For example, data collected for experiments undertaken as part of science lessons or the internal assessment task cannot be used as the basis of the EE in biology.

The biology EE and internal assessment

An EE in biology is not an extension of the internal assessment (IA) task. Students must ensure that they understand the differences between the two.

- The IA is more likely to focus on the syllabus content, whereas the EE could explore aspects of biologynot covered in the syllabus.
- The IA must include data collection and analysis (from hands-on experiments, databases, simulations or modelling) and cannot purely be a literature review.
- The EE must construct a theoretical framework for the underlying biology of the chosen topic, whereas the IA focuses on the application of the scientific method to a problem of interest and will only include some background information.
- The EE explicitly assesses the students' ability to analyse and evaluate scientific arguments.

Supervisors play an important role in guiding students on these distinctions. Students risk their diploma if academic misconduct is detected.

Interpreting the assessment criteria

Criterion A: Focus and method

(Strands: Topic, Research question, Methodology)

The topic of the biology EE must be outlined at the start of the essay and should clearly establish the context of the research question. This should include the area of the research and the purpose and focus of the essay.

It is usually appropriate also to include the general background biological theory required to understand how the research question has arisen. For example, an essay's topic may be "Factors affecting the distribution of seagrass in Californian bays". The explanation of this topic may include reference to inshore ecosystems, pollution, the decline in seagrasses and the possible relationship to sea otter populations.

The research question is best expressed in the form of a question. It should be the precisely formulated question that the research will attempt to answer. The research question based on factors affecting the distribution of seagrass in Californian bays could be: "How do different concentrations of ammonium nitrate in sea water tanks affect the growth of seagrass (*Zostera spp)* over a three-month period?"

The research question must be:

- answerable within the limitations of resources, time and words at the student's disposal
- identified clearly
- clearly set within the academic framework of biology
- set out prominently at the start of the essay.

The student can then use the research question to formulate a hypothesis, or hypotheses, which can be tested.

Students need to demonstrate within the essay that the research has been well planned. They should show that they have researched the topic and selected an appropriate biological approach to address the research question. This applies both to their literature research and to practical data collection.

Students must demonstrate that their chosen methods and materials are appropriate for addressing the research question. They should explain their rationale for choosing practical methods. If they undertake experimental work, they must include sufficient information on their methodology for the work to be repeated.

The sources consulted must be sufficient and each must contribute to the research focus of the essay. If the study is based on the research of secondary data, students need to ensure that their selection of sources is sufficiently wide and reliable.

If students have undertaken an investigation under guidance in an external laboratory, they must clearly demonstrate:

- their understanding of the methods and materials applied

- their role in choosing and applying them.

If students are investigating a well-documented or standard topic, they should attempt to look for a new perspective on the issue.

Criterion B: Knowledge and understanding

(Strands: Context, Subject-specific terminology and concepts)

Experimental work is not a requirement for a biology EE. However, a theoretical dimension must be part of any empirical investigation.

The source materials accessed should be:

- clearly relevant and appropriate to the research question
- effectively referenced and incorporated into the body of the essay in a way that demonstrates the student's understanding
- predominantly from acknowledged scientific sources.

Students must demonstrate the ability to apply their selected sources and methods effectively in making relevant connections and in support of their argument.

Students need to show a mastery of, and fluency in, the use of appropriate terminology. At the same time, students need to avoid excessive use of jargon and focus on communicating clearly.

Any technical terms that are used should be explained and the student must demonstrate an understanding of these terms by using them appropriately within the text.

The student must try to maintain a consistent linguistic style throughout the essay.

Symbols, equations, significant digits and SI units should be applied appropriately and consistently.

Criterion C: Critical thinking

(Strands: Research, Analysis and Discussion and evaluation)

The "research" refers to both literature sources and data collected and processed by the students themselves. This research must be consistently relevant to the research question.

Use of data

The student is expected to analyse the data and sources and related uncertainties. This analysis will often include:

- mathematical transformations
- statistical analysis such as standard deviations and t-tests
- tables of processed data
- graphs.

If the data are analysed statistically, the student must clearly show understanding in the body of the essay of:

- why that particular measure or test was chosen
- how it was applied
- what the results mean in this context.

If graphs are used, they must be correctly selected and drawn to illustrate key elements of the analysis. They should only be included if they improve communication.

Students must analyse and present their data in such a way that they support and clarify the argument leading to the conclusion.

Students must make a special effort to maintain a reasoned, logical argument that focuses on the research question. Essays that attempt to deal with a large number of variables are unlikely to be focused and coherent. A clear and logical argument can be achieved by making repeated reference to the research question and to the hypotheses derived from it.

An assessment of the extent to which the hypotheses are supported, or the question is answered, by the data or information accessed should form part of the argument.

The stated conclusion(s) must be based on, and consistent with, the research presented in the essay. Biological research often reveals unexpected outcomes and these should be pointed out.

The original research question may not be fully answered by the investigation. In these cases, the student may point out unresolved issues and may make suggestions as to how these might be further investigated.

The student must comment on the quality, balance and quantity of the secondary sources and data used. They are also expected to show an awareness of any limitations or uncertainties inherent in their approach. In particular, they should critically comment on the validity and reliability of their data relative to their management of variables within the investigation.

Criterion D: Presentation

(Strands: Structure, Layout)

This criterion relates to the extent to which the essay conforms to accepted academic standards in relation to how research papers should be presented. It also relates to how well these elements support the reading, understanding and evaluation of the essay.

Structure

Students may use numbered and headed paragraphs to impose a clear structure. Subheadings should not distract from the overall structure of the essay or argument presented.

Recording experiments

Students should aim for scientific paper style, rather than a cookery book recipe approach. The record should include:

- a scientific annotated diagram to introduce key elements of the set-up
- relevant details of key equipment
- a summary of the essential procedural steps.

Students should avoid including minor or irrelevant details and repetitions, but must include those elements needed for reliability and replicability.

Charts, images, graphs and tables

- Any graphs, figures or tables generated by students or taken from literature sources must be carefully selected and labelled. They should only be used if they are directly relevant to the research question, contribute towards the understanding of the argument and are of a good graphic quality.
- Students must accompany images, charts and tables with analysis and discussion to show how they further the essay's argument.
- Only processed data that is central to the argument of the essay should be included in the body of the essay, as close as possible to its first reference.
- Tables should enhance a written explanation but not themselves include significant bodies of text. If they do, then these words must be included in the word count.
- Clarity in tables and graphs (legend) is important and students should not use unnecessary "over-formatting" that may detract from communication.
- A representative sample of raw data collected in large amounts by the student must be included in the core of the essay in a data table, including uncertainties and units. Any table should be designed to clearly display the information in the most appropriate form.
- Large tables of raw data collected by the student are best included in an appendix, where they should be carefully labelled.
- Graphs or charts drawn from the analysed data should be selected to highlight only the most pertinent aspects related to the argument. Too many graphs, charts and tables will detract from the overall quality of the communication.
- The use of a summary table and the combination of multiple graphs into one graph (family of curves) will avoid unnecessary repetitions.
- Students should illustrate key mathematical transformations with examples. Equations referred to in the text should be numbered.

Any material that is not original must be carefully acknowledged, with specific attention paid to the acknowledgment and referencing of quotes and ideas. This acknowledgment and referencing is applicable to audiovisual material, text, graphs and data published in print and electronic sources. If the referencing does not meet the minimum standard as indicated in the guide (name of author, date of publication, title of source and page numbers as applicable), and is not consistently applied, work will be considered as a case of possible academic misconduct.

A bibliography is essential and has to be presented in a standard format. Title page, table of contents, page numbers, etc must contribute to the quality of presentation.

The essay must not exceed 4,000 words of narrative. Graphs, figures, calculations, diagrams, formulas and equations are not included in the word count. Students must be aware that examiners will not read beyond the 4,000-word limit, nor assess any material presented past this.

Criterion E: Engagement

(Strands: Reflections on planning and progress)

This criterion assesses the student's engagement with their research focus and the research process. It will be applied by the examiner at the end of the assessment of the essay, and is based solely on the candidate's reflections as detailed on the RPPF, with the supervisory comments and extended essay itself as context.

Students are expected to provide reflections on the decision-making and planning process undertaken in completing the essay. Students must demonstrate how they arrived at a topic as well as the methods and approach used. This criterion assesses the extent to which a student has evidenced the rationale for decisions made throughout the planning process and the skills and understandings developed.

For example, students may reflect on:

- the approach and strategies they chose, and their relative success
- the *Approaches to learning* skills they have developed and their effect on the student as a learner
- how their conceptual understandings have developed or changed as a result of their research
- challenges they faced in their research and how they overcame these
- questions that emerged as a result of their research
- what they would do differently if they were to undertake the research again.

Effective reflection highlights the journey the student has engaged in through the EE process. Students must show evidence of critical and reflective thinking that goes beyond simply describing the procedures that have been followed.

The reflections must provide the examiner with an insight into **student** thinking, creativity and originality within the research process. The **student** voice must be clearly present and demonstrate the learning that has taken place.