Bule Hora University

College of Natural and Computational Sciences

Department of Biology

Remedial program of Biology

Target group – Pre-university natural sciences students

Instructor's Name	**Medhanit A. (M.Sc.)**

Unit 1: The science of biology (4 hrs.)

Learning competencies

- Define and explain science as a way of knowledge and looking at and thinking about natural events.
- Describe and explain the main steps scientific methods .
- Demonstrate scientific methods by narrating Louis Pasteur and Alexander Fleming work.
- Plan and conduct an experiment to investigate a particular observation.
- Write a report for a scientific experiment.
- Name and describe the function of the main pieces of apparatus that are used by biologists the world over.
- Describe how these pieces of apparatus work.
- Explain how, and under what circumstances, these pieces of apparatus would be used and demonstrate the use of some of them.
- Classify the apparatus as laboratory tools, field tools or both.
- Be aware of possible health and safety implications of using these tools.

1.1 The methods of science

What is the science of biology?

- *The word biology is derived from two Greek words:* **bios** *–'life' and* **logos** *–'study'*
- Biology is the science of life and living organisms.
- An organism is a living being made from one cell (for example bacteria, unicellular algae) or many cells (for example, animals, plants and most fungi).

What is science?

- The word science comes from the Latin word *scientia*, which means 'knowledge'.
- But science isn't just about having knowledge: science is a unique system of acquiring knowledge based on the **scientific method**.
- This science is sometimes called **experimental science**, because it depends very heavily on experimentation to obtain the information.

- This is different from **applied science**, in which scientific research is used to meet certain human needs. However, it is often difficult to separate the two.
- Science is an ongoing effort to find new information and principles which can increase human knowledge and understanding.
- In their research, scientists collect evidence that supports or disproves a particular suggested explanation of a natural phenomenon.
- One important idea in science is that any suggested explanation of a phenomenon should be capable of being proved wrong.
- If there is no way of proving it wrong, how can other people accept that it is correct? This is what distinguishes science from religious beliefs.

KEY WORDS

- **Scientific method** *the process by which scientists approach their work*
- **Experimental science** *the use of experiments to obtain information*
- **Applied science** *the use of scientific research to meet certain human needs*

The Scientific methods

- This is the process by which biologists and all other scientists approach their work.
- The scientific method is a **process of experimentation** that is used to **explore observations** and **answer questions**.
- It is an **empirical method** of acquiring knowledge.
- It is also the **technique** used in the **construction** and **testing** of a **scientific hypothesis**.
- For centuries, people based their explanations of what they saw going on in the world around them on observations, without testing their ideas to see if they were true.
- One ancient belief was that simple living organisms could come into being by **spontaneous generation**.
- This idea suggests that nonliving *objects* can give rise to living *organisms*.
- But, this idea was disproved in the current world.

What are the main steps of the scientific method?

- The scientific method consists of a number of stages. These are summarized in the flowchart.
- So what is happening at each of these stages? What is the biologist doing and what do we mean by **hypothesis**?

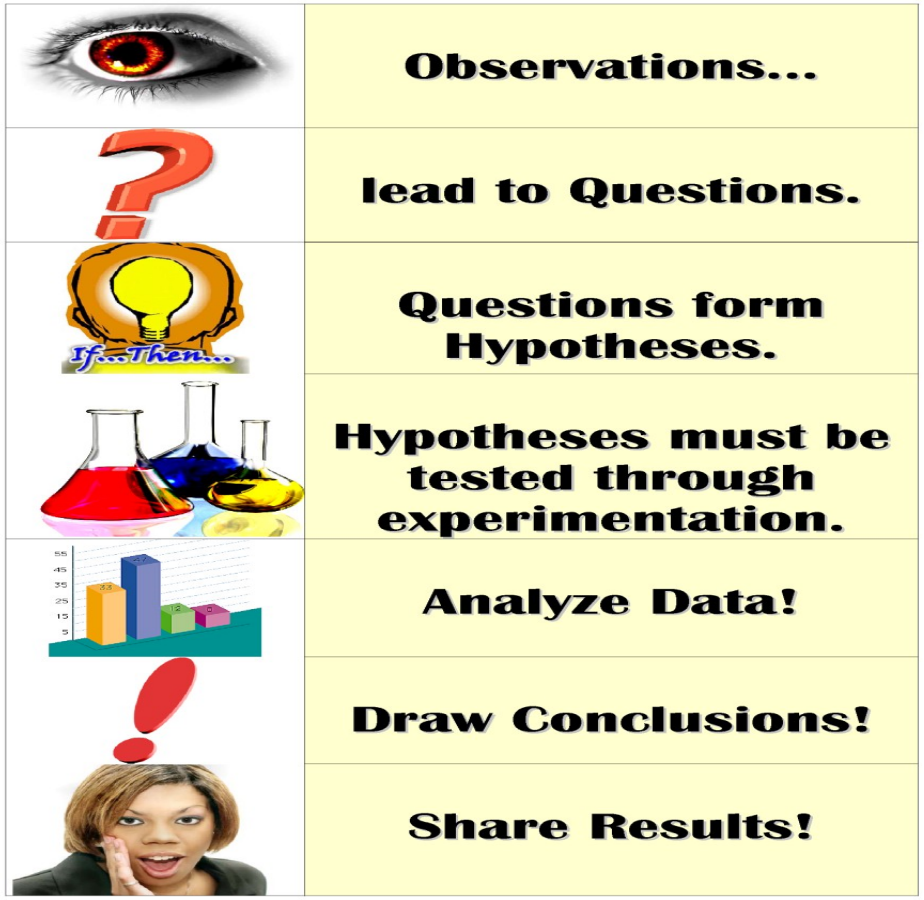




Figure 1.1 *The scientific method*

Steps in the scientific method commonly include:

1. ***Observation*** **-** *Quantitative and qualitative measurements of the world.*

2. ***Asking Question*** : Defining the problem (research question) you wish to explain.

3. ***Formulation of Hypothesis***:

   - ✓Hypothesis is a potential answer to the question, one that can somehow be tested.
   - ✓hypothesis is not necessarily the right explanation.
   - ✓Instead, it's a ***possible explanation*** that we can test to see if it is likely correct, or if we need to make a new hypothesis.
   - ✓A hypothesis must be testable and falsifiable in order to be valid.

4. ***Make predictions***

✓A prediction is an ***outcome we would expect*** to see if the hypothesis is correct.

- To test the hypothesis, we need to ***make an observation*** or perform ***an experiment associated*** with the prediction

- The results of a test may either support or contradict-oppose a hypothesis.

- Results that support a hypothesis can't conclusively prove that it's correct, but they do mean it's likely to be correct.

- On the other hand, if results contradict a hypothesis, that hypothesis is ***probably not correct***.

- Unless there was a ***flaw in the test-a possibility*** we should always consider-a contradictory result means that we can discard the hypothesis and look for a new one.

- When possible, scientists test their hypotheses using controlled experiments.
- ***A controlled experiment*** is a scientific test done under controlled conditions,
  - ✓ meaning that just one (or a few) factors are changed at a time, while all others are kept constant.
- In some cases, there is no good way to test a hypothesis using a controlled experiment ***(for practical or ethical reasons).***
- ✓ In that case, a scientist may test a hypothesis by making predictions about patterns that should be seen in nature if the hypothesis is correct.
- Then, she or he can collect data to see if the pattern is actually there.

- What are the ***key ingredients of a controlled experiment***? To illustrate, let us consider a simple example.
- Suppose I decide to grow **bean sprouts** in my kitchen, near the window. I put bean seeds in a pot with soil, set them on the window sill, and wait for them to sprout. However, after several weeks, I have no sprouts. Why not? Well...it turns out I forgot to water the seeds.

- **So, I hypothesize that they did not sprout due to lack of water**.
- To test my hypothesis, ***I do a controlled experiment.*** In this experiment, I set up two identical pots.
- Both contain ten bean seeds planted in the same type of soil, and both are placed in the same window. In fact, there is only one thing that I do differently to the two pots:
  - ✓ ***One pot of seeds gets watered every afternoon.***
  - ✓ ***The other pot of seeds does not get any water at all.***
- After a week, nine out of ten seeds in the watered pot have sprouted, while none of the seeds in the dry pot have sprouted.
- It looks like the "seeds need water" hypothesis is probably correct!

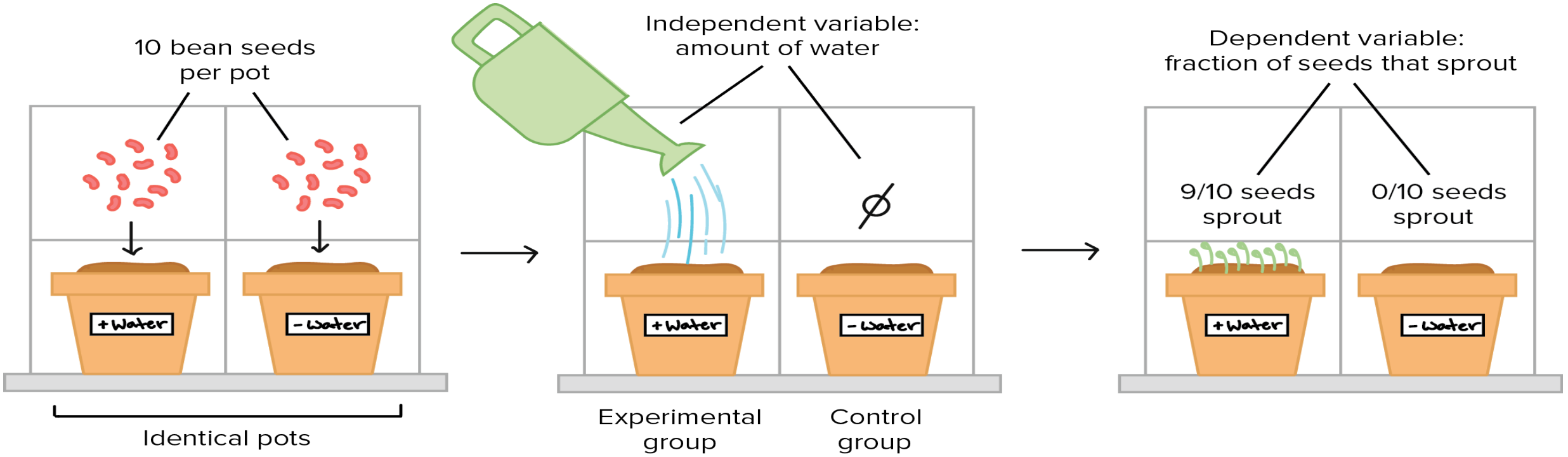


Figure 1.2. a simple example illustrates the parts of a controlled experiment

Panel 1: Two identical pots are prepared. 10 bean seeds are added to each pot. The pots are placed near the window.

Panel 2: One pot (experimental group) is watered. The other pot (control group) is not watered. The ***independent variable*** is ***the amount of water*** given.

Panel 3: In the experimental (watered) pot, 9/10 seed sprout. In the control (unwatered) pot, 0/10 seeds sprout. ***The fraction of seeds*** that sprout is the ***dependent variable***.

Control and experimental groups

- There are two groups in the experiment, and they are identical except that one receives a treatment (example water in figure 1.2) while the other does not.
- The group that receives the treatment in an experiment (here, the watered pot) is called the ***experimental group***,
- while the group that does not receive the treatment (here, the dry pot) is called the ***control group***.
- The control group ***provides a baseline*** that lets us see if the treatment has an effect.
- ***A control group*** acts as a 'standard' for comparison. It is used to 'isolate' the factor we are investigating and show that changes are due to this factor.
- **Experimental group** *the group in an experiment which is being experimented on in order to compare with the control group*

What do we mean by cause and effect?

- Scientific experiments try to establish cause and effect.
- This means that they try to prove that a change in one factor brings about a change in another factor.
- The factor that is different between the control and experimental groups (in figure 1.2, ***the amount of water***) is known as the ***independent variable (IV)***.
- This variable is independent because it does not depend on what happens in the experiment.
- Instead, it is something that the experimenter applies or chooses him/herself.
- In contrast, the ***dependent variable (DV)*** in an experiment is the response that is measured to see if the treatment had an effect. In figure 1.2, the ***fraction of bean seeds that sprouted*** is the dependent variables (DV)
- The dependent variable (fraction of seeds sprouting) depends on the independent variable (the amount of water), and not vice versa.
- Experiments can only establish cause and effect if changes in the IV are shown to cause changes in the DV
- We must ***take all the steps*** we can to ensure that the experiment is a ***fair test***.

What do we mean by cause and effect?

- We must make sure that any other factors which could affect the results are the same for the different conditions we set up.

- We must keep constant anything other than the IV that might influence the results. These are ***controlled variables***. In the figure 1.2. simple illustration experiment, the controlled variables were:
  - ✓ Temperature
  - ✓ Lighting conditions
  - ✓ Number of seeds sown per pots
- Occasionally, there is a variable that might influence the results that you can't control. Such a variable is a ***confounding variable***.
- This is because it 'confounds' the interpretation of the results. You couldn't be certain that it was the IV producing the changes in the DV because of the presence of the confounding variable.
- For example, if you measure the carbon dioxide uptake by wheat plants as the light intensity changes over the day, you cannot control the effect of change in temperature. It could be a confounding variable.

- ✓As a more realistic example of a controlled experiment, let us examine a recent study on coral bleaching.
- ✓Corals normally have tiny photosynthetic organisms living inside of them, and bleaching happens when they leave the color, typically due to environmental stress.
- ✓The photo below shows a bleached coral in front and a healthy coral in back.

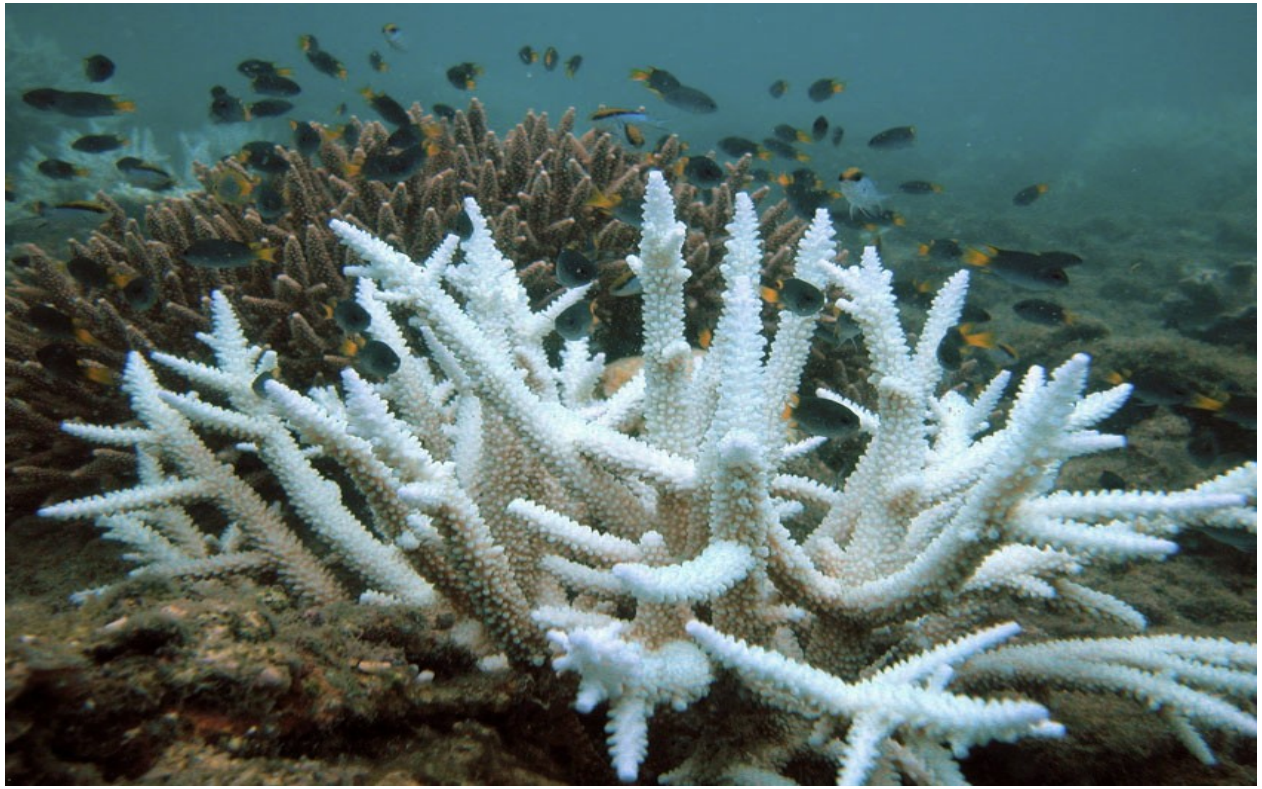


Figure 1.3. bleaching coral reef

Controlled experiment case study: CO_2 and coral bleaching

- A lot of research on the cause of bleaching has focused on water temperature.
- [1]However, a team of ***Australian researchers hypothesized that other factors might be important too***.
- Specifically, they tested the hypothesis that high CO2, levels, which make ocean waters more acidic, might also promote bleaching[2].
- What kind of experiment would *you* do to test this hypothesis?
- Think about:
  - ✓ What your ***control*** *and* ***experimental groups*** would be
  - ✓ What your ***independent and dependent variables*** would be
  - ✓ What results you would predict in each group

Experimental setup **Cont.**

…

- The Australian team collected many fragments of a certain coral species (*Acropora intermedia*) from the Great Barrier Reef.
- Then, they split the fragments into three groups, putting each group in water with a different pH (acidity level).
- After eight weeks, the researchers ch

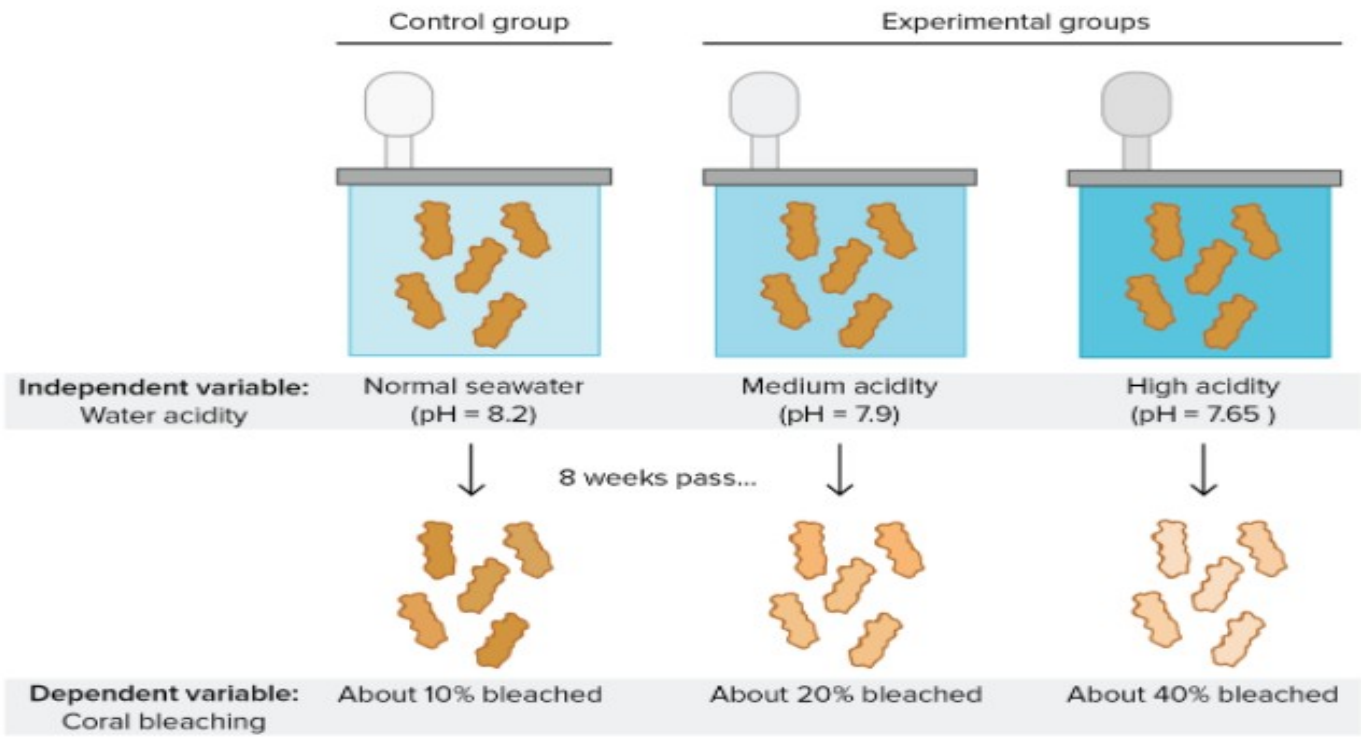


Figure 1.4. ***Experimental setup to test effects of water acidity on coral bleaching***

Non-experimental hypothesis tests

- Some types of hypotheses cannot be tested in controlled experiments for ***ethical*** *or* ***practical*** *reasons*.
- For example, a hypothesis about ***viral infection*** can't be tested by dividing healthy people into two groups and infecting one group.
- infecting healthy people would not be safe or ethical.
- Similarly, an ***ecologist*** studying the effects of ***rainfall*** can't make it rain in one part of a continent, while keeping another part dry as a control.
- In situations like these, biologists may use ***non-experimental forms of hypothesis testing***.
- In a non-experimental hypothesis test, a researcher ***predicts observations*** or patterns that should be seen in nature if the hypothesis is correct.
- She or he then collects and analyzes data, seeing whether the patterns are actually present.

Case study: Coral bleaching and temperature

- A good example of hypothesis testing based on observation comes from early studies of coral bleaching.
- As mentioned above, bleaching is when corals lose the photosynthetic microorganisms that live inside of them, which makes them turn white.
- Researchers suspected that high water temperature might cause bleaching, and they tested this hypothesis experimentally on a small scale (using isolated coral fragments in tanks)
- What ecologists most wanted to know, however, was whether water temperature was causing bleaching for lots of different coral species in their natural setting.
- This broader question could not be answered experimentally, as it wouldn't be ethical (or even possible) to artificially change the water temperature surrounding entire coral reefs.

Case study: Coral bleaching and temperature

- Instead, to test the hypothesis that natural bleaching events were caused by increases in water temperature, a team of researchers wrote ***a computer program*** to predict bleaching events based on real-time water temperature data.

- For example, this program would generally predict bleaching for a particular reef when the water temperature in the reef's area exceeded its average monthly maximum by 1∘C or more.

- The computer program was able to predict many bleaching events weeks or even months before they were reported, including a large bleaching event in the Great Barrier Reef in 1998.

- The fact that a temperature-based model could predict bleaching events supported the hypothesis that high water temperature causes bleaching in naturally occurring coral reefs.

- What about the belief that rotting meat produces flies? How could you disprove that by using the scientific method? Well, in 1668 an Italian biologist, **Francesco Redi**, did just that.
- Many scientists consider this to be the first true ‘experiment’.
- He used wide-mouth jars containing meat. Some jars were left open to the air. Others were covered with a piece of gauze.
- After several days, maggots and then flies could be seen in the open jars, but none appeared in the closed jars.

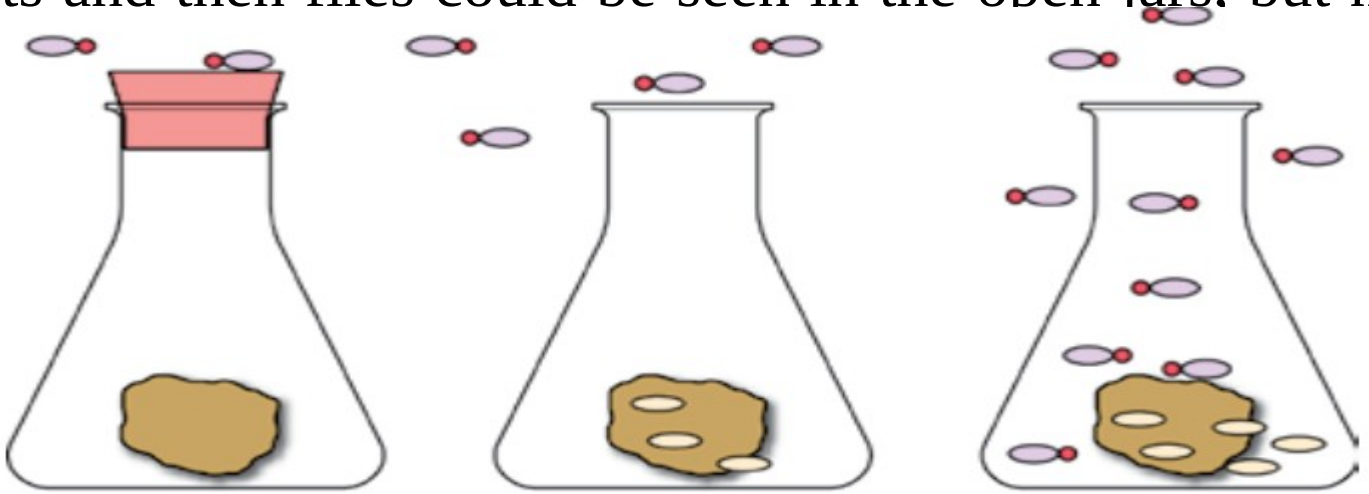


Figure 1.5 *Francesco Redi’s 1668 experiment*

How did the scientific method disprove the idea of spontaneous generation?

- Redi hypothesized that only flies could produce more flies and predicted that, in his experiment, flies would be found in the open jars, but not in the covered jars.
- He maintained all the jars under the same conditions and so he controlled many variables.
- By choosing to cover some jars with gauze rather than an impermeable seal, he allowed air to enter all the jars – again he controlled a variable that could have affected the outcome of the experiment.
- His results matched his prediction and when other people tried the experiment, they too got the same results.
- Redi was able to conclude that flies cannot be produced from rotting meat.
- He also went on to say that it was unlikely that any form of spontaneous generation was possible
- Most people accepted this for larger organisms, but, at round about this time, the microscope had been invented and the whole world of microbiology was opened up.
- Many people still believed that micro-organisms could arise by spontaneous generation. It took the work of Louis Pasteur to ***disprove this***.

How did the scientific method disprove the idea of spontaneous generation?

- In 1859, Pasteur carried out experiments to show that the micro-organisms that caused ***wine and broth*** to go cloudy came from the air and were not made from the broth itself.
- He used special '***swan-necked flasks***' like that shown in Figure 1.6.
- Pasteur boiled broths in swan-necked flasks to kill any microorganisms that might be in them. The boiling forced steam and air out of the flasks.
- When the boiling stopped and the broth cooled, air was sucked back into the flasks.
  - ✓ Some contained a filter to prevent all solid particles from getting into the growth medium from the air.
  - ✓ Others had no filter but, in these, the dust (and the microorganisms) in the air settled in the lowest part of the neck of the flask.
- All the flasks were kept under the same conditions in Pasteur's laboratory.

How did the scientific method disprove the idea of spontaneous generation?

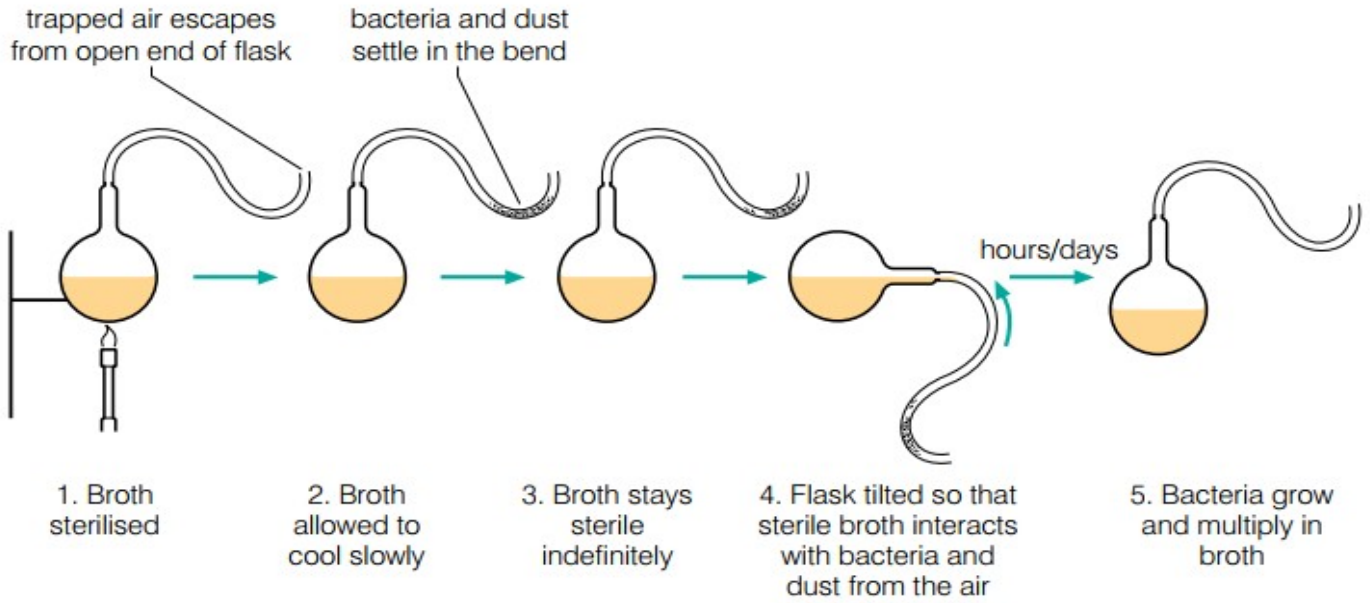


Figure 1.6 *A sw*

- The broths in the second two groups of flasks turned cloudy (due to the presence of micro-organisms) within days. The broths in the first group remained clear.
- After this, people were forced to ***admit that spontaneous generation***, even of micro-organisms, could not happen.

Accuracy, reliability and validity in scientific experiments

- They are really quite separate notions and all are important to how well an experiment is received by other scientists.

Accuracy

- Accuracy refers to how precisely you measure or count something.
- The level of accuracy you choose must reflect the magnitude of what you are measuring.

Reliability

- *A measure of how dependable and consistent the results of an experiment are*
- If we were to repeat the investigation, would we get more or less the same results?
- There are several things we can do to increase the ***reliability of our experiments***.
  - ✓ We can standardize all our procedures, so that we always do exactly the same thing. This makes it much more likely that we will be able to repeat our results.

Accuracy, reliability and validity in scientific experiments

- We can repeat it many times ourselves. This allows us to see, hopefully, a general pattern.
- It also allows us to:
  - ✓ spot any ***anomalous results*** and, if it is justified, to exclude these
  - ✓ calculate an average result, which is likely to be more representative than any individual result
- We can try not to use personal judgement.

Validity

- This is about whether or not our experiment measures what it says it is measuring.

How do we write reports on scientific experiments?

- When biologists write a report on an investigation they have just done, they write it with a view to having it published in a scientific journal, such as nature or science.

- ***Components of scientific report writing includes***:

1. ***A title***, which states clearly what is being investigated
2. ***A hypothesis***, stated clearly in terms of how the independent variable is expected to influence the dependent variable
3. A clear description of the ***experimental procedure***;
4. ***The results*** obtained; it is often helpful to summarise these (where appropriate) in graphs, charts and tables
5. **The conclusions** that have been drawn from the results
6. ***An evaluation*** of the procedure; this is an honest assessment of the limitations of the procedure that has been used, pointing out any unavoidable limitations and inaccuracies that arose
7. ***An acknowledgement*** of the use of any other person's work.

1.2 The tools of a biologist

What apparatus do biologists use?

- The main items of biologist apparatus are:
  - ✓ Laboratory equipment and
  - ✓ Field equipment

What do biologists use in the laboratory?

- This is still a large list. But there are some basic tools. These include:

- Microscopes
- Balances
- Dissecting equipment
- Measuring cylinders
- Petri dishes
- Pipettes and syringes
- Centrifuges

What do biologists use in the laboratory?

- ***Microscopes*** are one of the most vital tools in a biology laboratory. There are two main types:
  - **Light microscopes** that use beams of light to produce magnified images
  - **Electron microscopes** that use beams of electrons to produce magnified images



What do biologists use in the laboratory?

Measuring cylinders, pipettes, burette and syringes

- All these are used for measuring volumes, usually of liquids, but in some investigations they can be used to measure the volume of a gas.
- To measure 3.5 cm3 accurately, the pipette would be best. To measure 200 cm3 you would use the measuring cylinder.

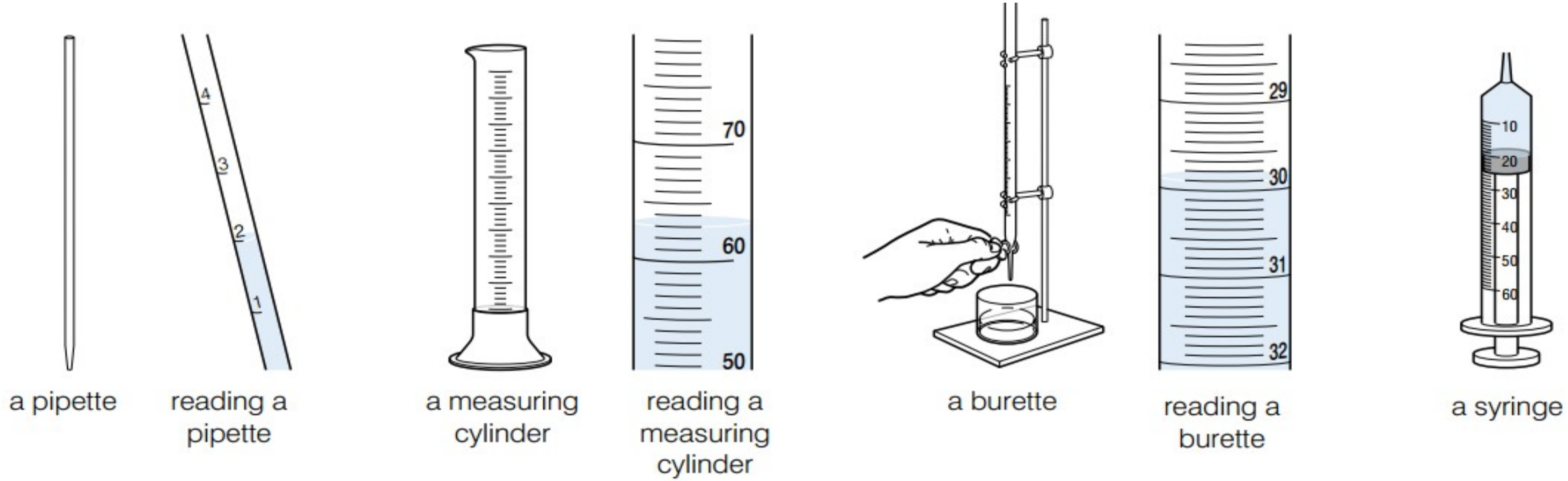


Figure 1.8 *Different measuring apparatus*

What do biologists use in the laboratory?

- ***Balances*** are used for measuring mass.
  - ✓ They come in a range of sizes and properties.
  - ✓ Some can measure the mass of very heavy objects, but not with any great degree of precision.
  - ✓ Others measure smaller masses to the nearest 0.0001 g (one ten-thousandth of a gram).



A



B

What do biologists use in the laboratory?

- **Dissecting Kit** used *to cut apart or separate tissue for anatomical study*



Figure 1.11 A standard dissecting kit



Figure 1.12 Dissecting a frog

What do biologists use in the laboratory?

Petri dishes are round dishes made from glass or from plastic.

- They are used in many different ways, but usually to culture some organisms.

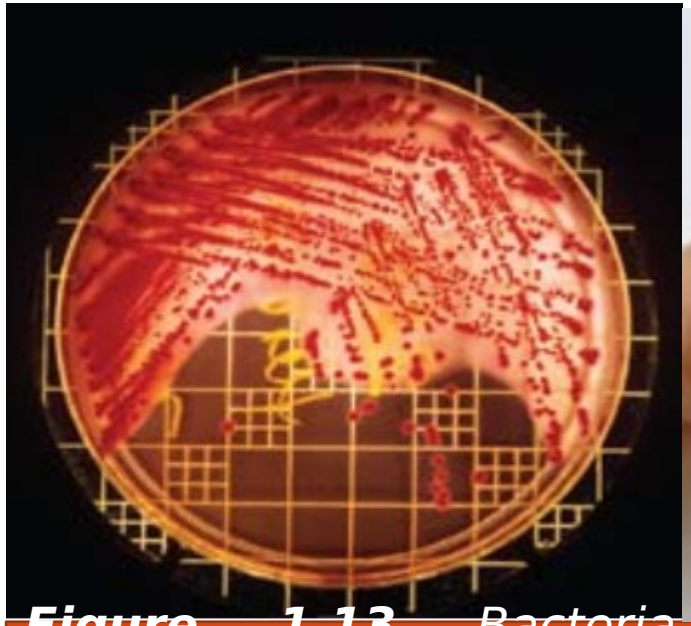


Figure 1.13 *Bacteria growing on agar in a Petri dish. The grid allows biologists to work out what proportion of the Petri dish is covered with each type of bacterium*



Figure 1.14 *Plantlets or 'explants*



Figure 1.15 Bacteria being cultured on agar in a Petri dish with several different antibiotic discs.



Figure 1.16 'Starch-agar' with four 'wells' cut in the agar; each well contains a different strength of enzyme solution

What do biologists use in the laboratory?

- ***Centrifuges*** machine that spins to separate solids from liquids where simple filtration is not adequate for the task.
- Some solid particles are very tiny and float around in a liquid, although they are not properly dissolved in the liquid.
- Centrifugation is commonly used in hospitals for stool tests where the ability to separate particles quickly and clearly is very useful.

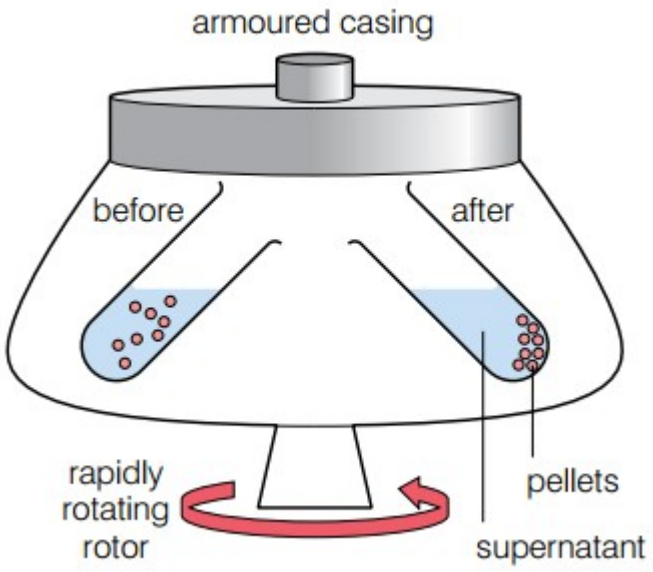


Figure 1.19 A centrifuge

What do biologists use in the field?

- This is still a large list. But there are some basic tools. These include:

- A quadrat
- A plant press
- A pitfall traps
- A nets to collect and study insects
- A flow meter – this is used to measure the rate of flow of water
- *A field microscope – this is used to investigate the structure of specimens in the field, whilst still fresh*
- *A theodolite – this is used to measure the height of trees or of slopes in the area*
- A data logger – this is used to record information
- A pH kit – this is used to measure the pH of soil or water
- A GPS (Global Positioning System) receiver

What do biologists use in the field?

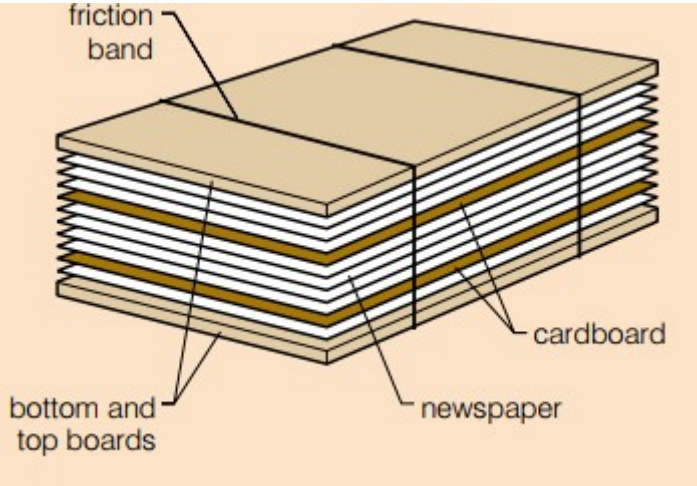
quadrat *a small frame used for ecological or population studies*

- ✓There are many different types, but the simplest is just a metal square.
- ✓It is placed randomly on the ground and the organisms found inside it are counted and the numbers and types recorded.
- ✓This data can be used to make an estimate of the abundance of the organisms in the area.



What do biologists use in the field?

- To collect specimens for identification in the laboratory, biologists use a range of equipment.
- Collecting plants is relatively easy, if they are not too large.
- Small parts (for example, leaves and flowers) can be collected and kept in reasonable condition for a short period in plastic jars or plastic bags.
- Parts of plants can also be preserved using a ***plant press***.
- This preserves the shape and form of the plant parts for some time and specimens can be analyzed later.



- a plant press

What do biologists use in the field?

- However, animals pose a different problem. Because they move, they must be caught.
- Biologists do this in many different ways. Some insects can be caught using nets. Others are caught using pitfall traps



Figure 1.22 *Students using nets to collect and study insects*

What do biologists use in the field?

- Some other instruments that biologists use in the field are illustrated below.



Figure 1.23 *A data logger – this is used to record information*



Figure 1.24 *A pH kit – this is used to measure the pH of soil or water*



Figure 1.25 *A flow meter – this is used to measure the rate of flow of water*



Figure 1.26 *A field microscope – this is used to investigate the structure of specimens in the field, whilst still fresh*



Figure 1.27 *A theodolite – this is used to measure the height of trees or of slopes in the area*

What do biologists use in the field?

- One recent addition to the tool list of field biologists is the GPS (Global Positioning System) receiver.
- This equipment makes it possible to record positions quickly and extremely accurately.
- By taking several readings at different points on the perimeter of the area, an accurate map of the area can be drawn.



Figure 1.28 *A GPS (Global Positioning System) receiver*