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 chemistry provides students with an opportunity to investigate a specific aspect of a material of our environment. The essay must be characterized by a particular chemical emphasis within a more general set of research criteria.

Chemistry is the science that deals with the composition, characterization and transformation of substances. A chemistry EE should incorporate chemical principles and theory, and emphasize the study of matter and of the changes it undergoes.

The outcome of the research should be a coherent and structured piece of writing that effectively addresses a particular research question and arrives at a particular, and preferably personal, conclusion or response to the research question.

Choice of topic

The topic must allow an approach that specifically involves chemistry. Where a topic might be approached from different viewpoints, the treatment of the material must be from a chemistry perspective. For example, an EE in an option area of the IB syllabus such as biochemistry will, if registered as a chemistry EE, be judged on its content within the scope of the biochemistry option of the syllabus.

The scope of the topic and the research associated with it should enable all the criteria to be addressed. The research question must be sharply focused and able to be treated effectively within the word limit.

Suitability of topics

Broad or complex literature-based topics do not allow the student to discuss conflicting ideas and theories, nor to produce an in-depth personal analysis within the word limit. Students should therefore avoid these topics (eg investigations into health problems caused by water pollution, chemotherapy for cancer treatment or the use of spectroscopy in chemical analysis).

Some topics may be unsuitable for investigation because of safety issues. These are clearly stated in the chemistry guide and all students must be aware of them before embarking on their EE. Experiments involving toxic or dangerous chemicals, carcinogenic substances or radioactive materials are strictly prohibited.

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

However, some care does need to be exercised in deciding whether a topic is suitable or not; for example, previously, the study of the allotropes of carbon might have been thought to be trivial, but this would not be the case today.

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
Determination of chloride, nitrate and calcium ion concentration in sea water	Study of sea water
Spectrophotometric determination of vitamin B2 content in cow's milk	Study of milk
Investigating the possibility of substituting hydrazine for kerosene as a rocket fuel	Theoretical investigation of hydrazine
Extracting DNA from peas using two different primary alcohols	DNA in plants

Once they have chosen their topic, students must then further define and refine it for study by expressing it in the form of a research question.

Treatment of the topic

An EE in chemistry may be based on:

- literature
- theoretical models
- experimental data.

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

Students who choose to write a literature- or survey-based essay should ensure that it clearly shows its chemical basis. Essays written at the level of a newspaper or news magazine article are unlikely to achieve a high mark.

Since chemistry is an experimental science, students are strongly encouraged to undertake experimental work as part of their research, although this is not compulsory.

In order to place their research into the appropriate context, students should research the area of the investigation before commencing any experimental work. Where possible, they should consult original research using:

- scientific journals
- personal communications
- online sources
- textbooks.

The internet should never be the sole source of information.

All essays involving experimental work undertaken by the student should include a clear and concise description of the experimental work. Students should indicate clearly whether they have personally designed the experiment or used an existing method. If they use an existing method, they must give its source and state how they have adapted and improved upon it.

Supervision

All essays must be supervised by a school supervisor.

Many of the best essays are written by students investigating relatively simple phenomena using apparatus and materials that can be found in most school laboratories, and this approach is to be encouraged.

If the practical work is carried out in an industrial or university laboratory, the essay should be accompanied by a letter from the external supervisor outlining the nature of the supervision and the level of guidance provided. The school supervisor must be satisfied that the work described in the essay is genuine and essentially that of the student.

The supervisor has the responsibility to ensure that students understand that the EE must not duplicate the research topic, data or the results of the internal assessment. A statement to that effect should be included in the supervisor's comment on the cover of the EE.

Generating and presenting data should not be an end in itself; students must analyse data using appropriate techniques, evaluate it and where appropriate compare it with appropriate models or literature values.

Use of secondary data

Students can also use data collected elsewhere. For example, for a research question that requires calculation of enthalpy changes in reactions, students can obtain average bond enthalpies from databases and manipulate these in order to answer the question.

However, to achieve high marks, students must devise their own method to analyse the secondary data in a way that leads to a specific answer to their research question.

In any chemistry EE, students must demonstrate that they understand the theory underlying any experimental work and state any assumptions made.

They should show an understanding of the results obtained and be able to interpret them with reference to the research question posed.

They should be critical of inadequate experimental design, the limitations of the experimental method and any systematic errors.

Students should be encouraged to consider unresolved questions in their research, and to suggest new questions and areas for further investigation. Throughout the essay, students should emphasize clearly their own personal contribution.

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 storage temperature on alkaline battery discharge time**
Research question	What is the effect of storage temperature on the operational lifespan of an alkaline battery?
Approach	Experimental: set of 3 batteries is subjected to 5°C, 20°C, 30°C, 40°C, 50°C for a specific period of time, after which the batteries are discharged. Voltage is measured before and after storage period.

Topic	**Investigation of changing reflux time on the yield of aspirin**
Research question	Does increasing reflux time increase the percent yield of aspirin for the reaction between acetic anhydride and salicylic acid?
Approach	Experimental: aspirin is produced from acetic anhydride and salicylic acid at varying reflux time intervals.

Topic	**Replacement of coal with natural gas for electric power generation**
Research question	What would be the reduction in CO_2 emission (measured as % change by mass) in Germany of replacing all coal-fired power plants with modern CH_4 power stations?
Approach	Data based: calculate the CO_2 emission per kWh using public domain data for the heat of combustion, composition and efficiency of coal and natural gas power plants.

Topic	**Periodic properties of super-heavy elements 113–118**
Research question	Can the physical and chemical properties of the undiscovered elements be predicted using the law of periodicity?
Approach	Literature based: examine the ionization potential, electron affinity and other periodic trends, predict if the super-heavy elements obey the periodic law.

An important note on "double-dipping"

Students must ensure that their EE does not duplicate other work they are submitting for the Diploma Programme.

The chemistry EE and internal assessment

An EE in chemistry 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 chemistry not 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 chemistry 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 EE assessment criteria

Criterion A: Focus and method

(Strands: Topic, Research question, Methodology)

The EE in chemistry must have a clear chemical emphasis and should focus on the chemistry aspect of the investigation.

It should incorporate chemical principles and relate to the study of matter and its chemical changes.

The topic can come from:

- the core
- the AHL topics or
- one of the IB Chemistry options of the syllabus.

However, the emphasis should be on chemistry.

The research question must be formulated as an actual question, such as "Can the spectator ions influence the rate of oxidation-reduction reaction?"

To address the research question the student must research the existing literature on the topic and choose an appropriate methodology to pursue the investigation by:

- undertaking work in the laboratory or
- basing their research on existing data.

If practical work is undertaken, the rationale for choosing the procedure should be clearly explained.

If the investigation is undertaken in an external laboratory, students have to show clearly their understanding of the methods and materials, and their role in collecting the data.

Criterion B: Knowledge and understanding

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

Students are expected to show understanding of the relevant chemical principles and ideas and to apply them correctly.

Students must demonstrate clearly the underlying chemistry behind the research question and the techniques and apparatus chosen.

The source materials accessed should be:

- clearly relevant and appropriate to the research question
- effectively referenced and incorporated into the main body of the essay in a way that demonstrates the students' understanding.

Literature cited should predominantly come from acknowledged scientific sources.

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

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

Chemical nomenclature and terminology should be used consistently and effectively throughout the essay. Students should also use appropriately and consistently:

- relevant chemical and structural formulas
- balanced equations with state symbols
- mechanisms of reactions
- significant digits
- SI units.

Criterion C: Critical thinking

(Strands: Research, Analysis and Discussion and evaluation)

In a chemistry EE, the "research" refers to both literature sources and data collected by the students themselves. This research must be consistently relevant to the research question.

The student is expected to appropriately present and analyse the data. This analysis will often include:

- mathematical transformations
- statistical analysis
- tables of processed data and graphs.

If the data are analysed statistically, the student must clearly show understanding of why that particular test was chosen and what the results mean.

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 particular 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.

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

The stated conclusion(s) must be based on and be consistent with the research presented in the essay.

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

Inadequate experimental design or any systematic errors should be exposed. The uncertainties of the measurements should be evaluated and discussed.

The student must comment on the quality, balance and quantity of their sources. Students are 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.

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.

Use of charts, images and tables

Any charts, images or tables from literature sources included in the essay 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.

Large tables of raw data collected by the student are best included in an appendix, where they should be carefully labelled. Tables of processed data should be designed to clearly display the information in the most appropriate form. 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 distract from the overall quality of the communication.

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.

If an experimental method is long and complex, students may place the raw data in an appendix and include a summary of the methods in the body of the essay. Students who choose this option must be careful to ensure that the summary contains all elements that contribute to the quality of the investigation, since appendices are not an essential section of the EE and examiners are not required to read them.

In other words, any important information that contributes to the evaluation of the method must be in the body of the essay and not the appendix. For experiments where numerical results are calculated from data obtained by changing one of the variables, it is generally good practice to show one example of the calculation in the main body of the essay. The remainder can be displayed in tabular or graphical form.

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. Students should be aware that examiners will not read beyond the 4,000-word limit, nor assess any material presented thereafter. Graphs, figures, calculations, diagrams, formulas and equations are not included in the word count.

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.