Biology and the Scientific Method

1.01: What Do Biologists Study?

Definition of Biology

Biologists study all living things. There is a wide diversity of living organisms (or biodiversity) on this planet: some biologists estimate that there may be 100 million types of organisms made up of plants, animals, bacteria and viruses. Most of these are still undiscovered and unnamed. Biology is the study of all forms of life. The word 'biology' comes from two Greek words: bio means 'life' and ology means 'the study of'.

Here are two definitions:

Definition 1. Biology is the study of living things.

This is a general definition but is not really good enough for someone studying biology.

Definition 2. Biology is the scientific *study of living things.*

This definition is better because it uses the terms 'scientific'. You will study the meaning of scientific later on in this chapter.

Examples of areas of study incorporated in biology

Biologists study more than just the whole organism. They study the parts that make up organisms such as cells, or bones and organs such as the heart or the leaves of plants. They also study populations of organisms to see how they share the environment and live together.

Some biologists specialise in describing and naming new organisms that are discovered. They are called taxonomists. Taxonomy is becoming an important part of biology in the 21st century as it is necessary to have descriptions of organisms, and their life cycles if we are to prevent them from dying out. It also helps us understand how they fit into their ecosystem (the place where they live).

Biologists that study fossils are called palaeontologists. They study not only the bones of prehistoric animals but the footprints of animals or impressions of leaves or soft-bodied animals. Palaeontologists can help date rocks, work out past climates or construct ancient ecosystems.

All living things evolve or change their shape and behaviour over long stretches of time. Evolution is central to biology. It links all the areas that biologists study. Anthropologists are biologists who study the evolution of Man. Man is part of a group of animals called Primates. Monkeys and Orang-utans are typical primates. We have evolved from a primate; anthropologists are trying to find out which one.

Did you know?

A biologist studies biology; a zoologist studies zoology; a microbiological studies microbiology; a geneticist studies genetics and an ecologist studies ecology.

Remember

Biology is the scientific study of living things

Remember

Remember at least three areas studied by biologists.

Key Terms

ZOOLOGY
BOTANY
TAXONOMIST
PALAEONTOLOGIST
ANTHROPOLOGIST
ONCOLOGIST
PHYSIOLOGIST
ECOLOGIST
GENETICS
ECOLOGY
MICRBIOLOGY
MOLECULAR BIOLOGY
BIOMOLECULES
SCIENTIFIC

Figure 1.1
This photograph is of a fossil fern that is over 350 million years old. Palaeontologists are biologists that study fossils. Palaeontologists can use fossils like this to date rocks and work out the type of habitat the organism lived in.

Figure 1.2
Botanists specialise in studying plants. Not all plants have green leaves. This photograph shows the leaves of Sundew, a plant that grows in Irish bogs and catches insects using a sticky glue on tentacles. The scientific name for this plant is *Drosera rotundifolia*.

Figure 1.3
This group of botanists are recording and mapping the distribution of plants in an ecosystem called a machair. Some are using a hand lens. The data is then transferred to a computer where maps are created. This will help the biologists to understand how a machair ecosystem works.

Biologists that study cancer are called oncologists. Cancer seems to arise naturally in the cells of some animals. However cancer is much more common in areas of the environment that are polluted; it is more common in people who smoke or in white people who expose their unprotected skin to the sun. Oncologists try to understand why this is so, and look for cures by examining cells in great detail.

Zoologists study animals; botanists study plants. Microbiologists study very small organisms such as bactertia and viruses. Biologists who study the bodily functions of organisms are called physiologists. For example, a physiologist would try to figure out why some animals can live in deserts with very little available water, while others would die there; or they study the stress the kidneys or heart undergo during exercise. Physiology helps ecologists understand how and why animals like one particular habitat over another.

E. O. Wilson is a well know biologist. He has said that the 21st century will be known as the Age of the Environment because it is the time when Man must understand and respect the environment. If we do, we can live in harmony with it for many more years; if we don't then we will kill the environment and we too will die because of this. Regardless of how we behave, it will be known as the Age of the Environment! Biologists that study the environment are called ecologists. Ecology is the study of the relationships between plants, animals and the physical world around them.

The Importance of Biology for you

This might be the only biology course you ever study. If that is so then it is very important to help you understand the world you live in. You are a biological organism that takes in oxygen and food from the planet and returns carbon dioxide and waste material to it. This biology course will help you understand this in greater detail. It will help you understand many issues in newspapers, magazines on the television and radio that relate to the living world and environmental issues.

If you are going to study further you will need biology for medicine, pharmaceutics, dentistry, agriculture and veterinary studies. If you want to be an environmental scientist, a food scientist or molecular biologists, then biology is your primary area of study.

1.02: Scientific And Non-Scientific Ways Of Thinking

It is possible to study the natural world both in a scientific and a non-scientific way. Take, for example the night sky.

The astrologers view of the starry sky

If you read your 'stars' in the newspaper you are reading the work of an astrologer. To the astrologer the night sky can predict or help map out events in our lives. They use the positions and motions of the planets and stars to do this. The rules astrologers follow were set down a long time ago and are never challenged, tested or modified by present day astrologers. They are simply a*ccepted and passed on from one generation of astrologers to the next.*

Did you know?

Observation is the first step in the scientific method. Many instruments have been developed, for example, to help us observe things that we normally cannot see. The microscope allows us to see very small objects while xrays enable us to see internal body parts.

The astronomers view of the starry sky

To the astronomer the same night sky makes sense in a different way. They try to work out the composition of stars or the atmosphere of nearby planets. Astronomers make statements, rules and laws about what they see. They are *continually updating their observations to gain more accurate data and information.*

Why is astronomy considered to be scientific?

Astronomy is considered to be a science subject because:

Information (data) is continually collected and the laws of astronomy are updated to explain the new observations.

Did you know?

Biology is one of the most important sciences of the 21st century.

This means that science is a *process*: it continually proceeds or develops by making observations.

All science subjects do this. Scientists develop instruments such as microscopes and telescopes, to help us make better and more accurate observations about the world.

Why is Astrology considered to be Non-scientific?

Astrology is considered to be a non-scientific subject because:

1/ It just accepts the information it has about the sky or about its own rules. It stays with the same rules generation after generation. It is not interested in collecting new data about the sky and rewriting its rules.

2/ It is unchanging: it is not a process. Astrology does not proceed.

Remember

Science is a process. Non-science is not a process.

For example, astrologers are not interested in knowing whether their predictions were really correct or not. There is no process of development involved.

Biologists use the scientific method to study the living world. The next few pages explain how the scientific method works.

1.03: How Scientists Seek Knowledge - The Scientific Method?

So what method does science use to explain the world around us? When a scientist is looking for new knowledge, he/she will generally follow four steps.

1/ Question-Observation Stage - this stage may begin with a simple observation (the sky is blue) and then progress to a question (why is the sky blue?). The question will lead to some speculation or hypothesis.

2/ Hypothesis Stage - this is basically a story used to fit or explain an observation (the sky is blue because....)

3/ Experiment Stage - the experiment is carried out to test the hypothesis. This requires more detailed observation.

4/ Theory Stage - if the hypothesis (story) is not shown to be false after many different types of experiments and observations, then it may be called a theory.

These four steps describe the scientific method. If a scientist is happy with stages 1, 2 and 3 above and he/she thinks the rest of the scientific world should know about it, then a report or scientific paper is written about it and published in a journal such as Nature.

A famous example of the scientific method in action

There was an outbreak of cholera in Soho in London in 1854. It was not known how cholera spread, or that it was due to dirty water. A doctor named John Snow used the scientific method to try and stop the cholera. He plotted all the cholera outbreaks on a map of London. He then made some observations and proposed a hypothesis, which he tested.

First observation: he noticed that most of the cholera outbreaks were near a water pump in Broadwick Street; he also observed that cholera affected the digestive tract (victims got diarrhoea and died).

Second observation: he interviewed the people who lived on the street (collected data) and discovered that all the cholera victims had drunk from the pump. He also discovered that visitors to Broadwick Street who had drunk from the pump died. People nearby who drank beer instead of water did not get cholera.

Hypothesis: he suggested that the cholera was picked up from the water in the pump in Broadwick Street.

Experiment: He blocked off the pump by removing its handle.

Result: The cholera epmidemic died out.

This hypothesis was taken to be correct. It was applied to similar outbreaks of cholera around the world and saved millions of lives.

Memonomic

QUESTION
HYPOTHESIS
EXPERIMENT
THEORY

QHET - QUIT HOME ET

Think about this

Observation: ' the moon looks as though its made of cheese'.
Hypothesis: ' the moon is made of cheese'.
Experiment: ' a man is sent to the moon (1969) to taste the cheese'.
Result: ' he discovers it is not made from cheese at all'.
So the hypothesis was wrong. Try another hypothesis.

Beware !

A hypothesis is a 'story' used to explain the observations. A hypothesis may not be true. You must test it by doing an experiment.

Did you know?

It is a natural human trait to observe and hypothesise. Watch it in your own behaviour.

1.04: A Bit More Detail About The Scientific Method

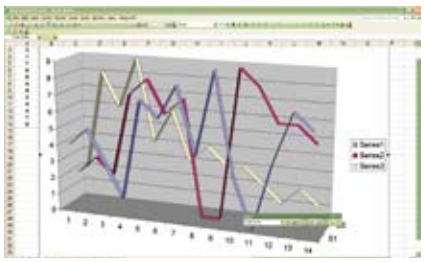


Figure 1.4
Data is often turned into maps (GIS - Geographical Information System) or graphs to help scientists see patterns more easily than just looking at the numbers. Computers are used to create the maps (using GIS software) or graphs (using spreadsheets).

Figure 1.5
The scientific method depends on being able to make measurements. Measurement removes bias and helps scientists unravel the laws of nature. Without measurement, the natural world cannot be described accurately. In Holland people say meten is weten'; measuring is knowing.

The Question-Observation Stage

Sometimes a scientist will just ask a question while musing or making an observation. Some observations are made with the help of instruments that expand our senses. For example, microscopes (electron and light) allow us to observe very small organisms. Biologists who study bats use instruments that pick up sounds that bats make, that the human ear cannot hear. Cameras help us to see things that happen too quickly for us to observe with the naked eye.

The Hypothesis Stage

The hypothesis used to explain observations often relies on or uses knowledge the scientist already has. This can sometimes be a hindrance, as what we know can often stop us from thinking of something new.

The Experiment Stage - include a control experiment

An experiment can be set up to (i) try and make further detailed observations or to try and *disprove* a hypothesis. Designing a really good experiment is the sign of a great scientist. The *experiment is the most important stage* in the scientific method. Non-scientists do not use experiments as a tool to help them.

Control Experiment

As part of the experiment design a good *control experiment* must also be used. See the control experiment later in this chapter.

Collect Data - collect large samples randomly and remove bias

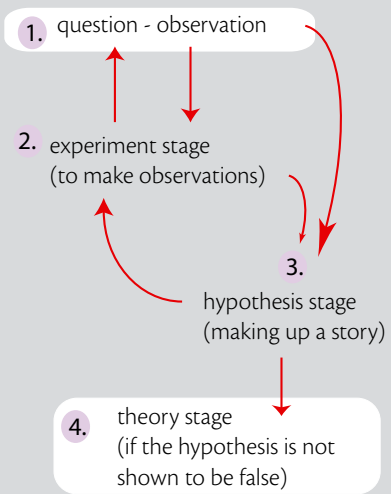
Experiments need data to disprove a hypothesis. Data has to be collected from a sufficiently large sample. The more data the better. Imagine you want to estimate the number of daisies in an area of 1 square kilometre. It is unlikely you would get an accurate estimate if you used a 1 metre square clump of daisies to estimate the number in a square kilometre. There are two reason why the sample you took is not scientifically valid: (a) the sample was selected consciously so it is biased and (b) the sample is too small. A good estimate requires random samples.

Data must also be collected without *bias*. One of the best ways to remove bias is to use numbers. For example, it is better to say it is 2°C than it is 'very cold'. Some people might say 'its a bit chilly' or 'its a nice frosty morning'. These are too subjective; they depend on how you feel. To remove bias in estimating the number of daisies you should randomly select many 1 square metre areas. The more samples you collect the more accurate your total estimate.

Interpreting Data and Reaching Conclusions

This is the time when scientists show their true creativity and independence of thought. Again it is important not to be biased. Often a 'hunch' can lead to

SUMMARY OF THE SCIENTIFIC METHOD



a good interpretation. Other scientists may knock your interpretation of the data if they think your experiment was not good enough.

After looking at the data, a scientist may conclude that a new experiment must be set up (stage 3 again) or perhaps a new hypothesis needs to be developed (stage 2 again). If the conclusion is that the original hypothesis is correct then the scientist must see how it fits in with existing knowledge (the knowledge other scientists have about the subject).

Placing the Conclusions with Existing Knowledge

Even if a scientists concludes that the hypothesis is correct, it may not be accepted by other scientists if it does not fit in with existing data and knowledge. Sometimes a brilliant hypothesis is rejected because of this. However it can also lead to scientists looking at how good their knowledge is in other areas. If the hypothesis fits in well with other knowledge, then it is often accepted and welcomed by scientists immediately.

Reporting and Publishing the Results

It is important that the scientist reports the hypothesis, experiment and conclusions to other scientists. This is done by publishing the work in a *scientific journal* that is accessible to all other scientists. The report should contain enough detail to allow other scientists to repeat exactly that which is described in the report. This includes all references to other scientists work. One of the worlds most important journals for biologists is 'Nature'. In Ireland scientists often publish their work in the 'Proceedings of the Royal Irish Academy'. There are thousands of specialised Journals available for scientists on the Internet.

Development of Theories and Principles

If a hypothesis seems to be true after many different types of experiments have been carried out to try and disprove it then it can be called a *theory*. Think of a theory as a grown-up or mature hypothesis. Theories often explain many other hypotheses. Some important theories in biology are the *theory of evolution*: the *theory of biogenesis*: the *cell theory*. The theory of evolution explains many hypotheses such as how evolution takes place, how biodiversity arose and why fossils are different than organisms alive today.

What is a Scientific Principle?

The term 'principle' is not used in biology; it is used mainly in physics. Principles are basic statements that scientists make about how nature works. They are often named after the person who discovered them. For example, there is Doppler's Principle. Principles are sometimes called 'laws of nature'. There is Boyle's Law. In biology the word 'law' is rarely used. Later in this text you will learn about Mendel's Laws (see Genetics). Principles or laws do not arise from theories, in

Remember

A theory is a mature hypothesis. When many vain attempts have been made to disprove a hypothesis, it becomes a theory.

Did you know?

Life cannot arise from non living things. Life comes from life. This is known as the theory of biogenesis.

Definition

A scientific principle is a basic statement about nature such as 'genes never blend, they always remain separate from each other. Principles are sometimes called 'laws'. They are usually named after the person who spotted them in nature.

1.05: What Are The Scientific Method's Limitations?

If something cannot be studied using the scientific method then it will not be studied by scientists. What sort of things cannot be studied scientifically? Science deals with what our senses tell us about the world. Also, if it can be observed, it must be observable more than once; this is called repeatability (can you show us the pink elephant you saw?).

These restrictions (use of the senses and difficulty of repeatable observations) limit science. There are many ideas that we have about the world that cannot be studied using the scientific method. This does not mean that these areas do not have any value; on the contrary, they are often the most important areas in our everyday lives. Here are some problems the scientific method does not help us with.

Does God exist?

Many people believe in God. Many people deny that a God exists at all and others will say they don't know what to believe. The scientific method cannot help any of these people to confirm or deny their belief.

The study of God is outside the scientific method. To a scientist the existence of God is a hypothesis and there is no known experiment to prove or disprove the hypothesis. People's belief or disbelief in God is an act of faith.

Science deals only with hypothesis and not truth

Truth is unchanging. The scientific method is a process. In other words science is always open to changing its hypothesis and theories about the world. This means that the scientific method cannot deal with truth (if you believe that truth is unchanging). Truth is often based on a religious or cultural belief.

The fact that a rabbit can run faster than a tortoise is true. However it is not necessarly true to say that a rabbit can beat a tortoise in a running race; a scientist could hypothesise that the rabbit will always win, but the day the tortoise wins disproves the hypothesis (i.e., the hypothesis is proven false).

Moral decisions cannot be made using the scientific method

The scientific method cannot to applied to a problem which helps you make a correct moral decision. It cannot help you to decide whether something is good or bad. However the scientific method may reveal something about the world that will present us with a moral problem. For example the discovery of how AIDS is transmitted has caused many people to face moral decisions about their behaviour.

Value judgements cannot be made using the scientific method

A value judgement is a decision about the value of something. For example, a piece of music may be considered good or bad. This is a value judgement about the music. The scientific method cannot decide for you whether the music is indeed good or bad. Human values such as beauty, happiness, love and justice cannot be examined using science.

It was done on purpose!

Does Man exist for a purpose? What is the purpose of evolution? What is the purpose of existence? The scientific method will not help you answer any of these questions.

Some religions say the purpose of something is to serve God. This is a hypothesis. The Catholic Church hypothesises that all the animals of the Earth were created for Man's benefit. Through the Ages this has lead people to abuse animals and treat them as objects unworthy of respect.

1.06: Limitations Of The Value Of The Scientific Method

The value of the scientific method is limited by:

Figure 1.6
The study of God is outside the scientific method although the same logic used by scientists is used by theologians to 'prove' some religious beliefs.

The extent of our own basic knowledge

Observations that scientists make are based on their current scientific knowledge and on the limitations of the instruments they use. Questions are also based on the knowledge that scientists have. So the level of knowledge that science has is in itself a limitation. If you know very little about how a car works, then the number of questions you can ask about the car is limited. Similarly, the more you know the more you can observe/question.

The basis of investigation

This means that the scientific experiment must be set up to investigate a specific hypothesis. This is a very difficult thing to do. All great scientists are able to set up experiments to accurately investigate their hypothesis. Because the scientific method requires you to experiment, then not being able to set up an experiment limits scientific knowledge.

Our ability to interpret results

This is a limitation because interpretation depends on what we know already through using the scientific method! It is easy to misinterpret data. Misinterpreted data can have a worse affect on the progress of science than no data at all. The scientific method is therefore limited by how we interpret data from experiments. The less knowledge we have the more difficult it is to interpret results.

Sometimes scientists have 'fiddled' their data to make it easy to understand. This also holds back science.

Figure 1.7
The scientific method cannot help us to decide whether a work of art is good or bad. Many philosophers have looked at art that is generally thought to be beautiful and tried to work out the rules that make it beautiful. This study is called aesthetics. Aesthetics, like most philosophical ideas, fails in its objectives.

Its application to the continually changing natural world

The scientific method turns up new knowledge and hypotheses about the living world. The living world is continually changing (think of the present day problems with antibiotics), so the scientific method must be applied again and again to keep up with it. In this way the scientific method is limited; it does not provide us with absolute truth about the living world, only with a 'working truth' that helps use understand the world at the moment.

Accidental discoveries

Many great breakthroughs in science have occurred accidentally without the direct intervention of the scientific method. For example, Gregor Mendel was lucky to choose pea plants and traits such as pea shape and plant height; if he had not used these traits he probably would not have spotted the 'laws'. Alexander Fleming probably would not have discovered penicillin if he had not noticed a strange pattern in a mouldy petri disk he was just about to throw in the bin.

Questions - Now Its Your Turn

Q 01. Write down two definitions of the term 'biology'. Which definition is more accurate? Give a reason for your answer.

Q 02. Name five areas studied by biologists and explain three of them. If you were to be a biologist, which area would interest you? Explain why.

Q 03. If you were the leader of a expedition to explore the living organisms on a newly discovered island, which type of biologists would you take with you? Explain why.

Q 04. What is meant by the phrase 'the scientific method'? Name four stages of the scientific method.

Q 05. Name two differences between the scientific and non-scientific study of nature. Explain one difference in detail.

Q 06. What is a hypothesis? Give an everyday example of a hypothesis.

Q 07. At which stage of the scientific method is a hypothesis tested? Write a short note about that stage.

Q 08. Explain the phrase' science is a process'.

Q 09. Why does a scientist collect data? Explain how the collection of data lead to the discovery that cholera can be contracted from water.

Q 10. If you were a scientist, which stage of the scientific method would interest you most? Explain why.

Q 11. Some people say that the first stage of the scientific method is to ask a question; some people say it always starts with an observation. Which do you think it is? Would you prefer the first stage to stay with the title 'Question-Observation Stage' as it is in this book? Explain your thoughts.

Q 12. Explain the word 'bias'. How do scientists remove bias from their work? Give three examples of bias and state how this bias could be removed.

Q 13. Name two stages in the scientific method where scientific instruments can be used. Name the instruments and explain why they could be used.

Q 14. Why would a scientist set up an experiment? Explain what a control experiment is.

Q 15. What do scientists use scientific journals for? Name one Irish scientific journal.

Q 16. Write a brief note on each of the following: data collection, interpreting the data and reaching conclusions.

Q 17. List three limitations of the scientific method. Write a brief note on any two.

Q 18. What is a value judgement? Is science useful in making value judgements? Say why.

Q 19. Why is the study of God outside of the scientific method? Name something else that is commonly discussed in today's society that not helped by the scientific method.

Q 20. Write a note on each of the following: (a) repeatability in science (b) using instruments to extend our senses (c) hypothesis (e) scientific journals.

Q 21. Name two theories. Explain the difference between a theory and a hypothesis.

Q 22. Write a short note to explain each of the following terms used in the scientific method: (i) hypothesis (ii) control experiment (iii) data (iv) repeatability or replicate (v) theory.