Scientific Inquiry

Planning an Investigation

In our attempts to further our understanding of the natural world, we encounter questions, mysteries, or events that are not readily explainable. We can use controlled experiments, correlational studies, or observational studies to attempt to answer these questions or explain the events. The methods used in scientific inquiry depend, to a large degree, on the purpose of the inquiry.

Controlled Experiments

A controlled experiment is an example of scientific inquiry in which an independent variable is purposefully and steadily changed to determine its effect on a second dependent variable. All other variables are controlled or kept constant. Controlled experiments are performed when the purpose of the inquiry is to create, test, or use a scientific concept.

The common components of controlled experiments are outlined in the flow chart below. *Even though the sequence is presented as linear, there are normally many cycles through the steps during the actual experiment.*

Process Description

Stating the purpose

Choose a topic that interests you. Determine whether you are going to create, test, or use a scientific concept and whether you are going to carry out a given procedure or develop a new experimental design. Indicate your decision in a statement of the purpose.

Asking the question

Your question forms the basis for your investigation. Controlled experiments are about relationships, so the question could be about the effects on variable A when variable B is changed. The question may also be about what causes the change in variable A. In this case, you might speculate about possible variables and determine which variable causes the change.

Hypothesizing/ predicting

A hypothesis is a tentative explanation. You must be able to test your hypothesis, which can range in certainty from an educated guess to a concept that is widely accepted in the scientific community. A prediction is based upon a hypothesis or a more established scientific explanation, such as a theory. In the prediction you state what outcome you expect from your experiment.

Designing the investigation

The design of a controlled experiment identifies how you plan to manipulate the independent variable, measure the response of the dependent variable, and control all the other variables.

Example: A Test of the Collision–Reaction Theory

Stating the purpose

The collision–reaction theory sounds logical. The purpose of this investigation is to provide some concrete evidence to support or refute the collision–reaction theory.

Asking the question

How does changing the concentration of hydrochloric acid affect the time required for the acid to completely react with a fixed quantity of zinc?

Hypothesizing/ predicting

According to the collision–reaction theory, if the concentration of hydrochloric acid is increased, then the time required for the reaction with zinc will decrease. The reasoning that supports this prediction is that a higher concentration of $HCl_{(aq)}$ produces more collisions per second between the aqueous ions in hydrochloric acid and the zinc atoms. More collisions per second would produce more reactions per second and, therefore, a shorter time would be required to consume the zinc.

Designing the investigation

The same amount of zinc metal is made to react with different known concentrations of excess hydrochloric acid. The time for the zinc to completely react is measured for each concentration of acid solution. The independent variable is the concentration of hydrochloric acid. The dependent variable is the time for the zinc to be consumed. The temperature of the solution, the quantity of zinc, the surface area of the zinc in contact with the acid, and the volume of the acid are all controlled variables.

There are many ways to gather and record your observations during your investigation. It is helpful to plan ahead and think about what data you will need and how best to record them. This helps to clarify your thinking about the question posed at the beginning, the variables, the number of trials, the procedure, the materials, and your skills. It will also help you organize your evidence for easier analysis.

Gathering, recording, and organizing observations

Time to completion for the reaction will be measured using a stopwatch and recorded in a table like **Table 1.**

After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to enable you to answer the question posed at the beginning of the investigation.

Analyzing the observations

The observations will be presented in graphical format, with time on the *x*-axis and concentration of $HCl_{(aq)}$ on the *y*-axis. In this format any trends or patterns will be easier to see.

At this stage of the investigation, you will evaluate the processes that you followed to plan and perform the investigation. Evaluating the processes includes evaluating the materials, design, the procedure, and your skills. You will also evaluate the outcome of the investigation, which involves evaluating the hypothesis, i.e., whether the evidence supports the hypothesis or not. You must identify and take into account any sources of error and uncertainty in your measurements. Compare the answer created in the hypothesis/prediction with the answer generated by analyzing the evidence. Is the hypothesis acceptable or not?

Evaluating the evidence and the hypothesis

For a sample evaluation, see the Lab Report in Appendix A4.

In preparing your report, your objectives should be to describe your design and procedure accurately, and to report your observations accurately and honestly.

Reporting on the investigation

For the format of a typical lab report, see the sample Lab Report in Appendix A4.

Table 1: Reaction Time for Zinc with $HCl_{(aq)}$

Concentration of $HCl_{(aq)}$ (mol/L)	Time for reaction (s)
2.5	
2.0	
1.5	
1.0	
0.5	

Correlational Studies

When the purpose of scientific inquiry is to test a suspected relationship (hypothesis) between two different variables, but a controlled experiment is not possible, a correlational inquiry is conducted. In a correlational study, the investigator tries to determine whether one variable is affecting another without purposefully changing or controlling any of the variables. Instead, variables are allowed to change naturally. It is often difficult to isolate cause and effect in correlational studies. A correlational inquiry requires very large sample numbers and many replications to increase the certainty of the results.

The flow chart below outlines the components/processes that are important in designing a correlational study. The investigator can conduct the study without doing experiments or fieldwork, for example, by using databases prepared

Process Description	Stating the purpose	Asking the question	Hypothesizing/ predicting	Designing the investigation
	Choose a topic that interests you. Determine whether you are going to replicate or revise a previous study, or create a new one. Indicate your decision in a statement of the purpose.	**In planning a correlational study, it is important to pose a question about a possible statistical relationship between variable A and variable B.**	**A hypothesis or prediction would not be useful. Correlational studies are not intended to establish cause–and–effect relationships.**	**The design of a correlational study identifies how you will gather data on the variables under study and also identifies potential sources. There are two possible sources—observation made by the investigator and existing data.**
Example: Fish Death and Acidity	The purpose of this investigation is to determine whether there is a relationship between aquarium acidity and fish death and if so, what the relationship is.	Is there a statistical relationship between the acidity of the water in an aquarium and the death of fish, and if so, what is the relationship?	Does not apply.	It is generally considered to be unethical and inappropriate to conduct a controlled experiment in which the pH is manipulated in order to determine the acidity at which most fish die. However, we can obtain valuable data by involving a large sample (N=100) of home aquarium owners in a pH-monitoring program. Aquarium owners will measure the pH of their aquariums at regular intervals (every three days) over a period of three months. They will note and record the deaths of all fish. Participants will be expected to maintain their aquariums as they normally would and will also be asked to make other observations (e.g., the species of dead fish, symptoms leading up to the death) during the study period.

by other researchers to find relationships between two or more variables. The investigator can also make his or her own observations and measurements through fieldwork, interviews, and surveys.

Even though the sequence is presented as linear, there are normally many cycles through the steps during the actual study.

There are many ways to gather and record your observations during your investigation. It is helpful to plan ahead and think about what data you will need and how best to record them. This is an important step because it helps to clarify your thinking about the question posed at the beginning, the variables, the number of trials, the procedure, the materials, and your skills. It will also help you organize your observations for easier analysis.

Gathering, recording, and organizing observations

The results of the pH-monitoring study will be recorded in a table like **Table 2**. The pH will be measured and recorded every third calendar day for three months.

Table 2: Observations of Aquarium Acidity

Day and date	pH	Number of dead fish	Species of dead fish	Other observations
1 – 28/01/02				
2 – 31/01/02				
3 – 03/02/02				
4 – 06/02/02				

After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to enable you to answer the question posed at the beginning of the investigation.

Analyzing the observations

We will analyze the data to determine if there is a relationship between the pH and the number of dead fish. We will also attempt to determine whether the relationship is statistically significant or is due simply to chance.

The additional data will be analyzed to determine if some species of fish are more affected by the acidity level than others. The additional data will also be analyzed for any warning signs that might alert the owner to a potential problem.

At this stage of the investigation, you will evaluate the processes used to plan and perform the investigation. Evaluating the processes includes evaluating the materials, design, the procedure, and your skills.

Evaluating the evidence

In order to determine whether our investigation provided valid evidence to answer our question we will need to ask several questions. Is the sample size large enough to enable us to generalize to the larger population? Are we reasonably confident that the participants measured the pH accurately and on schedule?

If we are confident that the evidence is reliable and valid, we may be able to make recommendations to aquarium owners to help them prevent the death of their fish. The investigation might lead us to conduct further studies or controlled experiments, to answer such questions, as "Are there other factors that are related to the death of aquarium fish?"

In preparing your report, your objectives should be to describe your design and procedure accurately and to report your observations accurately and honestly.

Reporting on the investigation

For the format of a typical lab report, see the sample Lab Report in Appendix A4.

Observational Studies

Often the purpose of inquiry is simply to study a natural phenomenon with the intention of gaining scientifically significant information to answer a question. Observational studies involve observing a subject or phenomenon in an unobtrusive or unstructured manner, often with no specific hypothesis. A hypothesis to describe or explain the observations may, however, be generated over time, and modified as new information is collected.

The flow chart below summarizes the stages and processes of scientific inquiry through observational studies.

Even though the sequence is presented as linear, there are normally many cycles through the steps during the actual study.

Process Description

Example: Water Quality in Public Swimming Area

Stating the purpose	Asking the question	Hypothesizing/ predicting	Designing the investigation
Choose a topic that interests you. Determine whether you are going to replicate or revise a previous study, or create a new one. Indicate your decision in a statement of the purpose.	**In planning an observational study, it is important to pose a general question about the natural world. You may or may not follow the question with the creation of a hypothesis.**	**A hypothesis is a tentative explanation. In an observational study, a hypothesis can be formed after observations have been made and information has been gathered on a topic. A hypothesis may be created in the analysis.**	**The design of an observational study describes how you will make observations relevant to the question.**
Although the bacterial quality of public swimming areas is normally tested by the municipal or provincial Department of Health, no chemical analysis is done unless a problem arises. The purpose of this investigation is to carry out an environmental assessment to determine the chemical quality of the local public swimming area.	What common chemicals are found in the local public swimming area and in what concentrations are they present?	At this point, we have no indication of which chemicals are present in the area, what their concentrations may be, and if there are any threats to swimmers. We have no hypothesis and can make no predictions.	We will take a sample of water from five different locations within the local swimming area each week for a month. Note will be made of other significant conditions (e.g., heavy rain, wind) that are present during the course of the study. The water samples will be tested for organic and inorganic chemicals that may pose a health hazard. The testing facilities at the Department of Health and the Chemistry Department at the local university will be used to determine the presence and concentrations of chemicals.

Table 3: Presence and Concentration of Chemicals in Public Swimming Area

Chemicals	Week 1					Week 2					Week 3					Week 4				
	Sample area					Sample area					Sample area					Sample area				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

There are many ways to gather and record your observations during your investigation. During your observational study, you should quantify your observations where possible. All observations should be objective and unambiguous as possible. Consider ways to organize your information for easier analysis.

Gathering, recording, and organizing observations

The data will be recorded in a table like **Table 3**. The chemicals to be tested for include the following:

- lead
- mercury
- cadmium
- nitrates/nitrites
- volatile organic compounds such as benzene, toluene, carbon tetrachloride
- petroleum products
- chlorine

After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to enable you to answer the question posed at the beginning of the investigation. You may also have enough observations to form a hypothesis.

Analyzing the observations

The concentrations of the chemicals found in the swimming area are determined.

At this stage of the investigation, you will evaluate the processes used to plan and perform the investigation. Evaluating the processes includes evaluating the materials, the design, the procedure, and your skills. The results of most such investigations will suggest further studies, perhaps correlational studies or controlled experiments to explore tentative hypotheses you may have developed.

Evaluating the evidence and the hypothesis

We must determine if our sampling and testing procedures are appropriate. Is the number of samples sufficient? Were they taken at the proper sites? Was the testing of the samples carried out with care and precision?

The presence of chemicals in concentrations higher than the acceptable levels will alert us to potential problems with the swimming site. This might suggest further investigations to determine the possible source(s) of the chemical(s).

In preparing your report, your objectives should be to describe your design and procedure accurately, and to report your observations accurately and honestly.

Reporting on the investigation

For the format of a typical lab report, see the sample Lab Report in Appendix A4.