Reading: The Scientific Method

In this lesson you will be learning about:

- Biology as the Study of Life
- The Characteristics of Life
- The Hierarchy of Life
- Science and the Scientific Method

Science

Many of us enjoy exploring, and seek to understand the world around us. Science arose from this curiosity. Science is a search for knowledge based on experimentation and observation.

Are Life Sciences?

Life Science is a broad field, covering the minute workings of chemical machines inside our cells, to broad scale concepts such as ecosystems and global climate change.

Branches of Life Science

There are many branches or specialties under the general study of Life Sciences. Taxonomy, microbiology, mycology, botany, ecology, and zoology are a few of the branches we will be covering in this course.

Specialties

These branches can be further divided into more specialized branches. For example, a zoologist studies animals but can specialize in entomology (insects), ichthyology (fish), ornithology (birds), herpetology (reptiles & amphibians), mammology (mammals), parasitology (parasites), etc.

Characteristics of Life

Biology is the study of living things, or organisms. But how do we decide whether something is living or not? It is generally agreed that all living things share the following characteristics:

1. Cells

All organisms are composed of cells. It is the fundamental unit of life. Unicellular organisms include bacteria and protists. Multicellular organisms include fungi, plants and animals. Living things (cells) arise only from other living things (Biogenesis).

2. Growth and Development

May involve an increase in size (unicellular organisms) or an increase in the number and specialization of cells (multicellular organisms).

3. Universal Genetic Code

Living things grow and develop according to a genetic „plan" encoded in their DNA. Copying of genetic information allows for passing on of traits to offspring.

4. Reproduction

All organisms produce new organisms, either by asexual or sexual means. Asexual reproduction involves a single organism producing offspring genetically identical to itself. Sexual reproduction involves uniting two cells from different parents to produce genetically unique offspring.

5. Metabolism and Use of Energy

Metabolism refers to the sum of all chemical reactions that enable an organism to maintain itself, grow and reproduce. In order for these reactions to occur, they require a constant input of matter and energy.

6. Response to Environment

Living systems respond and interact with their environment and are interdependent with other systems. Living thing exist in a complex balance with other living things and their environment.

7. Homeostasis

Organisms maintain an internal environment within a normal range through their regulatory mechanisms and behaviour.

8. Change Over Time (Evolution)

Evolution explains the unity and diversity of life.

- Unity: Living systems change through time and share common ancestry.
- Diversity: Evolution has produced diverse living systems on earth.

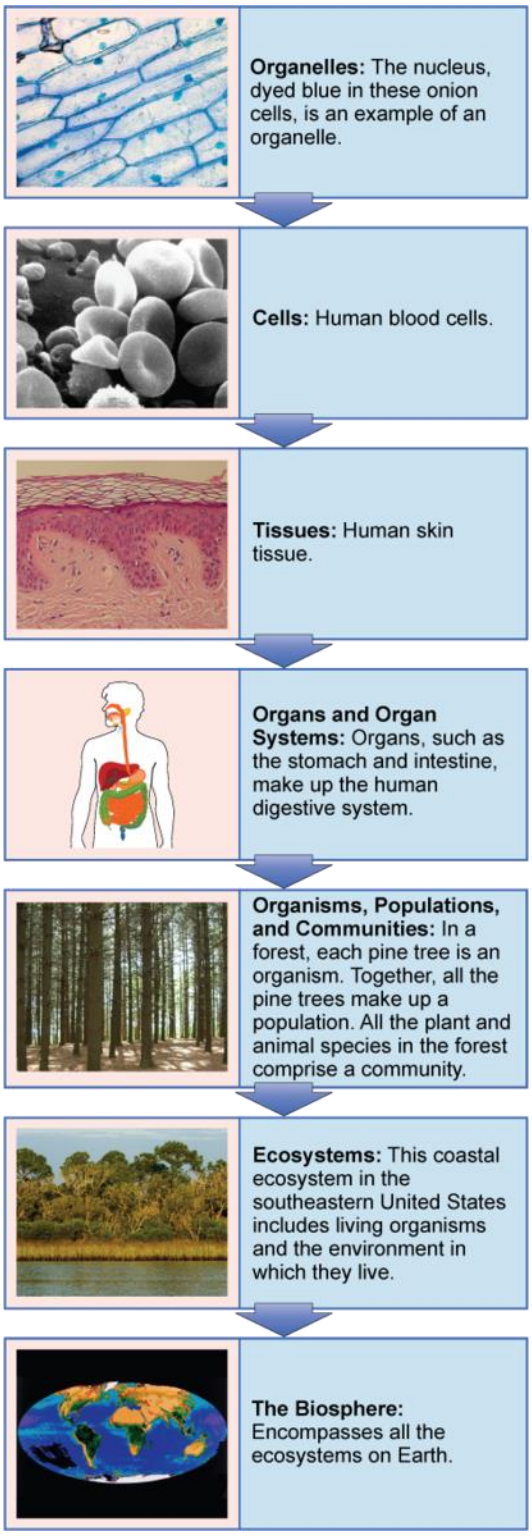
Living or not?

Some organisms exist on the border between living and non-living things (i.e. viruses). Other organisms, although clearly living, are difficult to classify further into groups.

The Hierarchical Organization of Living Things

Life is organized into a hierarchy of distinct levels starting with the smallest unit of life, cells, to the biosphere in which we live.

The diagram below shows the organizational level, and gives examples of what might fit into that level.



The Scientific Method

The scientific method is simply an organized way of figuring something out. It consists of several steps:

1. Observing

2. Stating a problem/asking a question

3. Forming a Hypothesis

4. Testing the Hypothesis (Experimenting)

5. Recording and Analyzing Data

6. Forming a Conclusion

Observations

The scientific method begins with a simple observation. For example: “Leaves change color in the fall.” This observation might lead to the question: “Why do leaves change color in the fall?”

A note about observations:

Observations are made using the human senses - often with the help from technological devices, such as microscopes or telescopes. There are two types of observations - qualitative and quantitative.

Qualitative

Qualitative observations are descriptive (i.e. the object feels warm; the pencil is orange.

Quantitative

Quantitative observations are those that are measured and contain numbers (i.e. the object is 42o Celcius; the pencil is 4.7 cm in length).

Precision

Scientists prefer to use quantitative observations whenever possible because they are more precise.

A vernier caliper for accurately measuring lengths.

Back to our question: “Why do leaves change color in the fall?” Once we have the question, we can then proceed to gather information that helps us form a hypothesis.

Hypothesizing

A hypothesis is a possible explanation about some natural event. Once a hypothesis is made, an experiment is designed and performed to test the hypothesis. Making a hypothesis provides a focus for an experiment.

An Example of a Hypothesis

Going back to our example, one might hypothesize that leaves change color in the fall because of temperature changes. There are other possible factors that might affect leaf color, such as light levels, amount of rainfall, soil conditions etc., but in scientific experiments we test the effects of a single factor at a time.

Types of Variables

All of the factors in an experiment that can change are called variables. There are three types of variables to keep in mind when performing an experiment. The condition or factor that is changed (manipulated) by the experimenter is called the manipulated variable.

The variable that the experimenter wants to observe and measure, is called the responding variable. The responding variable is dependent on what is done to the manipulated variable. For this reason, the responding variable is sometimes called the dependent variable and the manipulated variable is sometimes called the independent variable.

Confused? Manipulated variable = Independent variable; responding variable = Dependent variable

Controlled variables

Any other factors (variables) that can influence the results of an experiment must be kept constant/same: these are called the controlled variables. Experiments where all conditions (variables) except one are kept the same are called controlled experiments.

Why?

So that any differences observed can be attributed to the manipulated variable alone. Control vs. experimental groups. Most experiments have a control or control group. The control goes through all of the steps of the experiment except the variable being tested i.e. it has not been manipulated. It serves as a basis of comparison with the experimental group or samples.

Control vs. experimental groups

In a study to determine the effects of caffeine on test performance, the control group would be the subjects that wrote the test but did not have any caffeine.

Back to our leaf example…

In the hypothesis relating temperature to leaf color, the temperature is the manipulated variable and the leaf color is the responding variable. Other factors such as light levels, amount of rainfall, soil conditions, etc. would be the controlled variables.

Another Example

In an experiment to determine „How different fertilizers affect plant growth", the type of fertilizer would be the manipulated variable, the growth rate of the plants would be the responding variable, and all the other variables, such as light, temperature, watering, soil, etc. would be the controlled variables.

Measuring Variables

In science, the manipulated and responding variables must be stated in terms that are clear, precise and measurable (quantitatively). Temperature can be measured quantitatively, but it is difficult to measure leaf color. Instead, one could measure the number of leaves that fall, as this is directly related to leaf color. In this case the variables are stated in very clear, precise and measurable terms. Now we must revisit our hypothesis.

Restating our Hypothesis

Our original hypothesis was : "Leaf color changes in the fall are related to temperature changes." In a correctly formulated hypothesis one must state exactly how the manipulated variable will affect the responding variable---often the terms increase and decrease are used because they are measurable. Our new and improved hypothesis might be: "If the temperature decreases, then the number of leaves that fall will increase." The use of an "If…then…" statement when formulating a hypothesis is a scientific convention.

Summary: Steps for writing a Hypothesis

I. Identify the variables in a given event
II. Identify the manipulated and responding variables
III. Write the hypothesis relating the manipulated variable to the responding variable in an

"If…then.." statement. (Example: If the [manipulated variable] increases, then the [responding variable] will decrease.)

Collecting and Analyzing Data

The data collected is the exact number of leaves that fall at different temperatures. This type of data is often recorded in a data table. Analysis of the data would indicate the extent to which the number of leaves that fall is related to temperature. When graphing your data, the manipulated variable appears on the x-axis and the responding variable will appear on the y-axis.

Forming a Conclusion

Analysis of the data allows the experimenter to decide whether it supports or refutes the hypothesis. We call this forming a conclusion. If the hypothesis is rejected, then we must come up with a new hypothesis, devise an experiment to test it, and so on…

Summary The scientific method is a circular process in that new observations inevitably lead to new questions.

Scientific Facts

As soon as a hypothesis fails to agree with scientific observations, it is modified or discarded. A hypothesis that consistently holds true after repeated experimentation and observations becomes scientific fact.

Laws and Theories

A scientific law is a collection of facts, and a scientific theory is a collection of scientific laws. The biggest difference between a law and a theory is that a theory is much more complex and dynamic. A law governs a single action, whereas a theory explains a whole series of related phenomena.

Scientific Knowledge

Scientific laws and theories are continually tested in an attempt to prove them WRONG. Some pass some fail. Scientific knowledge, therefore, is dynamic, NOT a collection of cold, hard facts.

More on this…

If you would like to see more examples of the scientific method in action, try this link: Overview of the Scientific Method