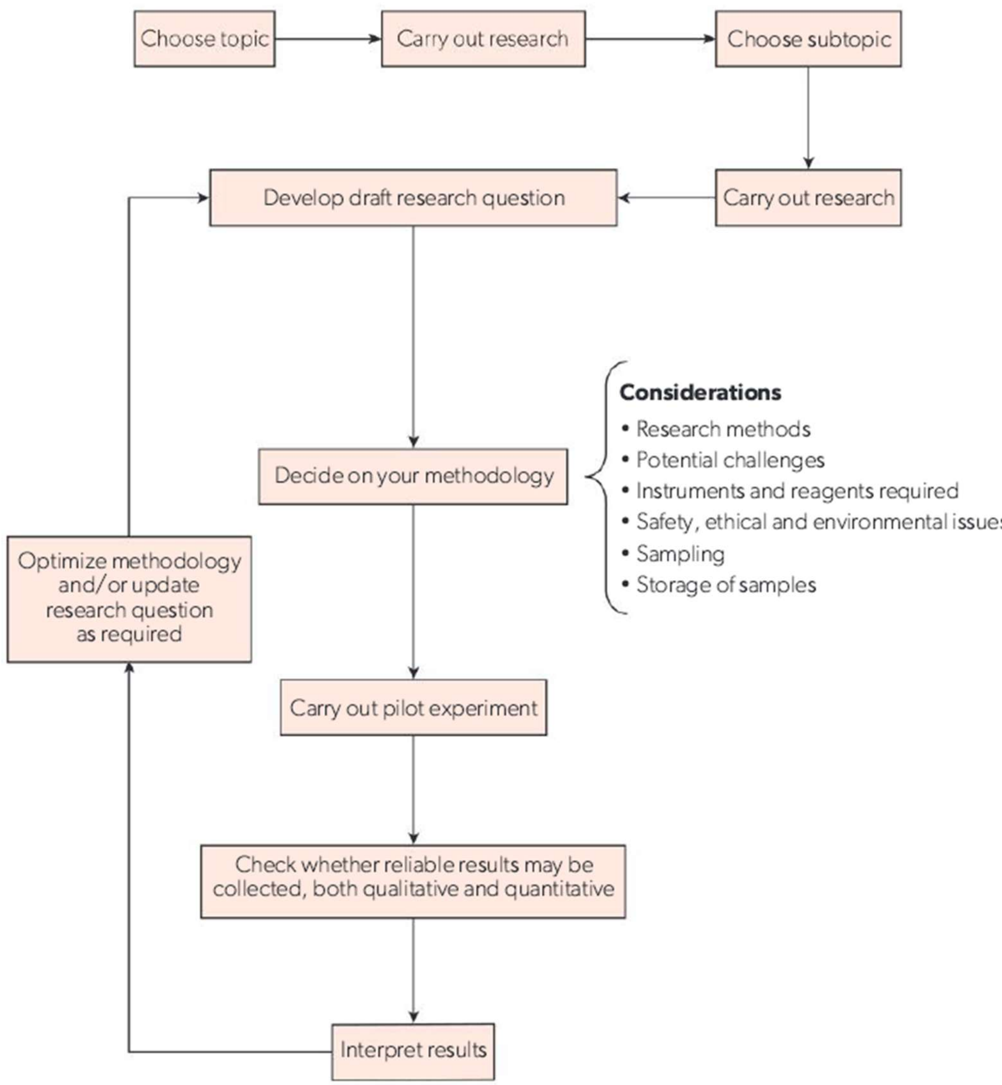
Starting Your IA Process – The Exploration Phase

In the exploration for your scientific investigation, you are required to

- produce a focused research question
- identify the best methodology to answer it
- clearly detail the steps of the chosen methodology
- carry out sufficient research to meet the requirements of each step and be able to justify every decision taken.

The research question should provide specific and appropriate context for your investigation. In your methodological considerations, you should describe how the chosen data collection methods allow you to answer the research question. The methodology used should be realistic in terms of the time and resources available. It must also be possible to effectively control variables that impact your results. You should present the description of the methodology clearly such that it could be easily reproduced.

You should also make sure that your overall exploration allows you to utilize the skills detailed in the inquiry process. Two different investigations will rarely follow the same path, but some of the steps in the flow chart on the right may be involved in developing your investigation:



When you are developing your investigation, you may find that your chosen methodology does not allow you to collect enough data to answer your research question. In this case, you must ask yourself what makes more sense: changing the methodology or changing the research question. The case studies below give examples of possible research designs and how they link to the inquiry process.

Case Study 1 (Exploring)

A student wants to devise a research design to investigate how the calcium content of kale changes as it is cooked in water. They suggest the following draft research question: "***What is the effect of temperature changes when cooking vegetables?***"

This question outlines possible independent and dependent variables for the investigation. However, the question lacks specificity: there are infinite ranges of temperature and many types of vegetables. Readers of the scientific report will not understand the purpose of the investigation with limited information.

The concentration of calcium ions could be measured in the vegetables or the water where they were cooked. Several methods are suitable for a school laboratory. Critical thinking and research skills should be used to determine which is most effective method. Considering a vegetable of local relevance and the range of temperatures typically used in local recipes would also improve the research question. The research question also fails to outline the methodology used, and there are many suitable techniques.

A more specific research question would be: "***What is the effect of temperature (35, 45, 55, 65, 75, 85 °C) on the calcium concentration in kale as determined by the titration with EDTA of the water used for cooking it?***"

Case Study 2 (Exploring, Designing, Controlling Variables)

A student wants to investigate the effect of citric acid concentration on the antioxidative action of ginger tea. The student decides to measure the change in total phenolic content using an antioxidant assay and colorimetry. The research question requires context, to explain the antioxidant properties of ginger extract and how citric acid enhances these properties.

Natural products are challenging because the results may be affected by the agricultural practices used to farm the ginger, such as soil composition, storage conditions and moisture content, so these factors must be considered. Performing an extraction will also require several decisions regarding the experimental conditions, such as choice of solvent, pH if aqueous, exposure time and temperature.

In developing the methodology, the student encounters the following challenges:

- The student decides to use the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay to test for the phenolic content in the ginger tea, and finds it in the school stock room. However, when doing further research, the student realizes that DPPH is not soluble in water. Therefore, the assay is not suitable for the analysis of tea solutions.
- The student conducts further research and finds out that the Prussian blue assay uses water-soluble reagents. The phenolic compounds in ginger tea will reduce the $Fe(CN)_6^{3-}$ ions in Prussian blue to $Fe(CN)_6^{4-}$ ions, which will react with iron(III) ions to give $Fe_4[(CN)_6]_3$. The color of $Fe_4[(CN)_6]_3$ is blue, and the intensity of this color will depend on the antioxidative properties of the ginger tea. The intensity of color can be measured by colorimetry.
- The student needs to produce a calibration curve, which will require the use of gallic acid as one of the reagents. The student also remembers to take at least three readings and use a blank to make this curve. The student monitors the temperature, as this will affect the absorbance.

When describing the methodology, the student details the Prussian blue test, and provides a brief explanation of Beer's law, both of which add value to the investigation report. The student also includes the chemical reactions that occur in the test for phenolic content using balanced equations with state symbols.

Case Study 3 (Designing, Controlling Variables)

A student wants to investigate how the cooking time affects the concentration of oxalic acid in the spinach. The student outlines their methodology as follows: they will determine the concentration of oxalic acid in the cooking water at different times by titrating it with potassium manganate(VII), $KMnO_4$.
Several control variables need to be considered for this investigation, such as the mass of the spinach, the volume of water, the range of cooking times, and the source and storage of the spinach sample. The following aspects of the methodology also need to be considered:

- Should the leaves, the stem or all the spinach be used?
- Which type of spinach should be used? The concentration of oxalic acid in spinach will vary significantly between different varieties. This information is required to prepare a suitable concentration of the titrant.
- Which range of temperatures is reasonable within the context of the investigation? For example, oxalic acid will decompose if the solution is boiling. Which intervals will provide sufficient and reliable data?
- Should the spinach be blended in a food processor first? How long should the sample be blended for? How can the surface area of the spinach sample be kept consistent?
- How will the potassium manganate(VII) solution be prepared? What is a suitable concentration for the solution? The student could run a pilot experiment with a concentration based on their research. The concentration used can be optimized for future experiments based on the results. For instance, the titrant volumes recorded could be very small, which means that the concentration of the titrant needs to be lower.
- Will a hot plate or a water bath be used to reach desired temperatures? A water bath could provide more uniform temperature throughout the sample. Should the temperature be monitored?
- How long should the spinach samples remain at each temperature? Should they be cooled down when removed? If the samples are not immediately cooled down, the cooking process will continue, affecting the results.
- Has appropriate experimental equipment been selected, considering their size and precision? Volumetric flasks and volumetric pipettes should be used for preparing solutions or dilutions. The golden rule is to use the highest precision instruments available.
- Is the titrant solution stable? This must be considered if data are collected in several sessions. Potassium manganate(VII) reacts with water, and this reaction is sped up in the presence of sunlight.
- Are there any specific requirements for the titration? It is a slow reaction, and therefore a gentle heating is advisable. The most suitable temperature can be ascertained in a pilot experiment. If the temperature is too high, the oxalate will decompose.
- Which safety issues must be considered? How can green chemistry come into the picture? How should the leftover spinach samples and reagents be disposed of? Are there any ethical issues? To mention a few: safety gear should always be worn even when the experiment does not involve serious risks. You must consider risks associated with chemical reagents, try to use as little as possible of them and state the environmental hazards involved.

Each decision must be based on a solid rationale and should be justified in the methodological considerations. The student decides to cut the leaf samples with scissors and uses a ruler to measure the pieces and ensure that the surface area of the spinach sample is consistent. The student opts for this method as a pilot experiment shows the sample gets warmer when using a food processor to chop the spinach. The student also decides to monitor the temperature using a thermometer and cool the samples immediately after heating, so the exposure time is the same for each sample. This shows thorough control of variables and adds value to the investigation.

The student also checks that there are high precision instruments available while planning their research design, therefore minimizing of uncertainties affecting the results.

The student conducts the experiment in the fume hood using a lab coat, safety goggles, mask and gloves due to the risks that potassium manganate(VII) presents. These hazards are briefly described in the research design. The student makes every effort to use the minimum quantities and the leftover chemical waste is disposed in a special bin for a company to collect. The report clarifies that the waste should not be disposed through the sink as this compound can cause damage to the environment. The leftovers of the spinach are used for composting. This approach shows that the student adheres to safety, ethical and environmental good practice.

Case Study 4 (Designing)

A student designs a research method to investigate how the time of chlorine exposure to UV light affects the extent of the photolysis reaction, using a mixture of sodium thiosulfate, $Na_2S_2O_3$, and starch as an indicator.

The following methodological considerations need to be made:

- reagents involved
- concentrations and storage of solutions
- chosen wavelength of UV light
- distance of chlorine sample from lamp
- elimination of other sources of light
- range of exposure times
- the best way to establish the endpoint of the titration and the number of trials.

Each will require several decisions, especially if the pilot shows that extended time periods are needed to obtain reliable results. For example, the temperature needs to be controlled as this will affect the reaction system. This is usually a challenge for longer investigations. If you the temperature cannot be kept constant in the experimental environment, the temperature of the reaction system should be monitored using a temperature probe.

The student's report includes the details of calibrating the pH probe with two buffers and they prepare a blank, showing good experimental technique. The buffers cover the optimum pH needed, to avoid systematic errors. The student covers the container with glass transparent to a wavelength of 365 nm, which gives a high rate of photolysis. This prevents evaporation and changes in concentration that would make the results unreliable.

Sodium thiosulfate is stable for 24 hours, so the student prepares a fresh solution each day that they carry out the experiment. The starch solution is also freshly prepared to avoid degradation.

The processing of errors must be considered before implementing the procedure. If the idea is to use a standard deviation, five trials are the minimum required. However, if any of the trials produce outlier results, then these results need to be excluded and more trials will be necessary. Diagrams or photographs of the experimental set-up could also add value to the description of the methodology.