An overview of the process of scientific inquiry

Scientific inquiry is a process that begins with an observation of a biological event, pattern or phenomenon. Once an observation has been made, an interesting question may come to mind, sparking a scientist to hypothesize about the cause of the event. A scientist may then try to explain the underlying mechanism that caused the event by testing predictions through experimentation (Figure 1).

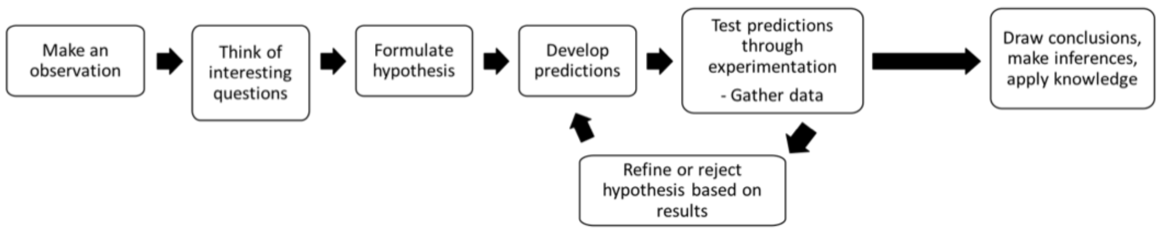

Figure 1: Steps in scientific inquiry.

If you consider all of the steps in scientific inquiry, you can see that there are clear stages of planning, doing, and applying (Figure 2).

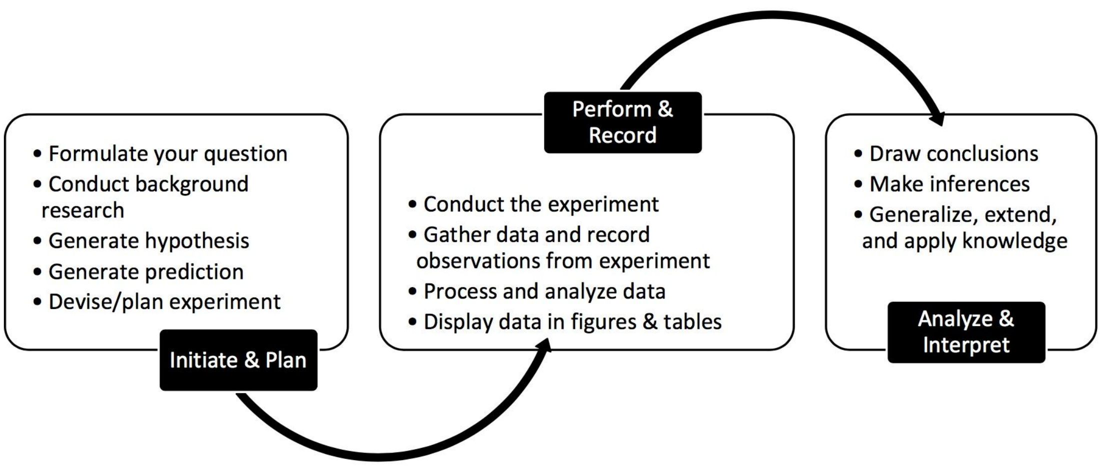

Figure 2: Scientific inquiry in stages.

Initiating and Planning

- You made an observation, but before you make inquiries about this observation you must formulate a research question.
- Conducting background research, or a literature search, is important so that you gather information to understand what the current state of knowledge is related to your research question. Identifying gaps in knowledge provides opportunities for

research - the results and interpretations of these results can then close these gaps.

- Gathering information through a literature search will also ensure that any hypotheses you devise will be consistent with current knowledge - one characteristic of a useable hypothesis.
- When devising an experiment, you should remember to design it so that it is testing what it is supposed to, it generates measurable data, and it is replicable or repeatable. Replication means that if another researcher wanted to, they should be able to follow your experimental protocol, or methods, in order to repeat or copy your experiment and obtain similar results. Replication leads to increased confidence of the results, increasing the significance of the conclusions drawn from the results.

Performing and Recording

- You will see that in this step data is displayed in figures and tables - once data are collected and analyzed, these results are visualized in figures and tables that act as quick visual snapshots of the results. One of the goals of research is to publish the work and share it with the scientific community - and these figures and tables (within the results section) are the heart of any journal article. You will learn more about scientific writing and the sections of a journal article in an upcoming seminar.

Analyzing and Interpreting

- Once the results of an experiment are gathered, processed, and analyzed, the next step is to discuss these results. The purpose of this discussion is to interpret and describe the significance of your results within the context of what is already known about the research problem that you have investigated, and to explain any new understanding or fresh insights about the problem after you've taken your findings into consideration. In a published journal article, you would find this analysis and interpretation within the discussion section.

A question you may be asking yourself: Does scientific inquiry always involve experimentation?

The answer is NO
See the next page about Observational studies and why they are an important part of scientific inquiry!!

But what about observational studies? Aren't they important?

Yes! They certainly are important!

Even though observational studies, or qualitative studies, sometimes do not collect 'measurable' data or follow strictly the scientific method, these types of research studies are extremely important.

The goal of any research is to gather data and interpret this data. Can you do this with observational studies? Absolutely!

Here's the big difference between an observational study and an experiment:

- Observational studies do not try to affect something, the researcher observes and records and reports these observational data
- In a controlled experiment (like really what we just described in the overview of scientific inquiry) researchers try to determine the effect of a treatment (or manipulation of a variable) on something else (another variable) whereas in observational studies, the researcher observes and does not manipulate.

The wonderful thing about observational studies is that they often will lead to experimental studies!

Introduction to Hypotheses

Here are several definitions or ways of thinking about what a **hypothesis** is:

- “A proposed explanation for a fairly narrow set of phenomena, usually based on prior experience, scientific background knowledge, preliminary observations, and logic.”   (from http://undsci.berkeley.edu/glossary/glossary_popup.php?word=hypothesis)
- “A supposition or conjecture put forth to account for known facts; *esp.* in the sciences, a provisional supposition from which to draw conclusions that shall be in accordance with known facts, and which serves as a starting-point for further investigation…” (Oxford English Dictionary)
- A hypothesis is a speculation about **why**
- A hypothesis is a possible explanation of cause and effect

- A hypothesis includes the **explanation**, or **mechanism,** for what you are observing.

Based on the definitions above there are a few things you must remember and consider when writing a hypothesis:

- Scientists formulate hypotheses that are supported by multiple lines of evidence and all of this evidence (such as previous research, experience, logic, preliminary observations, etc.) is taken together to write a statement that includes a possible explanation for an observed phenomenon.
- A hypothesis is a statement that is required in order to generate **testable** predictions.
- ***Hypotheses cannot be proven true*****.** This is because there is always the possibility that some new information in the future may disprove it. But we can (and do) prove hypotheses to be wrong. By eliminating or falsifying possible explanations or mechanisms with repeated experiments we are able to focus our questions and narrow the number of possible hypotheses that explain the world around us.

Consider the following two statements:

1. Table salt dissolves more quickly in water than rock salt
2. Surface area to volume ratio (SA:V) affects the time it takes salt to dissolve in water

Is statement 1 a hypothesis?
Statement 1 is not a hypothesis because:

- it does not include an explanation or mechanism for why one type of salt would dissolve faster than another.

Statement 1 is really just an observation - that could generate research questions and hypotheses.

Is statement 2 a hypothesis?
Statement 2 is a hypothesis because:

- It includes a mechanism (SA:V ratio) that may contribute to the observation (salt dissolving in water).
- It generates **testable** predictions - it generates expectations about what may happen in different situations (by changing variables – in this case the type of salt

or even the medium the salt is dissolving in - it could be cold or hot water, for example).

Introduction to Predictions

Now that you have been introduced to what a hypothesis is, now let's consider some ways of thinking about and defining what a **prediction** is:

- "The action of predicting future events; an instance of this, a prophecy, a forecast." (Oxford English Dictionary)
- In science, a possible outcome of a scientific test based on logically reasoning about a particular scientific idea (i.e., what we would logically expect to observe if a particular idea were true or false)
  (from https://undsci.berkeley.edu/glossary/glossary.php?start=n&end=r)
- A prediction is an **expected outcome** – something that you think will happen based on your hypothesis
- A statement about a future outcome that is generated by a hypothesis
- Scientists may use *expectation* as a synonym for prediction
- Predictions can take the form of **IF….. THEN**

Based on these definitions, you should remember that a prediction is a statement (for this class in the If….then form) about what you would expect to happen or what you would expect to observe if an idea (your hypothesis) was accurate.

Consider the following statements:

1. If SA:V affects how fast salt dissolves in water, then table salt will dissolve faster than rock salt
2. If SA:V affects how fast salt dissolves in water, then rock salt will dissolve slower than table salt
3. If SA:V affects how fast salt dissolves in water, then table salt will dissolve slower than rock salt
4. If SA:V affects how fast salt dissolves in water, then rock salt will dissolve faster than table salt

All of these statements are logical and testable predictions that were generated from the hypothesis that surface area affects how fast salt dissolves in water. Each of these predictions is in the IF…THEN format and each includes the expected outcome that would result from testing the prediction. Note that some of these predictions may be true and some may be false.

Hypotheses and Predictions are sometimes combined into one statement

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*BUT FOR BIOL*1070 YOU WILL WRITE THEM SEPARATELY*

Sometimes you may see hypotheses and predictions joined together in the same sentence – e.g. ‘If [hypothesis] is true, then….’.

However, writing the hypothesis and prediction together in one statement can make it really easy to start confusing hypotheses and predictions, and to lose track of the **explanation**, or **mechanism** of the observation that you are hypothesizing and predicting about. **So for this course we will keep them separated.**

<u>Here’s an example of a hypothesis and prediction written in combination:</u>
The Intermediate Disturbance Hypothesis (IDH) is a well-known ecological hypothesis (you’ll learn more about it online in Topic #2: Ecology, Part 3).
It states that:

> ‘Diversity is maximized at an intermediate frequency and / or magnitude of disturbance’ (Connell 1978).

In this case, the hypothesis is saying that the mechanism or explanation behind variation in levels of diversity is due (in part at least) to the level of disturbance.
When reading journal articles, keep in mind that hypotheses and predictions are often written in combination. Scientists may not explicitly state the hypothesis(es) and prediction(s) they have tested but may write statements like those above about the IDH.

Scaffolding Scientific Inquiry in Seminar

Over the next 7 seminars we will discuss the steps in the process of scientific inquiry and complete activities that will develop your understanding of the process. The process is broken down, or scaffolded, so that each week you will be focusing on one (or a few) of the steps of scientific inquiry and you will be practicing these steps with support. In future biology courses, you will be expected to understand the process and be able to apply all the steps on your own.

Here’s the schedule:

Seminar 3: Identifying trees in the digital forest

This seminar will address 4 steps of the process of inquiry: Observations, Questions, Hypotheses, and Predictions. You will practice making observations and formulating research questions using the digital forest as a medium for making these observations and formulating these questions. You will also practice formulating hypotheses and predictions in order to understand the difference between them and how they are used.

Seminar 4: An Introduction to Numeracy and Excel

This seminar addresses numeracy and its application to gathering data in an experiment. You will learn about different types of data that biologists encounter and collect when completing experiments. You will also practice data analysis, by reviewing some basic statistics and performing these statistics on a dataset.

Seminar 5: Methods I - Discrete data collection and visualization

This seminar addresses the step of experimentation. Within an experiment you are testing your predictions through gathering data and then analyzing this data. You will practice sampling and collecting discrete data on an insect population in the virtual Dairy Bush. You will also create a graph in order to visualize the results of the data you collected and analyzed.

Seminar 6: Methods II - Continuous data collection and visualization

In this seminar you will apply the knowledge and skills gained in Seminar 5 to gathering and visualizing continuous data on the same insect population in the virtual Dairy Bush.

Seminars 7: Beginning the Effect of Pesticide Project (EPP)

In this seminar you will begin to complete all of the steps in the process of scientific inquiry regarding the effect of pesticide on an insect population.

Seminars 8: Introduction to Scientific Writing

This seminar will introduce you to scientific writing and the elements of peer-reviewed literature. The final step of the process of scientific inquiry is drawing conclusions and applying the knowledge gained from the experiment, which will be addressed within this seminar.

Seminars 9: Finalizing the Effect of Pesticide Project (EPP) and starting the Interdisciplinary Assignment (IA)

The EPP is a culmination of the skills and knowledge gained in previous seminars regarding the process of scientific inquiry and the elements of peer-reviewed publications. When drawing conclusions and applying knowledge, often an interdisciplinary approach is taken - which will be highlighted during the completion of the IA.

What is Independent Learning?

Independent Learning is learning that takes place without a teacher or instructor, and without a prescribed learning template. All aspects of learning, including self-assessment of learning outcomes, are done independently, or with a learning cohort. Most adult learning in the knowledge-based economy is done using independent learning techniques and strategies.

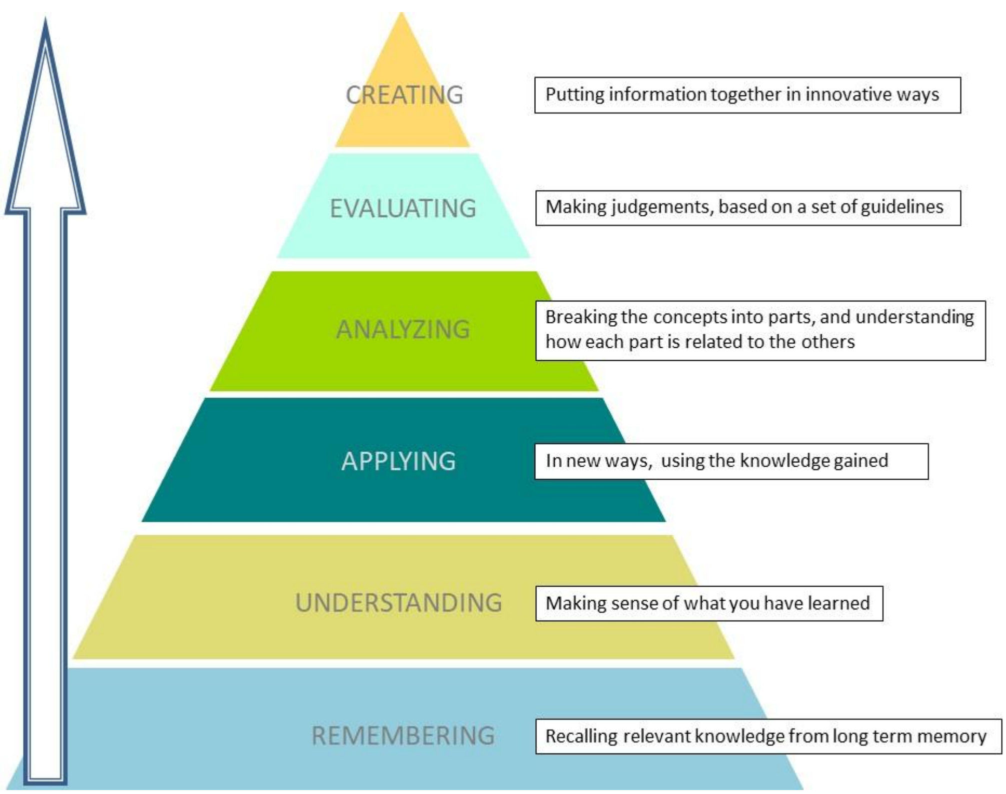
(Professional and Ethical Behaviour)

Learning outcomes are sets of guiding principles that describe what should be expected of a graduate from a degree program. These outcomes fall into the categories: Critical and Creative Thinking, Literacy, Global Understanding, Communicating and

Profesional and Ethical Behaviour and have been identified in relation to content throughout this website.

Independent learning can occur at all levels and depths of learning. Using the Revised Bloom's Taxonomy of Learning Objectives (illustrated below), our workshop will focus on learning mainly at the comprehension (understanding) level, with some aspects of application, analysis and evaluation built on that foundation. (**Professional and Ethical Behaviour**; **Problem Solving and Critical Thinking**)

Bloom's Taxonomy



This range of independent learning applications is appropriate for first year University students and for first year University science classes.

Note: Bloom's taxonomy also applies to a variety of adult workplace learning applications. **(Professional and Ethical Behaviour)**

What is Independent Learning in Biological Science?

Independent learning in biological science is the application of independent learning techniques and strategies to issues within the field of biological science. Students of biological science, and people working in careers related to the life sciences, will typically engage in independent learning on a continuous basis. The depth and breadth of existing knowledge and thought in biological science is enormous, and the rate of data and information accretion, and concept formation, is increasing exponentially. No formal course of study could allow a student to know all of biological science, even if new knowledge and concepts were frozen at today's levels. Similarly, no 'professional expert' in biological science could have expert-level knowledge over the whole field.

Students and working professionals in the field frequently use independent learning techniques and strategies in 3 major areas:

1. to learn, on their own, about sub-disciplines within biological science for which they have had little or no formal training
2. to learn about new, cutting-edge developments in their specialty area of biological science
3. to learn about how biological science affects the beliefs, behaviours and policies of other people and institutions

Independent learning in biology can occur in relation to school, work, or for personal interest.

Elements of Independent Learning in Biological Science

There are 5 critical elements for successfully engaging in any independent learning project in biology. The process starts when there is a stimulus to learn a specific knowledge set, or develop a certain skill or attribute, which motivates you to begin an independent learning project. (**Problem Solving and Critical Thinking**)