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Education Services

Pre-IB Chemical Research Skills Programme

Chemical Research Skills

A Skills-Building Programme for Independent Chemical Investigation

Module 1

Thinking Like a Chemical Researcher

From Curiosity to a Research Question

In this module, you will:

- Understand what chemical research is
- Explore the features of a good research question
- Identify variables and define the scope of an investigation
- Evaluate and refine research questions



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PREFACE

Learning to Think Like a Chemical Researcher

Pre-IB Chemical Research Skills Programme | Modules 1–10

Chemistry is more than the study of substances, reactions, and scientific principles. It is also a discipline built upon observation, questioning, experimentation, measurement, and evidence-based reasoning. For many students, learning chemistry begins with understanding concepts, applying equations, and performing laboratory experiments according to established instructions. These are essential foundations. However, there is an important difference between following an experimental procedure and understanding how to design one.

This distinction becomes particularly significant when students progress into the International Baccalaureate Diploma Programme (IBDP), where independent scientific investigation forms an important part of their learning experience. Students are increasingly expected to formulate meaningful research questions, select appropriate analytical techniques, justify experimental decisions, evaluate the quality of their measurements, and draw conclusions supported by scientific evidence. Yet these research skills do not necessarily develop simply through learning more chemistry content or completing more laboratory experiments. They require deliberate preparation.

The **Pre-IB Chemical Research Skills Programme** was developed to address this need.
Drawing upon my experience as an IB Chemistry educator and examiner, I have observed that students may possess a reasonable understanding of chemical concepts yet encounter considerable difficulty when asked to translate those concepts into an independent investigation.

A student may understand concentration but struggle to prepare a suitable series of standard solutions. Another may know the Beer–Lambert law but remain uncertain about constructing and interpreting a calibration curve. Others may be familiar with experimental procedures yet find it challenging to explain why a particular analytical technique is appropriate, how many measurements are necessary, or whether their results are sufficiently reliable to support a conclusion.

These difficulties are not always the result of insufficient chemical knowledge. Often, they reflect a missing connection between conceptual understanding and experimental research design. This programme seeks to build that connection.

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Organised into ten progressive modules, the programme introduces students to the essential thinking processes and practical skills involved in chemical research. Beginning with the formulation of research questions, students gradually develop their understanding of quantitative solution preparation, dilution, calibration, analytical techniques, standardisation, measurement reliability, and experimental planning.

Each module builds upon the skills established in the preceding modules, encouraging students to recognise that scientific research is not a collection of isolated laboratory techniques. Rather, it is a connected process in which every experimental decision must serve a clear scientific purpose.

Throughout the programme, particular emphasis is placed on a fundamental principle:
A sophisticated-looking experiment is not necessarily a good experiment. A simple experiment that is thoughtfully designed, carefully measured, and critically evaluated can be an excellent scientific investigation.

Students are therefore encouraged not merely to ask *what should I do?* but also *why should I do it this way?*

Why is a volumetric flask preferable to a measuring cylinder when preparing a standard solution? Why might several smaller extractions be more effective than a single extraction? Why is a calibration curve necessary? Why can repeated measurements still produce inaccurate results? How can we determine whether an experimental method is capable of answering a research question?

These questions represent the foundations of scientific reasoning.
Importantly, this programme is not intended to replace the IB Chemistry syllabus, nor is it a shortcut to completing an Internal Assessment (IA) or Extended Essay (EE). Instead, it provides an early introduction to the research skills that students will eventually need when undertaking more demanding independent investigations.

The intention is to help students enter the IB Diploma Programme with greater confidence, stronger experimental awareness, and a more structured approach to scientific problem-solving. By the end of these ten modules, students should begin to appreciate that successful chemical research does not start with selecting an impressive experiment or sophisticated instrument.

It begins with a meaningful question, followed by careful consideration of the evidence required to answer it.

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Ultimately, the purpose of this programme is not simply to teach students how to conduct experiments. It is to develop their ability to think independently, make scientifically justified decisions, and approach chemical investigations with clarity, confidence, and intellectual curiosity.That is where meaningful scientific research begins.

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Think Chemistry. Think Structurally.

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Module 1 — From Topic to Research Question

Chemical Research Skills

Learning objectives

By the end of this module, you should be able to:

- distinguish a **topic** from a **research question**
- identify the **independent, dependent and controlled variables**
- distinguish **observable** evidence from **measurable** evidence
- recognise **confounding variables**
- construct a research question that is **specific, measurable, controllable and chemically meaningful**
- evaluate whether a proposed investigation is experimentally feasible

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1. A topic is not a research question

Students often begin with an interesting idea:

Vitamin C

This is a **topic**. It tells us what we are interested in, but not what we intend to investigate.

We might narrow it to:

Does temperature affect Vitamin C?

This sounds like a research question, but scientifically it is still incomplete.

We need to ask:

Temperature of what?
What temperature range?
How long is the sample heated?
What exactly will be measured?
How will it be measured?
What variables must remain constant?

A stronger research question would be:

How does heating temperature affect the concentration of Vitamin C remaining in orange juice after 10 minutes of heating?

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Now an experiment can begin to be designed.

The progression

TOPIC → QUESTION → RESEARCHABLE QUESTION

For example:

Vitamin C

↓

Does temperature affect Vitamin C?

↓

How does heating temperature affect the concentration of Vitamin C remaining in orange juice after 10 minutes of heating?

The last question tells us both **what we change** and **what we measure**.

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2. Meet the variables

Most quantitative experimental investigations contain three important types of variables.

Independent variable — IV

The **independent variable** is the factor deliberately changed by the researcher.

In our Vitamin C investigation:

IV = heating temperature / °C

For example, we might investigate:

20, 40, 60, 80 and 100 °C.

There should normally be **one deliberately changed independent variable**.

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Dependent variable — DV

The **dependent variable** is the quantity measured to determine the effect of changing the IV.

For our investigation:

DV = concentration of Vitamin C / mol dm^{-3}

Notice that the DV is not simply:

"Vitamin C"

It must identify the **measurable quantity** associated with Vitamin C.

This distinction is extremely important in chemical research.

Controlled variables

Controlled variables are factors deliberately kept constant so that they do not influence the measured outcome.

Possible controls include:

- heating time
- volume of orange juice
- source/batch of orange juice
- analytical procedure
- apparatus
- exposure to air
- sample preparation procedure

If these change, we may no longer know whether the IV alone caused the observed change in the DV.

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3. Why control variables?

Suppose two samples give different Vitamin C concentrations.

Sample	Temperature	Heating time	Vitamin C remaining
A	40 °C	5 min	0.0038 mol dm^{-3}
B	80 °C	20 min	0.0019 mol dm^{-3}

Can we conclude that increasing temperature decreased Vitamin C concentration?

No.

Two variables changed:

temperature AND heating time.

The lower Vitamin C concentration could have resulted from:

- higher temperature,
- longer heating time,
- or both.

This introduces a **confounding variable**.

Golden rule

Change one important variable at a time.

Everything else that could significantly affect the DV should either be controlled or accounted for in the experimental design.

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4. The hidden third variable

Consider this experiment:

Two reactions involving hydrochloric acid are compared.

Experiment A

0.50 mol dm^{-3} HCl
Temperature = 20 °C

Experiment B

1.00 mol dm^{-3} HCl
Temperature = 35 °C

Experiment B reacts faster.

Can we conclude:

"Increasing HCl concentration increases reaction rate"?

Not from this experiment.

Why?

Because **both concentration and temperature changed**.

Temperature is therefore a **confounding variable**.

A scientifically defensible experiment would change concentration while maintaining temperature constant.

This leads to one of the most useful questions in experimental chemistry:

What else could affect my result?

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5. Observable is not necessarily measurable

Consider a coloured solution undergoing a reaction.

A student writes:

"The solution became lighter."

This is an **observation**.

It may be scientifically useful, but it is difficult to analyse quantitatively.

Compare it with: "The absorbance decreased from 0.68 to 0.31."

Now we have **quantitative evidence**.

We can calculate: $\triangle A = 0.31-0.68 = -0.37$

We can compare trials, plot graphs and perform statistical analysis.

Observable

Descriptive or qualitative:

- became lighter
- produced more bubbles
- reacted faster
- became cloudy
- produced more precipitate

Measurable

Quantitative:

- absorbance
- gas volume / cm^3
- reaction time / s
- concentration / mol dm^{-3}
- mass / g
- pH
- conductivity
- temperature / °C

A strong research question usually converts an **observation into a measurement**.

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6. Operationalising a variable

This is an important research skill.

Suppose you want to investigate:

"How does pH affect iron?"

What does **"affect iron"** mean?

It might mean:

- rate of corrosion
- mass loss
- concentration of Fe^{2+} produced
- concentration of Fe^{3+} produced
- colour intensity
- electrode potential

The dependent variable must therefore be **operationally defined**.

Instead of:

How does pH affect iron?

we might ask:

How does the pH of an aqueous solution affect the percentage mass loss of an iron sample after 48 hours?

Now "effect on iron" has been converted into something experimentally measurable.

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