Chapter 1

Foundations of Life Science

1.1 Lesson 1.1: Nature of Science

Lesson Objectives

- List the principles that should guide scientific research.
- Examine a scientist's view of the world.
- Outline a set of steps that might be used in the scientific method of investigating a problem.
- Explain why a control group is used in an experiment.
- Outline the role that reasoning plays in examining hypotheses.
- Examine the function of the independent variable in an experiment.
- Define what is meant by a theory and compare this to the meaning of hypothesis.

Introduction

The goal of science is to learn how nature works by observing the physical world, and to understand it through research and experimentation. Science is a distinctive way of learning about the natural world through observation, inquiry, formulating and testing hypotheses, gathering and analyzing data, and reporting and evaluating findings. We are all part of an amazing and mysterious phenomenon called "Life" that thousands of scientists everyday are trying to better explain. And it's surprisingly easy to become part of this great discovery! All you need is your natural curiosity and an understanding of how people use the process of science to learn about the world.

Goals of Science

Science involves objective, logical, and repeatable attempts to understand the principles and forces working in the natural universe. Science is from the Latin word, *scientia,* which means "knowledge." Good science is an ongoing process of testing and evaluation. One of the intended benefits for students taking a biology course is that they will become more familiar with the scientific process.

Humans are naturally interested in the world we live in. Young children constantly ask "why" questions. Science is a way to get some of those "whys" answered. When we shop for groceries, we are carrying out a kind of scientific experiment (**Figure** 11.1). If you like Brand X of salad dressing, and Brand Y is on sale, perhaps you try Brand Y. If you like Y you may buy it again even when it is not on sale. If you did not like Brand Y, then no sale will get you to try it again. To find out *why* a person makes a particular purchasing choice, you might examine the cost, ingredient list, or packaging of the two salad dressings.

Figure 1.1: Shopping sometimes involves a little scientific experimentation. You are interested in inventing a new type of salad that you can pack for lunch. You might buy a vegetable or salad dressing that you have not eaten before, to discover if you like it. If you like it, you will probably buy it again. That is a type of experiment. (44)

There are many different areas of science, or *scientific disciplines*, but all scientific study involves:

- asking questions
- making observations
- relying on evidence to form conclusions

- being skeptical about ideas or results

Skepticism is an attitude of doubt about the truthfulness of claims that lack empirical evidence. **Scientific skepticism,** also referred to as skeptical inquiry, questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes. Scientific skepticism uses critical thinking to analyze such claims and opposes claims which lack scientific evidence.

A Scientific View of the World

Science is based on the analysis of things that humans can observe either by themselves through their senses, or by using special equipment. Science therefore cannot explain anything about the natural world that is beyond what is observable by current means. The term *supernatural* refers to entities, events, or powers regarded as being beyond nature, in that such things cannot be explained by scientific means. They are not measurable or observable in the same way the natural world is, and so considered to be outside the realm of scientific examination.

When a natural occurrence which was once considered supernatural is understood in the terms of natural causes and consequences, it has a scientific explanation. For example, the flickering lights sometimes seen hovering over damp ground on still evenings or nights are commonly called *Will-o'-the-wisp.* This phenomena looks like a lamp or flame, and is sometimes said to move away if approached. A great deal of folklore surrounds the legend, such as the belief that the lights are lost souls or fairies attempting to lead travelers astray. However, science has offered several potential explanations for Will-o'-the-wisp from burning marsh gases to glowing fungi or animals that glow in a similar way to lightning bugs.

There is no fixed set of steps that scientists always follow and there is no single path that leads to scientific knowledge. There are, however, certain features of science that give it a very specific way of investigating something. You do not have to be a professional scientist to think like a scientist. Everyone, including you, can use certain features of scientific thinking to think critically about issues and situations in everyday life.

Science assumes that the universe is a vast single system in which the basic rules are the same, and thus nature, and what happens in nature, can be understood. Things that are learned from studying one part of the universe can be applied to other parts of the universe. For example, the same principles of motion and gravitation that explain the motion of falling objects on Earth also explain the orbit of the planets around the sun, and galaxies, as shown in **Figure** 1.2. As discussed below, as more and more information and knowledge is collected and understood, scientific ideas can change, still scientific knowledge usually stands the test of time. Science, however, cannot answer all questions.

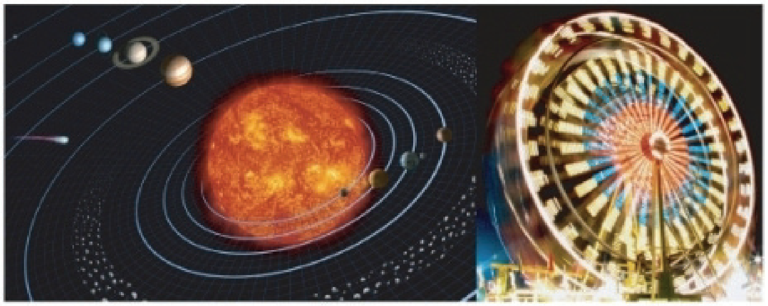

Figure 1.2: With some changes over the years, similar principles of motion have applied to different situations. The same scientific principles that help explain planetary orbits can be applied to the movement of a Ferris wheel. (55)

Nature Can Be Understood

Science presumes that events in the universe happen in patterns that can be understood by careful study. Scientists believe that through the use of the mind, and with the help of instruments that extend the human senses, people can discover patterns in all of nature that can help us understand the world and the universe.

Scientific Ideas Can Change

Science is a process for developing knowledge. Change in knowledge about the natural world is expected because new observations may challenge the existing understanding of nature. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving of theories goes on all the time. Scientists know that even if there is no way to gain complete knowledge about something, an increasingly accurate understanding of nature will develop over time.

The ability of scientists to make more accurate predictions about the natural world, from determining how a cancerous tumor develops a blood supply, to calculating the orbit of an asteroid, provides evidence that scientists are gaining an understanding of how the world works.

Scientific Knowledge Can Stand the Test of Time

Continuity and stability are as much characteristics of science as change is. Although scientists accept some uncertainty as part of nature, most scientific knowledge stands the test of time. A changing of ideas, rather than a complete rejection of the ideas, is the usual practice in science. Powerful ideas about nature tend to survive, grow more accurate and become more widely accepted.

For example, in developing the theory of relativity, Albert Einstein did not throw out Issac Newton's laws of motion but rather, he showed them to be only a small part of the bigger, cosmic picture. That is, the Newtonian laws of motion have limited use within our more general concept of the universe. For example, the National Aeronautics and Space Administration (NASA) uses the Newtonian laws of motion to calculate the flight paths of satellites and space vehicles.

Science Cannot Offer Answers to All Questions

There are many things that cannot be examined in a scientific way. There are, for instance, beliefs that cannot be proved or disproved, such as the existence of supernatural powers, supernatural beings, or the meaning of life. In other cases, a scientific approach to a question and a scientific answer may be rejected by people who hold to certain beliefs.

Scientists do not have the means to settle moral questions surrounding good and evil, or love and hate, although they can sometimes contribute to the discussion of such issues by identifying the likely reasons for certain actions by humans and the possible consequences of these actions.

Scientific Methods

It can be difficult sometimes to define research methods in a way that will clearly distinguish science from non-science. However, there is a set of core principles that make up the "bones" of scientific research. These principles are widely accepted within the scientific community and in academia.

We learned earlier in this lesson that there is no fixed set of steps that scientists always follow during an investigation. Similarly, there is no single path that leads scientists to knowledge. There are, however, certain features of science that give it a very specific way of investigating things.

Scientific investigations examine, gain new knowledge, or build on previous knowledge about phenomena. A **phenomenon**, is any occurrence that is observable, such as the burning match shown in **Figure** 1.3. A phenomenon may be a feature of matter, energy, or time. For example, Isaac Newton made observations of the phenomenon of the moon's orbit. Galileo Galilei made observations of phenomena related to swinging pendulums. Although procedures vary from one field of scientific inquiry to another, certain features distinguish scientific inquiry from other types of knowledge. **Scientific methods** are based on gathering observable, empirical (produced by experiment or observation), and measurable evidence that is critically evaluated.

A **hypothesis** is a suggested explanation based on evidence that can be tested by observation

Figure 1.3: The combustion of this match is an observable event and therefore a phenomenon. (49)

or experimentation. Experimenters may test and reject several hypotheses before solving a problem. A hypothesis must be testable; it gains credibility by being tested over and over again, and by surviving several attempts to prove it wrong.

Scientific Investigations

The scientific method is not a step by step, linear process. It is a way of learning about the world through the application of knowledge. Scientists must be able to have an idea of what the answer to an investigation is. Scientists will often make an observation and then form a hypothesis to explain why a phenomenon occurred. They use all of their knowledge and a bit of imagination in their journey of discovery.

Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses by experimentation, and analysis of the results that involves reasoning.

Scientific investigations begin with observations that lead to questions. We will use an everyday example to show what makes up a scientific investigation. Imagine that you walk into a room, and the room is dark.

- You observe that the room appears dark, and you question why the room is dark.
- In an attempt to find explanations to this phenomenon, you develop several different *hypotheses*. One hypothesis might state that the room does not have a light source at all. Another hypothesis might be that the lights are turned off. Still, another might be that the light bulb has burnt out. Worse yet, you could be going blind.
- To discover the answer, you experiment. You feel your way around the room and find a light switch and turn it on. No light. You repeat the experiment, flicking the switch back and forth; still nothing.
- This means your first two hypotheses, that the room is dark because (1) it does not have a light source; and (2) the lights are off, have been rejected.
- You think of more experiments to test your hypotheses, such as switching on a flashlight to prove that you are not blind.
- In order to accept your last remaining hypothesis as the answer, you could predict that changing the light bulb will fix the problem. If your predictions about this hypothesis succeed (changing the light bulb fixes the problem), the original hypothesis is valid and is accepted.
- However, in some cases, your predictions will not succeed (changing the light bulb does not fix the problem), and you will have to start over again with a new hypothesis. Perhaps there is a short circuit somewhere in the house, or the power might be out.

The general process of a scientific investigation is summed up in **Figure** 1.4.

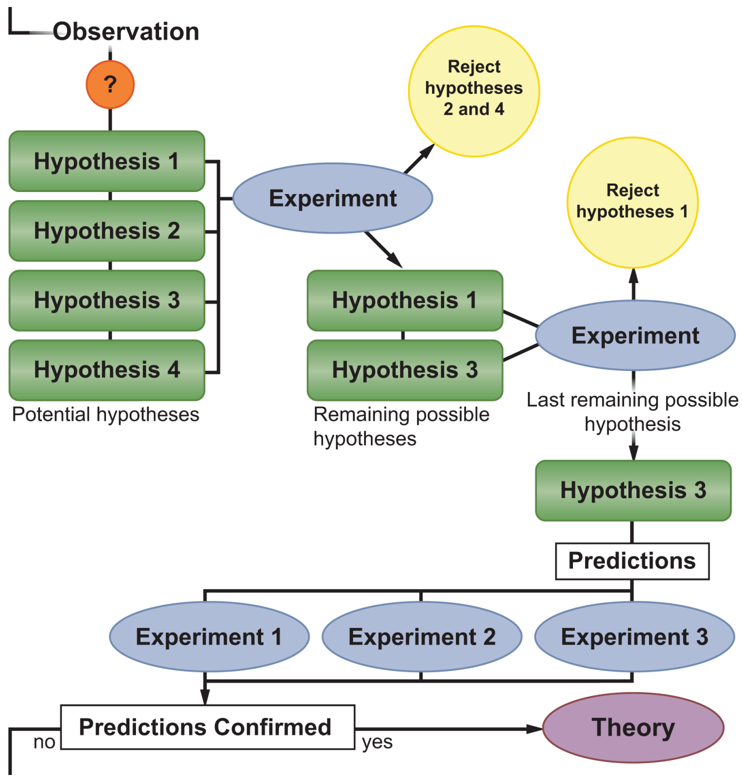

Figure 1.4: The general process of scientific investigations. A diagram that illustrates how scientific investigation moves from observation of phenomenon to a theory. The progress is not as straightforward as it looks in this diagram. Many times, every hypothesis is falsified which means the investigator will have to start over again. (53)

Table 1.1: **Common Terms Used in Scientific Investigations**

Term	Definition
Scientific Method	The process of scientific investigation.
Observation	The act of noting or detecting phenomenon by the senses. For example, taking measurements is a form of observation.
Hypotheses	A suggested explanation based on evidence that can be tested by observation or experimentation.
Scientific Reasoning	The process of looking for scientific reasons for observations.
Experiment	A test that is used to rule out a hypothesis or validate something already known.
Rejected Hypothesis	An explanation that is ruled out by experimentation.
Confirmed Hypothesis	An explanation that is **not** ruled out by repeated experimentation, and makes predictions that are shown to be true.
Inference	Developing new knowledge based upon old knowledge.
Theory	A widely accepted hypothesis that stands the test of time. Theories are often tested, and usually not rejected.

Making Observations

Scientists first make observations that raise questions. An **observation** is the act of noting or detecting phenomenon through the senses. For example, noting that a room is dark is an observation made through sight.

Developing Hypotheses

In order to explain the observed phenomenon, scientists develop a number of possible explanations, or *hypotheses.* A hypothesis is a suggested explanation for a phenomenon or a suggested explanation for a relationship between many phenomena. Hypotheses are always based on evidence that can be tested by observation or experimentation. Scientific investigations are required to test hypotheses. Scientists mostly base hypotheses on prior observations or on extensions of existing scientific explanations.

A hypothesis is not really an educated guess. To define a hypothesis as "an educated guess" is like calling a tricycle a ”vehicle with three.” The definition leaves out the concept’s most important and characteristic feature: the purpose of hypotheses. People generate hypotheses as early attempts to explain patterns observed in nature or to predict the outcomes of experiments. For example, in science, one could correctly call the following statement a hypothesis: identical twins can have different personalities because the environment influences personality.

Evaluating Hypotheses

Scientific methods require hypotheses that are falsifiable, that is, they must be framed in a way that allows other scientists to prove them false. Proving a hypothesis to be false is usually done by observation. However, confirming or failing to falsify a hypothesis does not necessarily mean the hypothesis is true.

For example, a person comes to a new country and observes only white sheep. This person might form the hypothesis: “All sheep in this country are white.” This statement can be called a hypothesis, because it is falsifiable - it can be tested and proved wrong; anyone could falsify the hypothesis by observing a single black sheep, shown in **Figure** 1.5. If the experimental uncertainties remain small (could the person reliably distinguish the observed black sheep from a goat or a small horse), and if the experimenter has correctly interpreted the hypothesis, finding a black sheep falsifies the ”only white sheep” hypothesis. However, you cannot call a failure to find non-white sheep as proof that no non-white sheep exist.

Figure 1.5: The statement “there are only white sheep in this country” is a scientific hypothesis because it is open to being falsified. However, a failure to see a black sheep will not necessarily falsify the hypothesis. (42)

Scientific Reasoning

Any useful hypothesis will allow predictions based on reasoning. Reasoning can be broken down into two categories: **deduction** and **induction**. Most reasoning in science is done through induction.

Deductive Reasoning (Deduction)

Deduction involves determining a single fact from a general statement; it is only as accurate as the statement.

For example, if the teacher said she checks homework every Monday, she will check homework next Monday.

Deductions are intended to have reasoning that is valid. The reasoning in this argument is valid, because there is no way in which the reasons 1 and 2, could be true and the conclusion, 3, be false:

- Reason 1: All humans are mortal.
- Reason 2: Albert Einstein is a human.
- Conclusion: Albert Einstein is mortal (**Figure** 1.6).

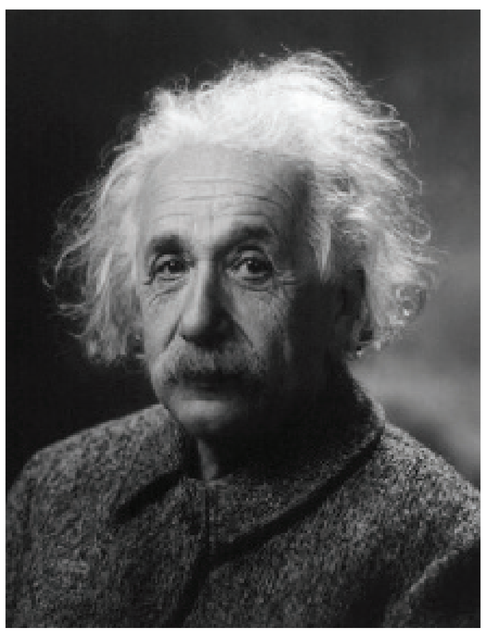

Figure 1.6: Albert Einstein (1879–1955) Deductive reasoning has helped us determine that Albert Einstein is a mortal being. (43)

Inductive Reasoning (Induction)

Induction involves determining a general statement that is very likely to be true, from several facts.

For example, if we have had a test every Tuesday for the past three months, we will have a test next Tuesday (and every Tuesday after that).

Induction contrasts strongly with deduction. Even in the best, or strongest, cases of induction, the truth of the reason does not guarantee the truth of the conclusion. Instead, the conclusion of an inductive argument is very likely to be true; you cannot be fully sure it is true because you are making a prediction that has yet to happen.

A classic example of inductive reasoning comes from the philosopher David Hume:

- Reason: The sun has risen in the east every morning up until now.
- Conclusion: The sun will also rise in the east tomorrow.

Inductive reasoning involves reaching conclusions about unobserved things on the basis of what has been observed already. Inferences about the past from present evidence, such as in archaeology, are induction. Induction could also be across outer space, as in astronomy, where conclusions about the whole universe are drawn from the limited number of things we are able to observe.

Experiments

A scientific experiment must have the following features:

- a control, so variables that could affect the outcome are reduced
- the variable being tested reflects the phenomenon being studied
- the variable can be measured accurately, to avoid experimental error
- the experiment must be reproducible.

An **experiment** is a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains. The experiment is a cornerstone in the scientific approach to gaining deeper knowledge about the physical world. Scientists use the principles of their hypothesis to make predictions, and then test them to see if their predictions are confirmed or rejected.

Scientific experiments involve **controls**, or subjects that are not tested during the investigation. In this way, a scientist limits the factors, or *variables* that can cause the results of an investigation to differ. A **variable** is a factor that can change over the course of an experiment. **Independent variables** are factors whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable). **Dependent variables** change in response to the independent variable. **Controlled variables** are also important to identify in experiments. They are the variables that are kept constant to prevent them from influencing the effect of the independent variable on the dependent variable.

For example, if you were to measure the effect that different amounts of fertilizer have on plant growth, the independent variable would be the amount of fertilizer used (the changing factor of the experiment). The dependent variables would be the growth in height and/or mass of the plant (the factors that are influenced in the experiment). The controlled variables include the type of plant, the type of fertilizer, the amount of sunlight the plant gets, the size of the pots you use. The controlled variables are controlled by you, otherwise they would influence the dependent variable.

In summary:

- The independent variable answers the question "What do I change?"
- The dependent variables answer the question "What do I observe?"
- The controlled variables answer the question "What do I keep the same?"

Experimental Design

Controlled Experiments

In an old joke, a person claims that they are snapping their fingers "to keep tigers away," and justifies their behavior by saying, "See, it works!" While this experiment does not falsify the hypothesis "snapping your fingers keeps tigers away," it does not support the hypothesis either, because not snapping your fingers will also keep tigers away. It also follows that not snapping your fingers will not cause tigers to suddenly appear (**Figure** 1.7).

To demonstrate a cause and effect hypothesis, an experiment must often show that, for example, a phenomenon occurs after a certain treatment is given to a subject, and that the phenomenon does not occur in the absence of the treatment.

One way of finding this out is to perform a controlled experiment. In a **controlled experiment,** two identical experiments are carried out side-by-side. In one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.

A controlled experiment generally compares the results obtained from an experimental sample against a control sample. The control sample is almost identical to the experimental sample except for the one variable whose effect is being tested. A good example would be a drug trial. The sample or group receiving the drug would be the experimental group, and the group receiving the placebo would be the control. A **placebo** is a form of medicine that

Figure 1.7: Are tigers really scared of snapping fingers, or is it more likely they are just not found in your neighborhood? Considering which of the hypotheses is more likely to be true can help you arrive at a valid answer. This principle, called **Occam's razor** states that the explanation for a phenomenon should make as few assumptions as possible. In this case, the hypothesis "there are no tigers in my neighborhood to begin with" is more likely, because it makes the least number of assumptions about the situation. (27)

does not contain the drug that is being tested.

Controlled experiments can be conducted when it is difficult to exactly control all the conditions in an experiment. In this case, the experiment begins by creating two or more sample groups that are similar in as many ways as possible, which means that both groups should respond in the same way if given the same treatment.

Once the groups have been formed, the experimenter tries to treat them identically except for the one variable that he or she wants to study (the independent variable). Usually neither the patients nor the doctor know which group receives the real drug, which serves to isolate the effects of the drug and allow the researchers to be sure the drug does work, and that the effects seen in the patients are not due to the patients believing they are getting better. This type of experiment is called a **double blind** experiment.

Controlled experiments can be carried out on many things other than people; some are even carried out in space! The wheat plants in **Figure** 1.8 are being grown in the International Space Station to study the effects of microgravity on plant growth. Researchers hope that one day enough plants could be grown during spaceflight to feed hungry astronauts and cosmonauts. The investigation also measured the amount of oxygen the plants can produce in the hope that plants could become a cheap and effective way to provide oxygen during space travel.

Figure 1.8: Spaceflight participant Anousheh Ansari holds a miniature wheat plant grown in the Zvezda Service Module of the International Space Station. (28)

Experiments Without Controls

The term **experiment** usually means a controlled experiment, but sometimes controlled experiments are difficult or impossible to do. In this case researchers carry out **natural**

experiments. When scientists conduct a study in nature instead of the more controlled environment of a lab setting, they cannot control variables such as sunlight, temperature, or moisture. Natural experiments therefore depend on the scientist's observations of the system under study rather than controlling just one or a few variables as happens in controlled experiments.

For a natural experiment, researchers attempt to collect data in such a way that the effects of all the variables can be determined, and where the effects of the variation remains fairly constant so that the effects of other factors can be determined. Natural experiments are a common research tool in areas of study where controlled experiments are difficult to carry out. Examples include: **astronomy** -the study of stars, planets, comets, galaxies and phenomena that originate outside Earth's atmosphere, **paleontology** - the study of prehistoric life forms through the examination of fossils, and **meteorology** - the study of Earth's atmosphere.

In astronomy it is impossible, when testing the hypothesis "suns are collapsed clouds of hydrogen", to start out with a giant cloud of hydrogen, and then carry out the experiment of waiting a few billion years for it to form a sun. However, by observing various clouds of hydrogen in various states of collapse, and other phenomena related to the hypothesis, such as the nebula shown in **Figure** 1.9, researchers can collect data they need to support (or maybe falsify) the hypothesis.

An early example of this type of experiment was the first verification in the 1600s that light does not travel from place to place instantaneously, but instead has a speed that can be measured. Observation of the appearance of the moons of Jupiter were slightly delayed when Jupiter was farther from Earth, as opposed to when Jupiter was closer to Earth. This phenomenon was used to demonstrate that the difference in the time of appearance of the moons was consistent with a measurable speed of light.

Natural Experiments

There are situations where it would be wrong or harmful to carry out an experiment. In these cases, scientists carry out a natural experiment, or an investigation without an experiment. For example, alcohol can cause developmental defects in fetuses, leading to mental and physical problems, through a condition called fetal alcohol syndrome.

Certain researchers want to study the effects of alcohol on fetal development, but it would be considered wrong or *unethical* to ask a group of pregnant women to drink alcohol to study its effects on their children. Instead, researchers carry out a natural experiment in which they study data that is gathered from mothers of children with fetal alcohol syndrome, or pregnant women who continue to drink alcohol during pregnancy. The researchers will try to reduce the number of variables in the study (such as the amount or type of alcohol consumed), which might affect their data. It is important to note that the researchers do not influence or encourage the consumption of alcohol; they collect this information from volunteers.

Figure 1.9: The Helix nebula, located about 700 light-years away in the constellation Aquarius, belongs to a class of objects called **planetary nebulae**. Planetary nebulae are the remains of stars that once looked a lot like our sun. When sun-like stars die, they puff out their outer gaseous layers. These layers are heated by the hot core of the dead star, called a white dwarf, and shine with infrared and visible colors. Scientists can study the birth and death of stars by analyzing the types of light that are emitted from nebulae. (50)

Field Experiments

Field experiments are so named to distinguish them from lab experiments. Field experiments have the advantage that observations are made in a natural setting rather than in a human-made laboratory environment. However, like natural experiments, field experiments can get contaminated, and conditions like the weather are not easy to control. Experimental conditions can be controlled with more precision and certainty in the lab.

Predictions

A **prediction** is a statement that tells what will happen under specific conditions. It can be expressed in the form: *If A is true, then B will also be true.* Predictions are based on confirmed hypotheses shown to be true or not proved to be false.

For researchers to be confident that their predictions will be useful and descriptive, their data must have as few errors as possible. **Accuracy** is the measure of how close a calculated or measured quantity is to its actual value. Accuracy is closely related to **precision**, also called reproducibility or repeatability. Reproducibility and repeatability of experiments are cornerstones of scientific methods. If no other researcher can reproduce or repeat the results of a certain study, then the results of the study will not be accepted as valid. Results are called valid only if they are both accurate and precise.

A useful tool to help explain the difference between accuracy and precision is a target, shown in **Figure** 1.10. In this analogy, repeated measurements are the arrows that are fired at a target. Accuracy describes the closeness of arrows to the bulls eye at the center. Arrows that hit closer to the bulls eye are more accurate. Arrows that are grouped together more tightly are more precise.

Experimental Error

An **error** is a boundary on the precision and accuracy of the result of a measurement. Some errors are caused by unpredictable changes in the measuring devices (such as balances, rulers, or calipers), but other errors can be caused by reading a measuring device incorrectly or by using broken or malfunctioning equipment. Such errors can have an impact on the reliability of the experiment's results; they affect the accuracy of measurements. For example, you use a balance to obtain the mass of a 100 gram block. Three measurements that you get are: 93.1 g, 92.0 g, and 91.8 g. The measurements are precise, as they are close together, but they are not accurate.

If the cause of the error can be identified, then it can usually be eliminated or minimized. Reducing the number of possible errors by careful measurement and using a large enough sample size to reduce the effect of errors will improve the reliability of your results.

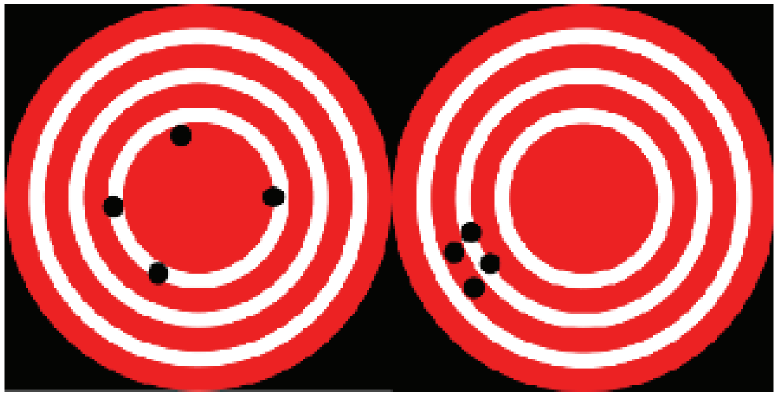

Figure 1.10: A visual analogy of accuracy and precision. Left target: High accuracy but low precision; Right target: low accuracy but high precision. The results of calculations or a measurement can be accurate but not precise; precise but not accurate; neither accurate nor precise; or accurate and precise. A collection of bulls eyes right around the center of the target would be both accurate and precise. (52)

Scientific Theories

Scientific theories are hypotheses which have stood up to repeated attempts at falsification and are thus supported by a great deal of data and evidence. Some well known biological theories include the theory of evolution by natural selection, the cell theory (the idea that all organisms are made of cells), and the germ theory of disease (the idea that certain microbes cause certain diseases). The scientific community holds that a greater amount of evidence supports these ideas than contradicts them, and so they are referred to as theories.

In every day use, people often use the word **theory** to describe a guess or an opinion. For example, "I have a theory as to why the light bulb is not working." When used in this common way, "theory" does not have to be based on facts, it does not have to be based on a true description of reality. This usage of the word theory often leads to a misconception that can be best summed up by the phrase "It's not a fact, it's only a theory." In such everyday usage, the word is most similar to the term hypothesis.

Scientific theories are the equivalent of what in everyday speech we would refer to as *facts*. In principle, scientific theories are always subject to corrections or inclusion in another, wider theory. As a general rule for use of the term, theories tend to deal with broader sets of phenomena than do hypotheses, which usually deal with much more specific sets of phenomena or specific applications of a theory.

Constructing Theories

In time, a confirmed hypothesis may become part of a theory or may grow to become a theory itself. Scientific hypotheses may be mathematical models. Sometimes they can be statements, stating that some particular instance of the phenomenon under examination has some characteristic and causal explanations. These theories have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic.

A hypothesis may predict the outcome of an experiment in a laboratory or the observation of a natural phenomenon. A hypothesis should also be falsifiable, and one cannot regard a hypothesis or a theory as scientific if it does not lend itself to being falsified, even in the future. To meet the "falsifiable" requirement, it must at least in principle be possible to make an observation that would disprove the hypothesis. A falsifiable hypothesis can greatly simplify the process of testing to determine whether the hypothesis can be proven to be false. Scientific methods rely heavily on the falsifiability of hypotheses by experimentation and observation in order to answer questions. Philosopher Karl Popper suggested that all scientific theories should be falsifiable; otherwise they could not be tested by experiment.

A **scientific theory** must meet the following requirements:

- it must be consistent with pre-existing theory in that the pre-existing theory has been experimentally verified, though it may often show a pre-existing theory to be wrong in an exact sense
- it must be supported by many strands of evidence rather than a single foundation, ensuring that it is probably a good approximation, if not totally correct.

Also, a theory is generally only taken seriously if it:

- allows for changes to be made as new data are discovered, rather than claiming absolute certainty.
- is the most straight forward explanation, and makes the fewest assumptions about a phenomenon (commonly called "passing the Occam's razor test").

This is true of such established theories as special relativity, general relativity, quantum mechanics, plate tectonics, and evolution. Theories considered scientific meet at least most, but ideally all, of these extra criteria.

In summary, to meet the status of a scientific theory, the theory must be falsifiable or testable. Examples of scientific theories in different areas of science include:

- **Astronomy**: Big Bang Theory
- **Biology**: Cell Theory; Theory of Evolution; Germ Theory of Disease
- **Chemistry**: Atomic Theory; Kinetic Theory of Gases

- **Physics**: General Relativity; Special Relativity; Theory of Relativity; Quantum Field Theory
- **Earth Science**: Giant Impact Theory; Plate Tectonics

Currently Unverifiable Theories

The term theory is sometimes stretched to refer to theoretical speculation which is currently unverifiable. Examples are string theory and various theories of everything. **String theory** is a model of physics, which predicts the existence of many more dimensions in the universe than the four dimensions that current science understands (length, width, height, and space-time). **A theory of everything** is a hypothetical theory in physics that fully explains and links together all known physical phenomena.

For a scientific theory to be valid it must be verified experimentally. Many parts of the string theory are currently untestable due to the large amount of energy that would be needed to carry out the necessary experiments as well as the high cost of conducting them. Therefore string theory may not be tested in the foreseeable future. Some scientists have asked if it even deserves to be called a scientific theory because it is not falsifiable.

Superseded Theories

A **superseded,** or obsolete, scientific theory is a theory that was once commonly accepted, but for whatever reason is no longer considered the most complete description of reality by mainstream science. It can also mean a falsifiable theory which has been shown to be false. Giraffes, shown in **Figure** 1.11, are often used in the explanation of Lamarck's superseded theory of evolution. In Lamarckism, a giraffe is able to lengthen its neck over its life time, for example by stretching to reach higher leaves. That giraffe will then have offspring with longer necks. The theory has been superseded by the understanding of natural selection on populations of organisms as the main means of evolution, not physical changes to a single organism over its lifetime.

Scientific Laws

Scientific laws are similar to scientific theories in that they are principles which can be used to predict the behavior of the natural world. Both scientific laws and scientific theories are typically well-supported by observations and/or experimental evidence. Usually scientific laws refer to rules for how nature will behave under certain conditions. Scientific theories are more overarching explanations of how nature works and why it exhibits certain characteristics.

A **physical law** or law of nature is a scientific generalization based on a sufficiently large number of empirical observations that it is taken as fully verified.

Figure 1.11: Superseded theories like Lamarck's theory of evolution are theories that are now considered obsolete and have been replaced by newer theories that have more evidence to support them; in Lamarck's case, his theory was replaced by Darwin's theory of evolution and natural selection, which will be discussed in the chapter on *Evolutionary Theory*. (14)

Isaac Newton's law of gravitation is a famous example of an established law that was later found not to be universal—it does not hold in experiments involving motion at speeds close to the speed of light or in close proximity of strong gravitational fields. Outside these conditions, Newton's laws remain an excellent model of motion and gravity.

Scientists never claim absolute knowledge of nature or the behavior of the subject of the field of study. A scientific theory is always open to falsification, if new evidence is presented. Even the most basic and fundamental theories may turn out to be imperfect if new observations are inconsistent with them. Critical to this process is making every relevant part of research publicly available. This allows peer review of published results, and it also allows ongoing reviews, repetition of experiments and observations by many different researchers. Only by meeting these expectations can it be determined how reliable the experimental results are for possible use by others.

Lesson Summary

- Scientific skepticism questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes. Scientific skepticism uses critical thinking to analyze such claims and opposes claims which lack scientific evidence.
- Science is based on the analysis of things that humans can observe either by themselves through their senses, or by using special equipment. Science therefore cannot explain anything about the natural world that is beyond what is observable by current means.

Supernatural things cannot be explained by scientific means.

- Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses by experimentation, and analysis of the results that involves reasoning.
- In a controlled experiment, two identical experiments are carried out side-by-side. In one of the experiments the independent variable being tested is used, in the other, the control, or the independent variable is not used.
- Any useful hypothesis will allow predictions based on reasoning. Reasoning can be broken down into two categories: deduction and induction. Most reasoning in science is formed through induction.
- A variable is a factor that can change over the course of an experiment. Independent variables are factors whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable). Dependent variables change in response to the independent variable.
- Scientific theories are hypotheses which have stood up to repeated attempts at falsification and are thus supported by much data and evidence.

Review Questions

1. What is the goal of science?
2. Distinguish between a hypothesis and a theory.
3. The makers of two types of plant fertilizers claim that their product grows plants the fastest and largest. Design an experiment that you could carry out to investigate the claims.
4. Identify how hypotheses and predictions are related.
5. What is the difference between the everyday term "theory" and the term "scientific theory?"
6. Identify two ways that scientists can test hypotheses.
7. Outline the difference between inductive and deductive reasoning.
8. What is the range of processes that scientists use to carry out a scientific investigation called?
9. To ensure that their results are not due to chance, scientists will usually carry out an experiment a number of times, a process called replication. A scientist has two types of plants and she wants to test which plant produces the most oxygen under sunny conditions outdoors. Devise a practical experimental approach, incorporating replication of the experiment.
10. In taking measurements, what is the difference between accuracy and precision?
11. Name two features that a hypothesis must have, to be called a scientific hypothesis.
12. Identify two features that a theory must have, to qualify as a scientific theory.
13. Give an example of a superseded theory.
14. Can a hypothesis take the form of a question? Explain your answer.
15. Why is it a good idea to try to reduce the chances of errors happening in an experiment?

Further Reading / Supplemental Links

- http://www.nap.edu/readingroom/books/obas/
- http://www.project2061.org/publications/sfaa/online/chap1.htm#inquiry
- http://www.nasa.gov/mission_pages/station/science/experiments/PESTO.html#applications
- http://biology.plosjournals.org/perlserv/?request=index-html&issn=1545-7885&ct=1
- http://biology.clc.uc.edu/courses/bio114/spontgen.htm
- http://www.estrellamountain.edu/faculty/farabee/biobk/diversity.htm
- http://www.nasa.gov/mission_pages/station/main/index.html
- http://books.nap.edu/html/climatechange/summary.html
- http://www.cisci.net/about.php?lang=1
- http://www.aaas.org/news/releases/2006/pdf/0219boardstatement.pdf

Vocabulary

control Something that is not tested during the investigation.

controlled experiment Two identical experiments are carried out side-by-side; in one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.

controlled variables Variables that are kept constant to prevent influencing the effect of the independent variable on the dependent variable.

deduction Involves determining a single fact from a general statement.

dependent variable Changes in response to the independent variable.

experiment A test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains.

hypothesis A suggested explanation based on evidence that can be tested by observation or experimentation.

independent variable Factor(s) whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable).

induction Involves determining a general statement that is very likely to be true, from several facts.

observation The act of noting or detecting phenomenon through the senses. For example, noting that a room is dark is an observation made through sight.

Occam's razor States that the explanation for a phenomenon should make as few assumptions as possible.

phenomenon Is any occurrence that is observable.

scientific methods Based on gathering observable, empirical (produced by experiment or observation) and measurable evidence that is critically evaluated.

scientific skepticism Questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes.

variable A factor that can change over the course of an experiment.

Points to Consider

The Points to Consider section throughout this book is intended to have students think about material not yet presented. These points are intended to lead students into the next lesson or chapter.

- Science is a particular way in which people examine and ask questions about the world. Can you think of other ways in which people examine and ask questions about the world?
- Consider the importance of replication in an experiment and how replication of an experiment can affect results.
- Scientists often disagree among themselves about scientific findings, and communicate such disagreement at science conferences, through science articles in magazines, or science papers and in scientific journals. Can you think of other ways in which scientists could communicate so that the public can get a better idea of what the "hot topics" in science are?

1.2 Lesson 1.2: Communicating Ideas

Lesson Objectives

- Outline the need for scientists to be able to share their ideas and findings with each other.

- Identify the role of graphics in presenting results of an investigation.
- Identify the role of peer review in the communication of ideas.
- Examine how ethics are applied to communicating ideas and research.
- Compare scientist to scientist communication to scientist to public communication.
- Identify the benefits of studying science, even if you do not intend on becoming a scientist.
- List three things that can influence scientific research.
- Identify two ways that biotechnology has affected our lives.

Introduction

The reliability of scientific knowledge comes partly from the objectivity of scientific methods, and also from scientists discussing ideas with each other. In talking with each other, researchers must use more than just their scientific understanding of the world. They must also be able to convince a community of their peers of the correctness of their concepts and ideas.

Scientist to Scientist Communication

A wide range of scientific literature is published and it is a format where scientific debates are properly carried out and reviewed. This includes scientific publications that report original research within a scientific field and can comprise of the following:

- scientific articles published in scientific journals
- books written by one or a small number of co-authors who are researchers
- presentations at academic conferences, especially those organized by societies (for example, the American Association for the Advancement of Science)
- government reports
- scientific publications on the internet
- books, technical reports, pamphlets, and working papers issued by individual researchers or research organizations

Scientific journals communicate and document the results of research carried out in universities and various other research institutions. They are like a type of magazine that contains many articles which are written by different researchers about their ideas and discoveries. Most scientific journals cover a single scientific field and publish the research within that field; the research is normally expressed in the form of a scientific paper.

An **academic conference** is a conference for researchers (not always academics) to present and discuss their work. Together with scientific journals, conferences are an important channel for exchange of ideas between researchers. Generally, work is shared in the form of visual posters or short presentations lasting about 10 to 30 minutes. These are usually followed by discussion. A researcher is presenting his work to his peers in **Figure** 1.12.

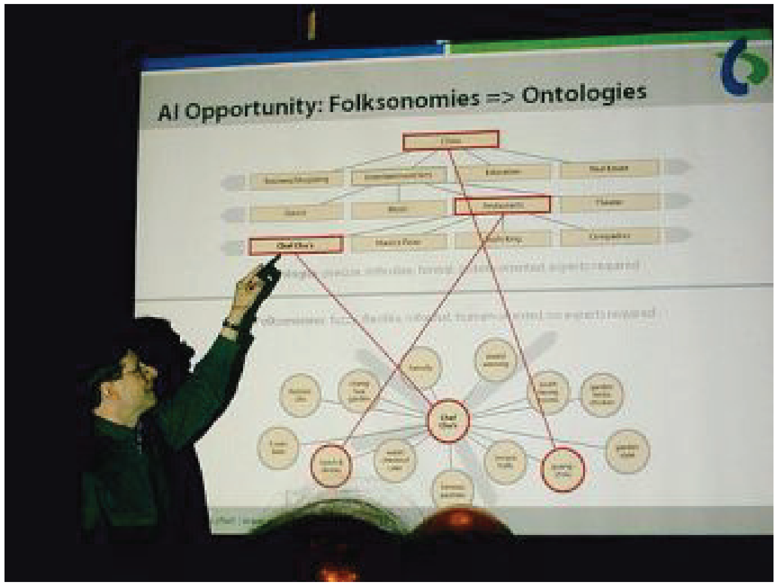

Figure 1.12: A presentation at an academic conference. At conferences, scientists are able to share ideas and their research results with many people at one time, and can talk directly to other researchers and answer their questions. (13)

Types of Scientific Publications: Scientific Journals

A scientific journal is a publication that reports new research, and sometimes contains general science news articles. Most journals are highly specialized for a particular field of research such as biochemistry, microbiology, or botany. However, some of the oldest journals such as *Nature* publish articles and scientific papers across a wide range of scientific fields. The journals shown in **Figure** 1.13 have a similar look and layout to science journals.

Scientific journals contain articles that have been peer reviewed in an attempt to ensure that articles meet the journal's standards of quality, and scientific validity. A scientific journal is not usually read casually as you would read a magazine. Some of the content can be very dense and detailed.

The publication of the results of research is an essential part of the scientific process. The researcher who has written the paper must give enough details about their experiments so that an independent researcher could repeat the experiment to verify the results.

The significance of these different parts of scientific literature differs between science disciplines and has changed over time. Peer-reviewed journal articles remain the most common publication type and have the highest level of trust. However, journals vary enormously in their prestige and importance, and the value of a published article depends on the journal, review process and the degree that it is referenced by other scientists.

Some well known and well respected science and medical journals include:

- Science
- Nature
- Proceedings of the National Academy of Sciences of the United States of America (PNAS)
- Public Library of Science (PLoS)
- Cell
- Journal of the American Medical Association (JAMA)
- The Lancet
- Journal of Theoretical Biology

Figure 1.13: These research journals publish research papers written by economists, people who study the economy, and related issues. However, the layout of research journals is very similar. (31)

Science Articles

New research is usually written up in the form of a **scientific article**, which often appear in journals. A scientific article has a standardized structure, which varies only slightly between the different sciences. This format can also be used for your lab reports as part of this class.

It is not really the format of the article that is important, but what lies behind it or the content. However, several key format requirements need to be met by every science article:

1. The title should be short and indicate the contents of the article.

2. The names of all authors that were involved in the research should be given. Where the authors work or study should also be listed.

3. The first section is normally an **abstract**: a one-paragraph summary of the work. The abstract is intended to serve as a quick guide for the reader as to the content of the article.

4. The format should be able to be stored in a library so that scientists years later will be able to recover any document in order to study and assess it

5. The content of the study should be presented in the context of previous scientific investigations, by citing related documents in the existing literature. This is usually in a section called an **introduction**.

6. Observations that were made, and measurements that were taken are described in a section usually called **Materials and Methods**. The experiments should be described in such a way that other scientists in the same or related fields can repeat the experiments and observations and know whether he or she gets the same results. This is called **reproducibility**.

7. Similarly, the results of the investigation are given in a section called, **results**. Data should be presented in tabular or graphic form (images, charts, graphs, photos, or diagrams, shown in **Figure** 1.14. Graphics should have a caption to explain what they are showing.

8. Interpretation of the meaning of the results is usually addressed in a **discussion** and/or **conclusion** section. The conclusions drawn should be based on previous studies and/or new scientific results. They should also be written in a way such that any reader with knowledge of the field can follow the argument and confirm that the conclusions are sound.

9. Finally, a **references** or **literature cited** section lists the sources cited by the authors in the format required by the journal.

Sources of Information

The reliability of information is dependent on whether the information appears in a primary source, secondary source, or a tertiary source.

Most research studies are first published in a scientific journal, which are referred to as **primary sources**. Technical reports, for minor research results are also primary sources.

Secondary sources include articles in review journals (collections of recent research articles on a topic). Review journals are usually published to highlight advances and new lines of research in specific areas, such as human genetics, specific medical disorders (such as heart disease), neurology (the study of the nervous system) or malacology, (the study of snails and other mollusks). Large projects, broad arguments, or a mix of different types of articles may

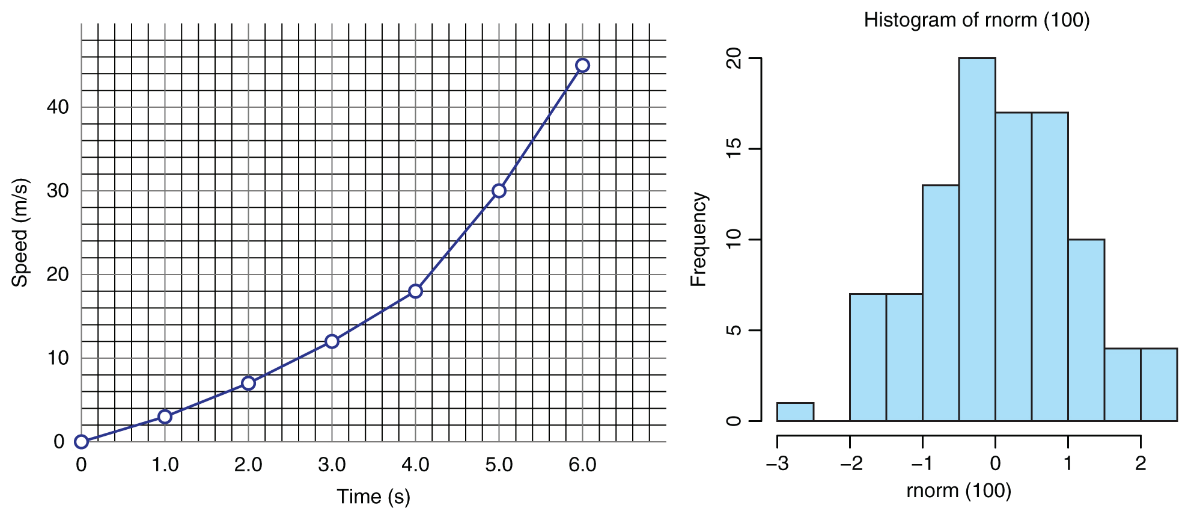

Figure 1.14: Examples of a graph and a chart that can be used to communicate data in scientific papers. (l-r) Graph showing how speed increases over time, Histogram which illustrates the frequency a particular trait appears in a population. Graphics help to illustrate ideas that would otherwise be too confusing to describe in words only. (29)

appear in a book. Review journals and books are referred to as secondary sources. Tertiary sources might include encyclopedias and news articles which are generally written for the public to read.

Peer Review

Scientists are expected to report their work truthfully and honestly. They are also expected to have their work reviewed by fellow scientists. This process is called peer review.

Peer review is a process of opening a scientist's research or ideas (in the form of a scientific paper) to examination by other scientists who are experts in the same field. The peer review process aims to make authors meet the standards of their area of study, and to meet the expected standards of science in general. Publications that have not undergone peer review are likely to be regarded with suspicion by scholars and professionals in many fields. However, even peer reviewed journals can contain errors.

A reason for the need for peer review is that it is rare for an individual author or research team to spot every mistake or flaw in a complicated piece of work. The review process provides an opportunity for improvement because a person with special expertise or experience reads the research paper before it is published. Typically, for publication in a science journal, it is also a requirement that the research is new and useful. Since reviewers are normally selected from experts in the areas of science covered by the article, the process of peer review is considered vital to establishing a reliable body of research and knowledge. Therefore, showing work to other scientists increases the likelihood that weaknesses will be found and corrected.

The process of peer review is not designed to detect fraud. As a result, there is usually a large scandal when a researcher and author of a science paper is found to have falsified the research in an article, as many other researchers may have relied upon their original research for their own work or the researcher could have received grant money based on falsified research. Peer review of scientific work assumes that the article reviewed has been honestly written. Usually reviewers do not have full access to the data from which the paper has been written, so they trust that the author is being truthful and honest.

Research Bias

It is important for the researcher to remain neutral or objective when conducting scientific research. A **bias** is a position for favoring one particular point of view over another, and it is usually based on preconceived ideas about a situation. The inability of a human being to remain completely objective is the source of such bias in research. Nevertheless, a researcher or their study is generally said to be *biased* only if the researcher's judgment is influenced by the biases they hold, which could influence their research results.

For example, you want to test whether your dog, Frankie, prefers his regular food or the super expensive brand dog food that you have just bought on sale. You would put each food in a bowl and offer both foods to Frankie at his meal time. However, you secretly hope he prefers his regular food because it is half the price of the more expensive food and you can buy it in the store down the road. Frankie takes a couple of mouthfuls of his regular food, but gobbles up all of the expensive food. You may think, "Well, he did eat some of regular food, so he still likes it," when in fact Frankie clearly preferred the expensive brand. You buy the regular food anyhow. Whether you like it or not, you are biased toward the regular dog food.

This example above is greatly simplified, but, illustrates how personal opinions may influence an investigation.

Another type of bias, called a *systematic bias* is introduced from a flaw in measurements. For example, an incorrectly calibrated thermostat may consistently read several degrees hotter or colder than actual temperature. As a consequence, systematic bias commonly leads to systematic errors in the results of an investigation. Peer review can usually detect systematic biases in a research study.

Conflict of Interest

A **conflict of interest** is a situation in which a researcher has professional or personal interests that are at odds with each other. For example, a researcher is about to investigate a new headache medicine from a drug company called Tinneas. The researcher carries out experiments and finds that the medicine works very well. End of story, right? Not exactly.

Later it is discovered that the researcher owns Tinneas stock. This means he owns part of the company. Even if everything was done correctly during the experiment, and the drug really does work, this researcher has a conflict of interest. As an owner of the company, he will earn money if the drug works, but will lose money if the drug does not work. Therefore, any scientist that may have a reason to favor one particular result from an investigation should not be involved in that investigation.

Competing interests can make it difficult for a person to carry out his or her duties without bias. A conflict of interest exists even if no wrong has been done, or nothing results from it. A conflict of interest can affect the public confidence in the person, a profession, or company.

Scientific Misconduct

When presenting their research to others, an ethical scientist would not falsify results, lie about their results, or plagiarize (steal other peoples ideas or work).

Scientific misconduct is the violation of these standard codes of scholarly conduct and ethical behavior in professional scientific research. Scientific misconduct may take place simply out of reputation. For example, academic scientists are often under enormous pressure to produce publications in peer reviewed journals. Alternatively, there may be commercial or political motivations where the financial or political success of a project depends on publishing evidence of a procedure working or not working. The consequences of scientific misconduct can be severe at a personal and professional level for the people involved. In addition, there are public health concerns attached to the promotion of medical or other procedures that are founded on doubtful research results.

Truth and Honesty in Research and Communication

Some instances of scientific fraud and scientific misconduct have gone through review and were detected only after other groups tried and failed to replicate the published results. An example is the case of physicist Jan Hendrik Schön, in which a total of fifteen papers on microelectronics and nanotechnology were accepted for publication in the top ranked journals, *Nature* and *Science*, following the usual peer review process. All fifteen were found to be fraudulent and were then withdrawn. The fraud was found, not by the peer review process, but by other research groups who tried and failed to reproduce the results of the paper.

Likewise, biomedical scientist Hwang Woo-Suk, rose to fame after claiming a series of breakthroughs in the field of stem cell research. He was once considered one of the pioneering experts in the field of stem cell research, because of his success in creating cloned human embryonic stem cells. However, his two most famous research articles on the cloning experiments were found to contain large amounts of fabricated data. Hwang's papers were retracted (withdrawn from publication), he lost his job at the university where he worked, and also lost his research funding.

Scientist to Public Communication

Science has become such a part of modern life that it is necessary to communicate the achievements, news, and ambitions of scientists to a wider audience. Scientists need to be able to tell each other and the public about their research and the results of their research. These two groups make up two very different audiences for scientists, however. The first audience is made up of their peers-fellow scientists who have an advanced understand of the technical language and procedures that are involved in scientific investigations. The second audience is made up of members of the public who may or may not understand or know about their research. For example, the following passage is a summary of a paper that appears in the Public Library of Science (PLoS), an online science journal:

A systematic analysis of Alzheimer disease amyloid peptide variants in *Drosophila* brain demonstrates that their predicted propensity to form protofibrillar aggregates correlates best with toxicity.

Biologists would have no problem understanding the language in this paragraph. However, to a person who is not familiar with this type of science, it may be interpreted as gibberish. In this, lies the challenge for scientists to communicate their research in a way that the general public can understand.

The results of the study could be written in the following way so that a general reader could follow what the researchers meant:

Studies of a particular type of brain protein, called amyloid peptides, have shown that they can sometimes change into a defective form that resembles sticky clumps. These clumps may become toxic and contribute to Alzheimer's disease, a wasting disease of the brain. Researchers are examining these proteins to find out what exactly causes them to form such clumps. The studies were carried out on fruit flies, which are commonly used as animal models for genetic and biochemical studies of humans.

Communicating to the Public Through the Internet

Many scientists do a good job of presenting their work in an accessible way on the Internet. Scientists and science journalists write news articles that explain the research in everyday language, and can show how the research relates to the reader and to their environment. For example, who would want to read an article that only talked about research that is taking place at the South Pole? An article packed with numbers, units, and percentage rates would be pretty boring to read if it were not related to other areas such the environment, people, animals, or the climate. Also, presenting such academic subjects in a readable and engaging way, allows people to understand what research is being done and why. Such general presentation of science appeals to people because it allows the reader to relate the subject to their life and experiences. For example, both the National Science Foundation (NSF) U.S Antarctic Program and the International Polar Year (IPY) 2007-2008 have websites that explain the types of research that is going on in Antarctica and the Arctic. An NSF research vessel that is taking part in the IPY 2007-2008 is shown in **Figure** 1.15.

Figure 1.15: Gentoo penguins watch the Research Vessel Laurence M. Gould in Antarctica. The Gould is one of two research vessels operated by the National Science Foundation and is taking part in the International Polar Year 2007-2008. (38)

A **science magazine** is a publication with news, opinions and reports about science and is written for a non-expert audience. Compare this to a scientific journal, which is written by and for scientific researchers. Science magazines are read by non-scientists and scientists who want accessible information on fields outside their specialization. Articles in science magazines are sometimes republished or summarized by the general press, in newspapers, online news sites, and blogs among other media forms.

Science magazines such as *New Scientist*, shown in **Figure** 1.16, and *Scientific American*, have non-technical summaries of popular areas of research, notable discoveries, and scientific advancements in different fields of research. Science books engage the interest of many more people. So, too, do science websites and science television programming add more images and illustrations that help tell a story. In this way, more people can become more aware of how science effects their lives and become better informed about science subjects.

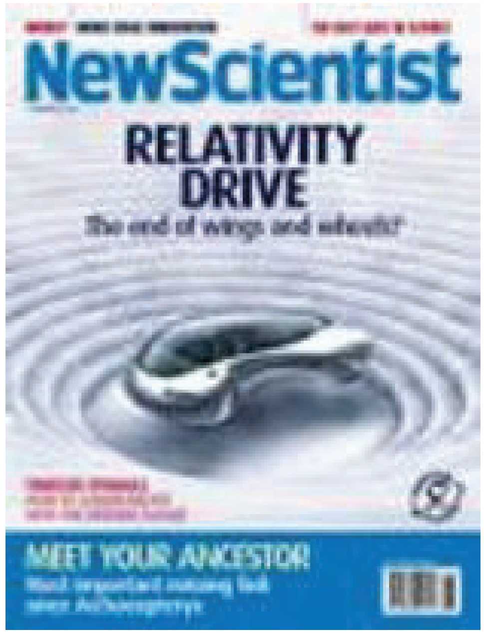

Figure 1.16: Cover of *New Scientist* magazine. (6)

Scientific Consensus

You may have already heard the term *scientific consensus* being used when the subject of global warming is talked about in the news. **Scientific consensus** is the collective judgment, position, and opinion of a community of scientists in a particular field of science, at a particular time. Scientific consensus is not, by itself, a scientific argument, and is not part of the "scientific method". But the topic for which a consensus exists may itself be based on both scientific arguments and scientific methods.

Consensus is normally carried out by scientists talking to each other and sharing their ideas and findings. Scientists can accomplish consensus by giving talks or presentations at conferences, or by publishing their ideas and findings for other scientists to read. This can lead to a situation where those within the field of science can recognize a consensus when it exists, but communicating that to others, such as non-scientists or the public, can be difficult. Sometimes, scientific institutes release statements that are meant to communicate a summary of the science from the inside to the outside. In cases where there is little controversy regarding the subject under study, laying out what the consensus is about can be straightforward.

Nevertheless, scientific consensus may be used in popular or political debate on subjects such as evolution or climate change that are controversial within the public sphere, but are not controversial within the scientific community.

Science and Society

Biology literally means "the study of life," and it is also a science that is very close to our everyday lives. Biology is a very broad field, covering the intricate workings of chemical processes inside our cells, to the more broad concepts of ecosystems and global climate change. Biologists study minute details of the human brain, the make up of our genes, and even the functioning of our reproductive system. For example, biologists recently finished decoding the human genome, the sequence of deoxyribonucleic acid (DNA) bases that may determine much of our abilities and predispositions for certain illnesses and can also play a major role in many court cases. For example, criminals have been caught, victims identified, and wrongly imprisoned people have been freed based on DNA evidence.

We are blitzed with headlines about possible health risks from certain foods as well as possible benefits of eating other foods. Commercials try to sell us the latest "miracle" pill for easy, fast weight loss. Many people are turning to herbal remedies to ease arthritis pain, improve memory, as well as improve their mood. Other people may choose the conventional medicines that can be bought at the pharmacist. It is important to know the effects such supplements, such as the ones shown in **Figure** 1.17, and medicines can have on the body.

Figure 1.17: Nutritional supplements. Understanding how your body works and how nutrients work will help you decide whether you need to take a nutritional supplement. It will also help you make sense of the large amount of information available about regular medicines, if and when you need to take them. (46)

Can a biology book give you the answers to these everyday questions? No, but it will enable you learn how to sift through the biases of investigators, the press, and others in a quest to critically evaluate the question. To be honest, five years after you are finished with this biology book, it is doubtful you would remember all the details of metabolism. However, you will have a better idea about where to look for the answer. Knowing about the process of science will also allow you to make a more informed decision. Will you be a scientist? Yes, in a way. You may not be formally trained as a scientist, but you will be able to think critically, solve problems, have some idea about what science can and cannot do, as well as an understanding of the role of biology in your everyday life.

Biology and You

So why should you study biology? Because you are surrounded by it every day! It is about what happens in your brain as your read the words on this page and about how hippopotamuses know to come up to the surface to breath even while sleeping. Biology is about why a person with hook worms doesn't sneeze as much and about why Velcro works. From understanding the benefits of the vitamin-enriched milk or juice you that have at breakfast, to discerning commercials that promise smoother thighs or a fuller head of hair, or snack foods that announce they are the "health busy livelier option for your," you cannot be fully informed about such claims unless you understand the science behind them, or can think like a scientist to analyze them. For example, you would need to know the types of fats you need to get from your food to know why eating salmon, shown in **Figure 7** 1.18, **or other foods such as flax seeds and kiwifruit may be good for your health.**

Figure 1.18: Salmon has recently been touted as "super-brain food," but do you know why it is so good for you? Educating yourself on how science affects your life is important. It will help you analyzing the validity of such claims, help you take better care of your health, be a wiser healthcare consumer, and make you more science literate in general. (11)

You may also become a stronger advocate for your community. For example, if a tree planting initiative has begun in your neighborhood, you can investigate the plan for your area and find out what you can do. You could then explain what the program is about to your friends and family.

Or, perhaps a city park has fallen into disrepair, and city officials are looking for feedback from the public about what to do with it. You could use scientific thinking to analyze the issue and options, and develop some solutions.

What Is a Scientist?

What exactly makes a person a "scientist" and what is their role in society? First, we should start with what scientists are not. They are not crazed geniuses with bad hair and a fondness for hysterical laughter, as **Figure a** 1.19 might suggest. Although they may not be on the cutting edge of fashion, they are regular people. They went to school like you, they studied math, reading, and science like you, and they probably exhibited at science fairs, just like the students in **Figure b** 1.19.

Figure 1.19: Spot the Scientist. (a) An example of what scientists are not. (b) Real-life young scientists at an exhibition where they are presenting their research. (18)

Being a scientist does not require you to learn everything in this book or any other science book by heart, but understanding the important concepts really helps. Instead, being a scientist begins by *thinking* like a scientist. Scientists are curious about how the world works; they have many questions and go about answering those questions using the scientific methods, which we discussed in the *Nature of Science* lesson.

If you are fascinated by how things work and why they work a certain way, you too could become a scientist! **Research scientists** are the people that do the investigations and make the discoveries that you read or hear about. To work as a research scientist, a person usually needs an advanced degree in science. An advanced degree is obtained by attending graduate school after getting a Bachelor of Science, Engineering, or Arts degree. A Bachelor degree normally takes four years to complete; graduate degrees usually take two years for a Masters degree and four or more years to complete a Doctorate degree.

Scientific research offers much more to a person than just discovering new things. Researchers have the opportunity to meet with other people (scientists and non-scientists) who care about the same subjects that the scientists research such as cancer research, marine ecology, or human nutrition. Many researchers also teach students who will become the next generation of scientists. Scientists have many opportunities to work with different people, explore new fields, and broaden their expertise.

Scientists are part of a community that is based on ideals of trust and freedom, and their work can have a direct effect on society. As a result, the public usually has an interest in the results of research that will directly affect them. Therefore it is important that you can understand the meaning of a science story when you read it, see it, or hear about it and become an engaged and active member of the public when making decisions involving science.

Science As a Human Endeavor

Conducting science requires part human creativity and part scientific skepticism. Researchers make new observations and develop new ideas with the aim of describing the world more accurately or completely. These observations and ideas are often based on existing theories and observations that were made by earlier scientists.

For example, the history of molecular biology, the study of molecules that make up living things, is a good example of how scientific knowledge builds on earlier knowledge.

Researchers from chemistry and physics were involved in the early investigations to discover what was responsible for heredity. Scientists in the late 19^{th} and early 20^{th} century knew that organisms inherited certain characteristics such as hair color from their parents. What we now call ”genes” were then called “units of heredity.” Scientists did not know exactly how these heredity units were inherited or what they were made of, however. Following the development of the Mendelian theory of heredity in the 1910s and the development of atomic theory and quantum mechanics in the 1920s, such explanations seemed within reach. Researchers from chemistry and physics turned their attention to this biological question. Still, in the 1930s and 1940s it was not clear which, if any, area of research would be most successful.

In 1940, geneticists George Beadle and Edward Tatum demonstrated a relationship between genes and proteins. In 1944, physician and researcher Oswald Avery further elaborated on that finding by demonstrating that genes are made up of DNA. In 1952, geneticist Alfred Hershey and lab assistant Martha Chase confirmed that the genetic material of a virus that infects bacteria is made up of DNA. And in 1953, biologist James Watson and biophysicist Francis Crick, with the help of X-ray crystallographer Rosalind Franklin, worked out the three dimensional structure of DNA and built a model of the double helix structure of the molecule.

There have been many additional discoveries about DNA and heredity since then, which you will learn more about in the Molecular Genetics and Biotechnology chapters.

Influences on Scientific Research

To nonscientists, the competition, frustration, cooperation, and disagreement between research scientists can seem disorganized. Scientific knowledge develops from humans trying to figure things out. Scientific research and discoveries are carried out by people—people who have virtues, values, shortcomings, and limitations—just like everyone else. As a result, science and research can be influenced by the values of the society in which the research is carried out. How do such values influence research?

This question is of interest to more than just the scientific community. Science is becoming a larger part of everyone's life, from developing more effective medicines to designing innovative sustainable air conditioning systems that are modeled after the self-cooling nests of termites. The public has become more interested in learning more about the areas of science that affect everyday life. As a result, scientists have become more accountable to a society that expects to benefit from their work.

It costs money to carry out scientific studies. Things such as the cost of equipment, transportation, rent, and salaries for the people carrying out the research all need to be considered before a study can start. The systems of financial support for scientists and their work have been important influences of the type of research and the pace of how that research is conducted. Today, funding for research comes from many different sources, some of which include:

- Government, for example, through the National Institutes of Health (NIH), Center for Disease Control and Prevention (CDC), and the Food and Drug Administration (FDA)
- Military funding (such as through the Department of Defense)
- Corporate sponsorship
- Non-profit organizations, such as the American Cancer Society, Stroke Awareness For Everyone, Inc. (SAFE)
- Private donors

When the economy of a country slows down, the amount of money available for funding research is usually reduced, because both governments and businesses try to save money by cutting out on non-essential expenses.

Many pharmaceutical companies are heavily invested in research and development, on which they spend many millions of dollars every year. The companies aim to research and develop drugs that can be marketed and sold to treat certain illnesses, such as diabetes, cancer, or high blood pressure. Areas of research in which the companies do not see any hope of a return on their huge investments are not likely to be studied.

For example, two researchers, Evangelos Michelakis and Steven Archer of the University of Alberta, Canada, recently reported that a drug that has been used for in the treatment of rare metabolic disorders could be an effective drug for the treatment of several forms of cancer. Dichloroacetic acid, (DCA), is a chemical compound that appears to change the way cancer cells get energy, without affecting the function of normal cells. The researchers found that DCA killed cancer cells that were grown in the lab and reduced the size of tumors in rats.

However, DCA is non-patentable as a compound. A **patent** is a set of rights granted to a person or company (the patentee) for a certain period of time which allows the patentee the exclusive right to make, use, sell, or offer to sell the patented item. Because DCA cannot currently be patented, concerns are raised that without the financial security a patent would ensure, the financial incentive for the pharmaceutical industry to get involved in DCA-cancer research would be reduced, and therefore clinical trials of DCA may not be funded.

But, other sources of funding exist; previous studies of DCA have been funded by government organizations such as the National Institutes of Health (NIH), the Food and Drug Administration (FDA), the Canadian Institutes of Health Research and by private charities such as the Muscular Dystrophy Association. Recognizing the possible challenges to funding, Dr. Michelakis's lab took the unusual step of directly asking for online donations to fund the research. After six months, his lab had raised over $800,000, which was enough to fund a small clinical study. Dr. Michelakis and Dr. Archer have nonetheless applied for a patent on the use of DCA in the treatment of cancer.

Funding for research can also be influenced by the public and by social issues. An intense amount of public interest was raised by the DCA study. The story received much media attention in early 2007. As a result, the American Cancer Society and other medical organizations received a large volume of public interest and questions regarding DCA. A few months later, the Department of Medicine of Alberta University reported that after the trial funding was secured, both the Alberta local ethics committee and Health Canada approved the first DCA Clinical Trial in Cancer.

Government funding of research can be indirectly influenced by the public. Funding priorities for specific research can be influenced by the ethical beliefs or reservations of elected public officials, or influenced by the public during constitutional amendment elections. Celebrities, often campaign to bring public attention to issues that are important to them. For example, Lance Armstrong, in **Figure** 1.20, talks publicly about his experiences as a former cancer patient to help raise awareness about cancer research and the importance of funding for clinical trials.

Science and Ethics

Ethics, also called moral philosophy, is the discipline concerned with what is morally good and bad, right and wrong. The term is also applied to any system or theory of moral values or principles. Personal ethics is the moral code that a person adheres to, while social ethics includes the moral theory that is applied to groups. Bioethics is the social ethics of biology and medicine; it deals with the ethical implications of biological research and applications,

Figure 1.20: Lance Armstrong, seven-time winner of the Tour de France, visited the NIH as part of the Tour of Hope, a week-long bicycle relay across the United States to raise awareness about cancer research and the importance of clinical trials. (7)

especially in medicine. Bioethicists are concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.

While scientific research has produced social benefits, it has also posed some troubling ethical questions. For example, when is it okay to test an experimental cancer drug on people? Developing a new drug takes a long time, maybe as much as 10 years, or more. There are many rules and regulations that drug researchers need to stick to while developing drugs to treat specific illnesses.

Generally, drugs cannot be tested on people until researchers have evidence that the drug does the job that they claim it does (in this case kills cancer cells), but also that the drug will not make patients more ill or cause death. However, if the drug has tested successfully in earlier experiments, and scientists are quite confident that the drug does help kill off cancer cells, is it ethical to allow patients with terminal cancer, who have no other treatment options, to try the experimental drug?

With new challenges in public health and health policy, and with advances in biotechnology, bioethics is a fast-growing academic and professional area of inquiry. Some recent bioethical debates also include:

Refusal of medical treatment The choice of a patient to refuse certain life-saving medical procedures such as a blood transfusion, or refusal by a parent or guardian for medical treatment for the patient.

Euthanasia The choice by a terminally ill person to have medical assistance in dying.

Stem cell research Research involving stem cells, which can be harvested from human embryos.

Animal cloning The ability and usefulness of scientists cloning animals for various needs, such as vaccine development, tissues for transplant into humans such as heart valve, and increased food production. Dolly the sheep, probably the most famous animal clone to date, is shown in **Figure** 1.21.

Figure 1.21: Dolly the sheep is seen here with one of her lambs. In 1997, Dolly was the first mammal to be cloned, and quickly became world-famous. She was euthanized in 2003 after she developed a common, but serious lung disease. To "grow" her, researchers at the Roslin Institute in Scotland, collected DNA from a mammary cell of another sheep (technically her (older) twin sister), and then injected the DNA into a stem cell which had its own DNA removed. That stem cell then developed into an embryo. (19)

Because research may have a great effect on the wellbeing of individual people and society in general, scientists are required to behave ethically. Scientists who conduct themselves ethically treat people (called *subjects*) who are involved in their research respectfully. Subjects are not allowed to be exploited deliberately, exposed to harm, or forced to do something they do not agree to.

Science in the Media

A lot of popular science articles come from sources whose aim is to provide a certain amount of entertainment to the reader or viewer. Many popular science articles will examine how a phenomenon relates to people and to their environment. Nevertheless, there is a tendency in the popular media to dilute scientific debates into two sides, rather than cover the complexities and nuances of an issue.

Even well-intentioned scientists can sometimes unintentionally create truth-distorting media firestorms because of journalists' difficulty in remaining critical and balanced, the media's interest in controversy, and the general tendency of science reporting to focus on apparent "groundbreaking findings" rather than on the larger context of a research field. Sometimes scientists will seek to exploit the power of the media. When scientific results are released with great fanfare and limited peer review, the media often requires skepticism and further investigation by skilled journalists and the general public.

The dichloroacetic acid (DCA) story, discussed earlier in this lesson, is an example of what can go wrong when a scientific discovery grasps the public's attention.

An intense amount of public interest was raised by the study and the story received much media attention. As a result, the American Cancer Society and other medical organizations received a large volume of public interest and questions about the "miracle cure," DCA.

One of the first stories about the findings contained the headline:

"Cheap, 'safe' drug kills most cancers"

The article did explain that the studies were only carried out on cancer cells grown in the lab and in rats. However, the headline may have given some readers the impression that human testing of DCA was complete. People were wildly interested in this new "cure" to cancer. This prompted the American Cancer Society and other organizations to issue reports that reminded people that although the study results were promising, no formal clinical trials in humans with cancer had yet been carried out. They stressed the need for caution in interpreting the early results. Doctors warned of possible problems if people attempted to try DCA outside a controlled clinical trial. The media received some criticism for the sensation that arose due to their coverage of the discovery.

Therefore, it is important to remember as a member of the public that some popular science news articles can be misleading. A reader can misinterpret the information, especially if the information has a emotional affect on the reader. Also, some articles are written by people who have limited understanding of the subject they are interpreting and can be produced by people who want to promote a particular point of view. Unfortunately, it can be difficult for the non-expert to identify misleading popular science. Sometimes, results are presented in the media without a context, or are exaggerated. Popular science may blur the boundaries between formal science and sensationalism. It is best to analyze such information with skepticism as you would if you were to make an observation in an investigation, and look at the whole context of an issue, rather than just the focus of a particular news item.

For example, in early 1999 West Nile virus, a virus most commonly found in Egypt, was accidentally introduced to New York. Although infection by the virus causes mostly mild or no symptoms in people, in rare instances, West Nile virus can cause inflammation of the brain. The illness, called West Nile Fever, spread across the continent from east to west, carried by infected birds. Mosquitoes spread the disease to mammals. Mosquito larvae (young) are shown in **Figure** 1.22.

There was intense media coverage about the spread of this disease across the United States, and much talk about what this meant for everyone. News coverage of West Nile Fever tended to focus on the serious form of the disease, West Nile Encephalitis, which can cause harmful illness and death. The fact that there is no vaccine for the disease was also emphasized.

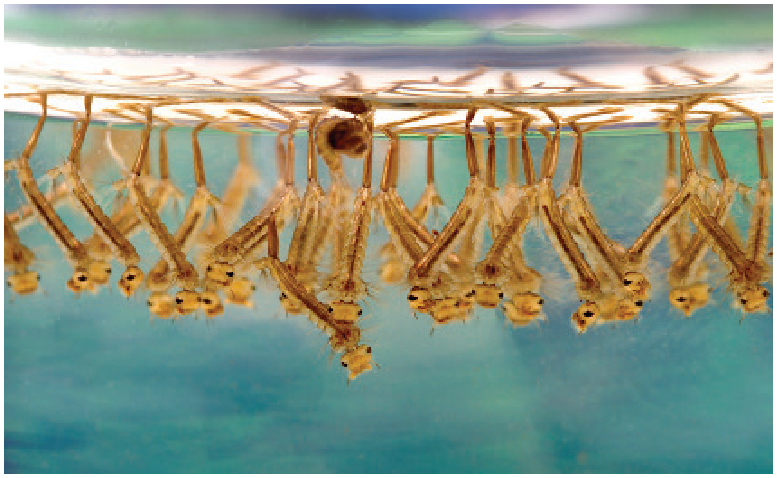

Figure 1.22: Mosquito larvae. As seen on the picture, larvae group together in standing water. The darker structure at the top center of the image is one pupa, another stage of the mosquito lifecycle. Mosquitoes can transfer diseases between animals, including West Nile Fever and malaria. You can avoid mosquito bites by covering your arms and legs while outside during the early morning and late evening, and by applying an insect repellant. (9)

However, it is worthwhile considering that until October 2007 there had been a total of 26, 997 confirmed cases of West Nile virus infection, and 1,038 confirmed deaths from the disease. Compare this to the estimated 15 to 60 million people in the United States who are infected with the flu virus every year, and the estimated 36,000 people who die every year from flu complications.

So the next time you are shocked or horrified by a seemingly gloomy forecast in the media, consider how the issue fits into the bigger story.

Biotechnology: Science Applied to Life

Biotechnology is technology based on biology; it involves the use of organisms or biological processes and can be especially used in agriculture, food science, and medicine. It is the application of biological knowledge to develop tools and products that allow us to control and adapt to our environment.

Biotechnology has effected society and in a number of ways. Although it has been used for centuries in traditional production processes, such as animal breeding shown in **Figure** 1.23, crop growing, and wine making, modern biotechnology is a recent field of science. Bioengineering is the science upon which all biotechnological applications are based. New developments and new approaches are developing at a very fast pace. Biotechnology combines scientific fields such as genetics, molecular biology, biochemistry, and cell biology.

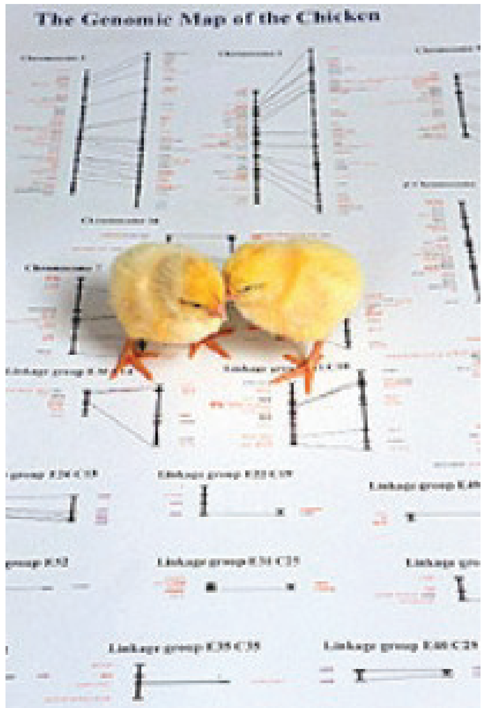

Figure 1.23: Chicks standing on a picture of a genetic map of a chicken. Mapping the genome of organisms is a major part of biotechnology. (1)

The field of modern biotechnology is thought to have largely begun in 1980, when the United States Supreme Court ruled that a genetically-modified microorganism could be patented. Indian-born researcher, Ananda Chakrabarty, had developed a bacterium that was able to break down crude oil, which he proposed to use in treating oil spills.

Applications of Biotechnology

Biotechnology has applications in four major industrial areas, including health care, crop production and agriculture, non-food uses of crops such as biofuels, and environmental uses. One application of biotechnology uses organisms to produce things such as nutritional supplements like vitamins or amino acids, and milk products like cheese, kefir, and yogurt. Biotechnology is also used to recycle, treat waste, and clean up sites contaminated by industrial waste. The use of microorganisms to clean up contaminated sites such as an oil spill is called **bioremediation.**

Medical applications of biotechnology include designing organisms to produce medicines such as antibiotics, or other chemicals. Medical applications for people also include gene therapy which could be used to treat a person who has a genetic disorder such as cystic fibrosis.

An example of an agricultural application is designing plants to grow under specific environmental conditions or in the presence (or absence) of certain chemicals, such as the cress shown in **Figure** 1.24. The cress plant has been genetically modified to turn red only in the presence of nitrogen dioxide, a chemical that is released by landmines and other unexploded bombs. Researchers at the Danish biotechnology company that developed the plant hope that the seeds can be spread over former battleground areas where they will grow and mark the sites of the explosives, thus speeding up the land mine removal process.

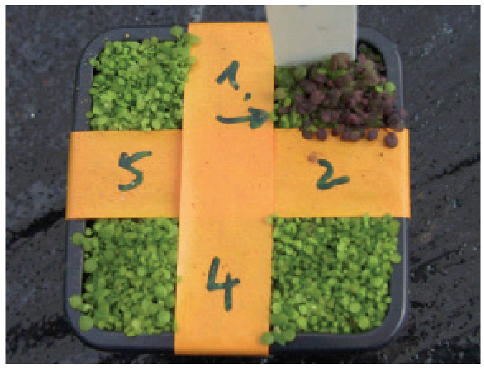

Figure 1.24: This thale cress *Arabidopsis thaliana* has been genetically modified to turn red only in the presence of nitrogen dioxide, a chemical marker for landmines or other unexploded bombs. Researchers hope that the cress seeds can be spread over former battleground areas, where they will grow and mark the sites of explosives, thus lessening the risk to the people and animals who live in those areas and work to remove the explosives. (45)

Another hope is that biotechnology might produce more environmentally friendly solutions than traditional industrial agriculture. An example of this is the engineering of a plant to express a pesticide, which cuts out the need to apply pesticides to the plants. The corn plants in **Figure** 1.25 have been genetically modified (changed) to produce a toxin that comes from a naturally occurring soil bacterium called *Bacillus thuringiensis.* The Bt toxin kills the pests that eat and destroy corn crops. Whether or not biotechnology products such as this are more environmentally friendly in the long run is a hot topic of debate.

Use of Computers in Science and Medicine

Bioinformatics is an interdisciplinary field which helps solve biological problems using computers. Lots of information is gathered from the mapping of DNA sequences and other related types of research. Bioinformatics allows scientists to gather this information, share it and to use it. It also speeds up the process of analyzing data the scientists have collected. The field may also be called computational biology. Bioinformatics plays a key role in various areas, and it is a key part of the biotechnology and the pharmaceutical industries.

Figure 1.25: People looking at a sign that explains what the genetically modified corn does. In an effort to reduce corn stem-borer infestations, corporate and public researchers came together to develop genetically modified corn varieties suitable for Kenya. The corn plants contain a gene (*Bt* gene) from a naturally occurring bacterium called *Bacillus thuringiensis*. The Bt gene causes the corn plants to make Bt toxin which kills the pests that feed on the plants. (47)

Psychologists David Patterson and Hunter Hoffman of the University of Washington in Seattle developed a virtual world computer game they called "Snow World" shown in **Figure** 1.26, in an effort to reduce the pain experienced by patients undergoing burn treatment and other medical procedures. They found that people who became fully engaged in the virtual reality snow world reported 60 percent less pain. This technology offers a promising new way to manage pain. The researchers say that an interactive digital world may distract us from reality because our minds focus on just a few things at once.

Figure 1.26: A scene from the interactive "Snow World." In this virtual reality game, players can move through the snowy landscape, throw snowballs, and watch penguins waddle past them. Researchers found that playing this game can distract people from the sense of burning pain. The researchers used healthy undergraduate student volunteers in these virtual world study to determine that perception can affect pain sensation. (8)

Lesson Summary

- The reliability of scientific knowledge comes partly from the objectivity of scientific methods, and also from scientists discussing ideas with each other. In talking with each other, researchers must use more than just their scientific understanding of the world. They must also be able to convince other scientists of the accuracy of their ideas.
- Graphics help to illustrate ideas that would otherwise be too confusing to describe in words only.
- The peer review process aims to make authors meet the standards of their area of study, and to meet the expected standards of science in general.
- Ethics is the discipline concerned with what is morally good and bad, right and wrong. Bioethics is the social ethics of biology and medicine; it deals with the ethical implications of biological research and applications, especially in medicine. Bioethicists are concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.

- Scientists need to be able to tell each other and the public about their research and the results of their research. These two groups make up two very different audiences for scientists. Presenting academic subjects in a readable and engaging way, allows the general pubic to understand what research is being done and why. Presentation of generally written science appeals to people because it allows the reader to relate the subject to their life and experiences.
- You cannot be fully informed about the scientific issues you read about unless you understand the science behind the issues, or have the ability to think like a scientist to analyze them.
- The cost of equipment, transportation, rent, and salaries for the people carrying out the research all need to be considered before a scientific study can start. The systems of financial support for scientists and their work have been important influences of the type of research and the pace of research. Today, funding for research comes from many different sources.
- Biotechnology is the application of biological knowledge to develop tools and products that allow us to control and adapt to our environment.

Review Questions

1. What is bias in scientific terms and how is it relevant to science?
2. Who do you think the ethical rules about scientific research are aimed toward? Who do they protect?
3. Investigate a science-based societal issue that affects your town, city, or state. Research literature and news reports about the issue, analyzing the data, and examine what an individual person, the community, the local government, or federal government could do about this issue. Present your finding in the form of a poster or computer slide presentation to your class.
4. Find a science article that you believe could be improved upon by adding a graph, a picture, or a drawing. Rewrite the article in your own words, and present it to your class, along with your added graphics.
5. How has biotechnology affected modern life?
6. Science and biotechnology are pursued for different purposes. Do you agree with this statement? Explain your answer.
7. Identify an ethical issue that is raised by biotechnology.
8. Identify an ethical issue that is raised by media coverage of science.
9. Why is it a good idea to study science even if you do not want to become a career scientist?
10. What are three sources of funding for scientific research?
11. How might ethics affect funding for scientific research?

Further Reading / Supplemental Links

- http://www.accessexcellence.org/
- http://www.ipy.org/
- http://www.newscientist.com/article.ns?id=dn10971
- http://response.restoration.noaa.gov/faq_topic.php?faq_topic_id=1
- http://www.milliontreesla.org/
- http://www.ctv.ca/servlet/ArticleNews/story/CTVNews/20070120/DCA_feature_070121/20070122?hub=Health
- http://www.newscientist.com/article/mg19325890.200-no-wonder-drug.html
- http://publications.nigms.nih.gov/biobeat/gallery/index.html
- http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5606a1.htm
- http://publications.nigms.nih.gov/findings/sept05/bedside_sept05.html

Vocabulary

abstract A brief, usually one-paragraph, summary of the work.

academic conference A conference for researchers (not always academics) to present and discuss their work.

animal cloning The ability and usefulness of scientists cloning animals for various needs, such as vaccine development, tissues for transplant into humans such as heart valve, and increased food production.

bioethicists People concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.

bioinformatics An interdisciplinary field which helps solve biological problems using computers; may also be called computational biology.

bioremediation The use of microorganisms to clean up contaminated sites, such as an oil spill.

biotechnology Technology based on biology; it involves the use of organisms or biological processes and can be especially used in agriculture, food science, and medicine.

conflict of interest A situation in which a researcher has professional or personal interests that are at odds with each other.

euthanasia The choice by a terminally ill person to have medical assistance in dying.

ethics The discipline concerned with what is morally good and bad, right and wrong.

peer review The process of opening a scientist's research or ideas (in the form of a scientific paper) to examination by others scientist who are experts in the same field.

reproducibility The ability to repeat experiments and get the same results.

research scientist A person that does scientific investigations and makes discoveries.

science magazine A publication with news, opinions and reports about science; written for a non-expert audience.

scientific article A scientific article discussing new research and findings; usually published in a scientific journal.

scientific consensus The collective judgment, position, and opinion of a community of scientists in a particular field of science, at a particular time.

scientific journal A publication that communicate and document the results of research carried out in universities and various other research institutions.

scientific misconduct The violation of standard codes of scholarly conduct and ethical behavior in professional scientific research.

stem cell research Research involving stem cells, usually harvested from human embryos.

systematic bias A bias that is introduced from a flaw in measurements.

Points to Consider

- Bias can also be introduced into an investigation by uncalibrated or broken equipment. Consider ways to avoid this type of bias in your investigations.
- If you had to explain to a younger student the importance of learning biology, how would you go about it?
- Rules for correct behavior in the lab include not eating or drinking, dressing correctly, and no horseplay. These rules are for general safety in the lab, but could they also be considered lab ethics?

1.3 Lesson 1.3: Tools and Techniques

Lesson Objectives

- Identify the units of measurement that scientists use.
- Contrast light microscopes and electron microscopes.
- Identify three items that are common to science labs.
- Outline the importance of mathematics to scientific research.
- Outline what students and researchers can do to stay safe while working in the lab.

Introduction

Scientists need to know they are talking the same language when it comes to measurements and analysis of data. Therefore a "standard language of measurement" called the SI system is used in scientific research. Other standard procedures and techniques are carried out so that scientists from around the world can understand what was done to get to a particular conclusion. These involve standard laboratory procedures and equipment, such as microscopes.

Units of Measurement

The measurements that scientists use are based on the **International System of Units (SI),** which is a form of the metric system. The term SI is shortened from the French term *Le Système international d'unités*. It is the world's most widely used system of units, both in science and business. It is useful to scientists because it is based on multiples of 10. The SI was developed in 1960 from an older metric system and is used in almost every country.

The SI is not static, as the technology of measurement progresses, units are created and definitions are changed through international agreement among many nations. The international system of units is made up of a seven base units, shown in **Table 2.2 ??** lists SI Base Units. From these seven base units several other units are derived.

Table 1.2: **SI Base Units**

Name	Symbol	Quantity
meter	m	length
kilogram	kg	mass
second	s	time
ampere	A	electric current
kelvin	K	thermal energy (temperature)

Table 1.2: (continued)

Name	Symbol	Quantity
mole	mol	amount of substance
candela	cd	luminous intensity

A prefix may be added to SI units to make a multiple of the original unit. An **SI prefix** is a name or symbol that is put before a unit of measure (or its symbol) to form a decimal or a multiple of the unit. For example, *kilo*- is a multiple of a thousand and *milli*- is a multiple of a thousandth, so there are one thousand *millimeters* in a meter, and one thousand meters in a *kilometer*. All prefixes are multiples of 10, as you can see from **Table 2.3 ??** lists SI Prefixes. The prefixes are never combined; a millionth of a kilogram is a *milligram* not a *microkilogram*.

Table 1.3: **SI Prefixes**

Name	Symbol	Factor of 10	
tera-	T	1,000,000,000,000 (10^{12})	trillion (thousand billion)
giga-	G	1,000,000,000 (10^{9})	billion (thousand million)
mega-	M	1,000,000 (10^{6})	million
kilo-	k	1000 (10^{3})	thousand
hecto-	h	100 (10^{2})	hundred
deca-	da	10 (10^{1})	ten
deci-	d	1 (10^{-1})	tenth
centi-	c	0.1 (10^{-2})	hundredth
milli-	m	0.01 (10^{-3})	thousandth
micro-	µ	0.00001 (10^{-6})	millionth
nano-	n	0.00000001 (10^{-9})	billionth
pico-	p	0.00000000001 (10^{-12})	trillionth

The Laboratory

A laboratory is a place that has controlled conditions in which scientific research, experiments, and measurement may be carried out. Scientific laboratories can be found in schools and universities, in industry, in government facilities, and even aboard ships and spacecraft, such as the one shown in **Figure** 1.27.

Because of the different areas of science, there are many different types of science labs that

Figure 1.27: Labs are not always Earth-bound, like the biochemistry lab to the left is. This astronaut is working in a lab on the International Space Station (right). (33)

each include different scientific equipment. For example, a physics lab might contain a particle accelerator, in which the particles that make up atoms are studied. A chemistry or biology lab most likely contains a fume hood where substances with poisonous fumes can be worked. A particle accelerator and a fume hood are both shown in **Figure** 1.28. Despite the great differences among labs, some features are common in them.

Most labs have workbenches or countertops at which the scientist may sit or stand to do work comfortably. This is important because scientists can spend all day working in the lab. A scientist usually records an experiment's progress in a lab notebook, but modern labs almost always contain a computer for data collection and analysis. In many labs computers are also used for lab simulations (modeling or imitating an experiment or a natural process), and for presenting results in the form of graphs or tables.

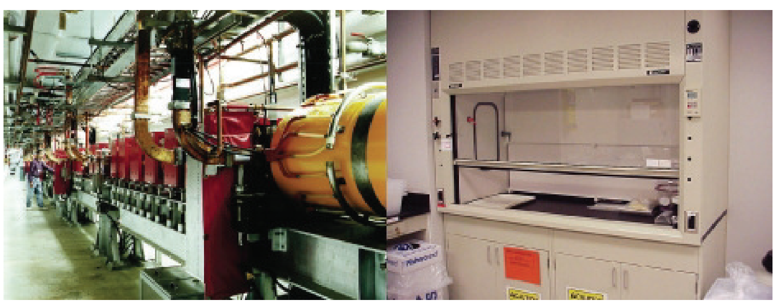

Figure 1.28: Different fields of science need different types of equipment, such as the particle accelerator at left, found in a physics lab, and the fume hood, at right, found in chemistry labs, but also sometimes in biology labs. (10)

Lab Equipment

Lab techniques include the procedures used in science to carry out an experiment. Lab techniques follow scientific methods, and while some of them involve the use of simple laboratory equipment such as glassware (shown on the shelves in **Figure** 1.27), others use more complex and expensive equipment such as electrical and computerized machines such as the particle accelerator shown in **Figure** 1.28, or use expensive supplies.

Equipment commonly found in a biology labs include microscopes, weighing scales or balances, water baths, glassware (such as test tubes, flasks, and beakers), Bunsen burners, tongs, pipettes shown in **Figure** 1.29, chemical reagents, lab coats, goggles, and biohazard waste containers.

Figure 1.29: Pipettes are small, but important tools in many biology labs. Micropipettes, such as these here, are calibrated to measure very small amounts of liquids. For example, 100 microliters (100 µL) which is about half the volume of your little finger tip; or even 1 µL, which is smaller than a drop of water. (16)

Light Microscopes

Microscopes are instruments used to view objects that are too small to be seen by the naked eye. Optical microscopes, such as the one shown in **Figure** 1.30, use visible light and lenses to magnify objects. They are the simplest and most widely used type of microscopes. Compound microscopes are optical microscopes which have a series of lenses, and have uses in many fields of science, particularly biology and geology. The scientist in **Figure** 1.31 is looking through a compound light microscope that is fitted with a digital camera.

Resolution is a measure of the clarity of an image; it is the minimum distance two points can be separated and still be distinguished as two separate points. Because light beams have a physical size, which is described in *wavelengths*, it is difficult to see an object that is about the same size or smaller than the wavelength of light. Objects smaller than about 0.2 micrometers appear fuzzy, and objects below that size cannot be seen.

Magnification involves enlarging the image of an object so that it appears much bigger than its actual size. Magnification also refers to the number of times an object is magnified. For example, a lens that magnifies 100X, magnifies an object 100 times larger than its actual size. Light microscopes have three objective lenses that have different magnifications, as

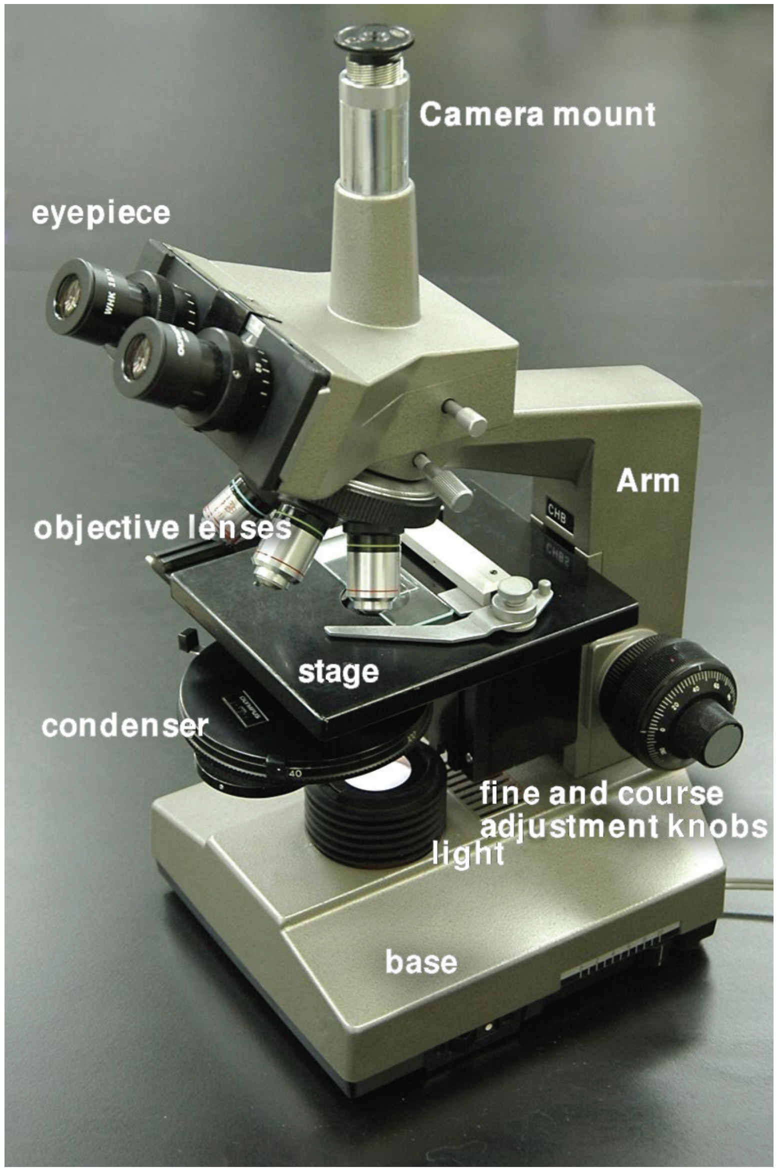

Figure 1.30: Compound light microscopes use lenses to focus light. Typical magnification of a light microscope is up to 1500x. This microscope has two optical lenses and is called a stereo microscope. The various parts of the microscope are labeled. (41)

Figure 1.31: This scientist is using a stereo microscope, which is a light microscope with two ocular lenses (the microscope lense that is closest to the eye). The microscope is fitted with a digital imaging device that can take digital photos of what the researcher sees. (37)

shown in **Figure** 1.32. The ocular lens has a magnification of 10X, so a 100X objective lens and the ocular lens together will magnify an object by 1000X.

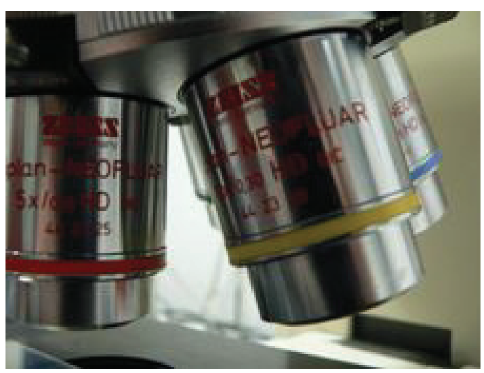

Figure 1.32: Objective lenses of a light microscope. (48)

Visible light has wavelengths of 400 to 700 nanometers, which is larger than many objects of interest such as the insides of cells. Scientists use different types of microscopes in order to get better resolution and magnification of objects that are smaller than the wavelength of visible light. Objects that are to be viewed under an electron microscope may need to be specially prepared to make them suitable for magnification.

Electron Microscopes

Electron microscopes use electrons instead of photons (light), because electrons have a much shorter wavelength than photons and thus allow a researcher to see things at very high magnification, far higher than an optical microscope can possibly magnify.

There are two general types of electron microscopes: the Transmission Electron Microscope that shoots electrons through the sample and measures how the electron beam changes because it is scattered in the sample, and the Scanning Electron Microscope that scans an electron beam over the surface of an object and measures how many electrons are scattered back.

Transmission electron microscopy (TEM) is an imaging method in which a beam of electrons is passed through a specimen. An image is formed on photographic film or a fluorescent screen by the electrons that scatter when passing through the object. TEM images show the inside of the object.

The **scanning electron microscope (SEM)** is a type of electron microscope capable of producing high-resolution images of a sample surface. Due to the manner in which the image is created, SEM images have a characteristic three-dimensional appearance and are useful for judging the surface structure of the sample. Sometimes objects need to be specially prepared to make them better suited for imaging under the scanning electron microscope, as shown with the insect in **Figure** 1.33.

Electron microscopes work under low pressures and usually in a vacuum chamber to avoid scattering the electrons in the gas. This makes the microscopes considerably larger and more expensive than optical microscopes. The different types of images from the two electron microscopes are shown in **Figure** 1.34.

Aseptic Technique

In the microbiology lab, **aseptic technique** refers to the procedures that are carried out under sterile conditions. Scientists who study microbes are called microbiologists. Microbiologists must carry out their lab work using the aseptic technique to prevent microbial contamination of themselves, contamination of the environment they are working in, including work surfaces or equipment, and contamination of the sample they are working on. Bacteria live on just about every surface on Earth, so if a scientist wants to grow a particular type of bacterium in the lab, he or she needs to be able to sterilize their equipment to prevent contamination by other bacteria or microorganisms. The aseptic technique is also used in medicine, where it is important to keep the human body free of contamination.

Aseptic technique is used whenever bacteria or other microbes are transferred between nutrient media or in the preparation of the nutrient media. Some equipment that is used in the aseptic technique include a Bunsen burner, an autoclave (**Figure** 1.35), hand and surface sanitizers, neoprene gloves, and a fume hood.

Figure 1.33: This insect has been coated in gold, as part of the preparation for viewing with an SEM. (12)

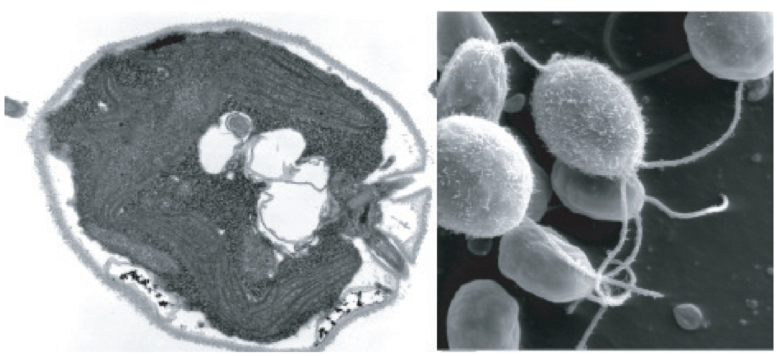

Figure 1.34: SEM and TEM images of the algae *Chlamydomonas*. The SEM image, shown at the right, is a three-dimensional image of the surface of the organism, whereas the TEM image is a two-dimensional image of the interior of the organism. (32)

Students of microbiology are taught the principles of aseptic technique by hands-on laboratory practice. Practice is essential in learning how to handle the lab tools without contaminating them.

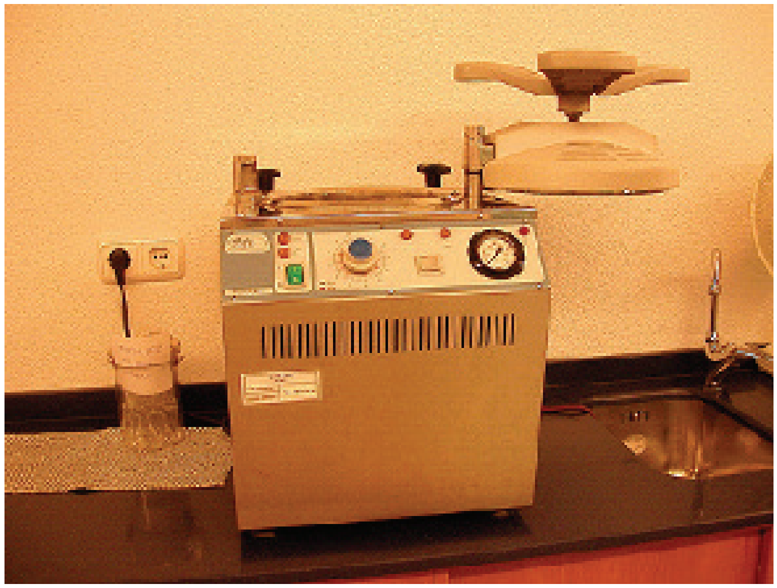

Figure 1.35: A worktop autoclave. Autoclaves commonly use steam heated to 121°C (250°F), at 103 kPa (15 psi) above atmospheric pressure. Solid surfaces are effectively sterilized when heated to this temperature. Liquids can also be sterilized by this process, though additional time is required to reach sterilizing temperature. (24)

Scientific Models

Scientific models are representations of reality. To describe particular parts of a phenomenon, or the interactions among a set of phenomena, it is sometimes helpful to develop a model of the phenomenon. For instance, a scale model of a house or of a solar system is clearly not an actual house or an actual solar system; the parts of an actual house or an actual solar system represented by a scale model are, only in limited ways, representative of the actual objects.

Scientific modeling is the process of making abstract models of natural phenomena. An **abstract model** is a theoretical construct that represents something. Models are developed to allow reasoning within a simplified framework that is similar to the phenomena being investigated. The simplified model may assume certain things that are known to be incomplete in some details. Such assumptions can be useful in that they simplify the model, while at the same time, allowing the development of acceptably accurate solutions. These models play an important role in developing scientific theories.

A **simulation** is a model that runs over time. A simulation brings a model to life and

Figure 1.36: A model of planets of the solar system. This model is clearly not a real solar system; it is a representation of the planets Jupiter, Saturn, Neptune, and Uranus. Scientists use representations of natural things to learn more about them. Also, the visitors to the Griffith Observatory in Los Angeles can get a better idea of the relative sizes of the planets (and Pluto!) by observing this model. (39)

shows how a particular object or phenomenon will behave. It is useful for testing, analysis or training where real-world systems or concepts can be represented by a model. For the scientist, a model also provides a way for calculations to be expanded to explore what might happen in different situations. This method often takes the form of models that can be programmed into computers. The scientist controls the basic assumptions about the variables in the model, and the computer runs the simulation, eventually coming to a complicated answer.

Examples of models include:

- Computer models
- Weather forecast models
- Molecular models
- Climate models
- Ecosystem models
- Geologic models

One of the main aims of scientific modeling is to allow researchers to quantify their observations about the world. In this way, researchers hope to see new things that may have escaped the notice of other researchers. There are many techniques that model builders use which allow us to discover things about a phenomenon that may not be obvious to everyone.

- The National Weather Service Enhanced Radar Images web site (http://radar.weather.gov/) is an excellent example of a simulation. The site exhibits current weather forecasts across the United States.

Evaluating Models

A person who builds a model must be able to recognize whether a model reflects reality. They must also be able to identify and work with differences between actual data and theory.

A model is evaluated mostly by how it reflects past observations of the phenomenon. Any model that is not consistent with reproducible observations must be modified or rejected. However, a fit to observed data alone is not enough for a model to be accepted as valid. Other factors important in evaluating a model include:

- Its ability to explain past observations
- Its ability to predict future observations
- Its ability to control events
- The cost of its use, especially when used with other models
- Ease of use and how it looks

Some examples of the different types of models that are used by science are shown in **Figures** 1.37 and 1.38.

Theories as "Models"

Theories are constructed in order to explain, predict and understand phenomena. This could include the movement of planets, weather patterns, or the behavior of animals, for example. In many instances we are constructing models of reality. A theory makes generalizations about observations and is made up of a related set of ideas and models. The important difference between theories and models is that the first is explanatory as well as descriptive, while the second is only descriptive and predictive in a much more limited sense.

Lab Safety

In some laboratories, conditions are no more dangerous than in any other room. In many labs, though, additional hazards are present. Laboratory hazards are as varied as the subjects of study in laboratories, and might include poisons, infectious agents, flammable, explosive, or radioactive materials, moving machinery, extreme temperatures, or high voltage. The hazard symbols for corrosive, explosive, and flammable substances are shown in **Figure** 1.39. In laboratories where conditions might be dangerous, safety precautions are important. Lab

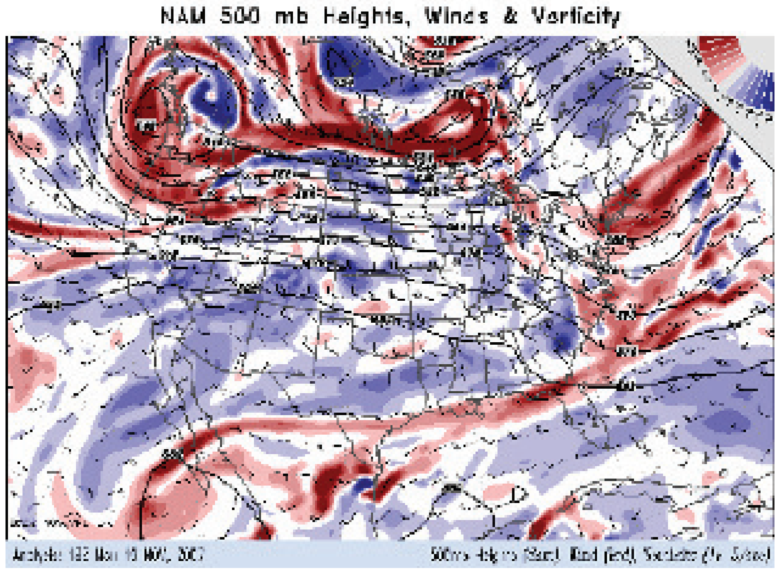

Figure 1.37: A computer model of wind patterns across the continental United States for 19 November, 2007. This model is used to forecast wind speeds and directions. Data on wind speed, direction, and related data are entered into a computer which then produces this simulation. This visual model is much easier for a person to understand than a large table of numbers. (15)

Figure 1.38: Biosphere 2 is an example of a very large three-dimensional model which biologists built to attempt to recreate a self-sustaining biome. To learn more about biomes and ecosystems, go to the *Biomes, Ecosystems and Communities* chapter. (5)

Figure 1.39: The hazard symbols for corrosive, explosive, and flammable substances. (40)

Figure 1.40: Immediate disposal of used needles, and other sharp equipment into a sharps container is standard procedure. (4)

safety rules minimize a person's risk of getting hurt, and safety equipment is used to protect the lab user from injury or to help in responding to an emergency.

Some safety equipment that you might find in a biology lab includes:

Sharps Container A container that is filled with used medical needles and other sharp instruments such as blades, shown in **Figure** 1.40. Needles or other sharp items that have been used are dropped into the container without touching the outside of the container. Objects should never be pushed or forced into the container, as damage to the container or injuries may result.

Laminar Flow Cabinet A carefully enclosed bench designed to prevent contamination of biological samples. Air is drawn through a fine filter and blown in a very smooth, laminar (streamlined) flow towards the user. The cabinet is usually made of stainless steel with no gaps or joints where microorganisms might collect.

Gloves Due to possible allergic reactions to latex, latex gloves are not recommended for lab use. Instead, vinyl or nitrile gloves, shown in **Figure** 1.41, are often used. Gloves protect the wearers hands and skin from getting contaminated by microorganisms or stained or irritated by chemicals.

Figure 1.41: A nitrile glove. Latex gloves are no longer recommended so vinyl gloves or nitrile gloves, which are usually green or blue in color, are preferred. (26)

Lab Coat A knee-length overcoat that is usually worn while working in the lab. The coat helps to protect the researcher's clothes from splashes or contamination. The garment is made from white cotton or linen to allow it to be washed at high temperature and make it easy to see if it is clean.

Safe Laboratory Practice

Safety precautions are in place to help prevent accidents. Always wear personal protective equipment such as goggles and gloves when recommended to do so by your teacher.

- Tell your teacher immediately if an accident happens.
- The production of aerosols due to poor technique such as squirting the last drop out of pipettes, and the spread of contamination due to spills is completely avoidable and especially important if you are handling infectious material or chemicals.
- Wear enclosed toe shoes, instead of sandals or flip flops, or thongs. Your feet and toes could easily get hurt or broken or if you dropped something. (**Figure** 1.42)
- Do not wear loose, floppy clothes in the lab; they can get caught in or knock over equipment, causing an accident.
- If you have long hair, tie it up for the same reasons listed above.
- Do not eat or drink in the lab.
- Do not use cell phones in the lab, even if you are only sending a text message. You can easily contaminate your phone with whatever you have been working with. Consider where your hands have been, and where your face will be the next time you talk on the phone.
- Sweep up broken glass immediately and dispose in a designated area or container, or notify your teacher.
- Always listen carefully to your teacher's instructions.

Figure 1.42: Although they may be comfy and casual, flip-flops and other open-toed shoes are not suitable footwear in the lab. (22)

Accidents

In the case of an accident, it is important to begin by telling your teacher and to know where to find safety equipment.

Some common safety equipment in a school lab:

- Fire Extinguishers
- Fire Blanket
- Eye-Wash Fountain (**Figure** 1.43)
- First-Aid Kit

Figure 1.43: Symbol for the eyewash fountain. (51)

Through the first three lessons, we have discussed what science is and how science is done. Now we need to turn our attention to Biology. Biology is the study of life. As the 'study of life,' a knowledge of biology is an extremely important aspect of your education. Biology includes the identification and analysis of characteristics common to all living organisms. What is known about biology is discovered or identified through the same processes as all other sciences, including the scientific method and peer review process.

Lesson Summary

- The measurements that scientists use are based on the International System of Units (SI), which is form of the metric system. Based on multiples of ten, It is the world's most widely used system of units, both in science and business.
- One important use for mathematics in science is the role it plays in expressing scientific models. Statistics allow scientists to assess the reliability and range of differences in experimental results.

- Light microscopes use visible light and lenses to magnify objects. They are the simplest and most widely used type of microscopes. Electron microscopes use electrons instead of photons (light), because electrons have a much shorter wavelength than photons and therefore allow a researcher to see things at very high magnification, that greatly exceeds what an optical microscope can possibly magnify. Electron microscopes are larger and more expensive than light microscopes.
- Equipment commonly found in a biology labs include microscopes, weighing scales or balances, water baths, glassware (such as test tubes, flasks, and beakers), Bunsen burners, tongs, pipettes, chemical reagents, lab coats, goggles, and biohazard waste containers.
- Always wear personal protective equipment such as goggles and gloves, wear enclosed shoes, and do not eat or drink in the lab.

Review Questions

1. Which one of the following units of measurement would be the most appropriate in determining the mass of a banana? Kilograms, micrograms, or grams.
2. Identify the type of microscope that is most common in laboratories.
3. Contrast microscope magnification and resolution.
4. If an objective lens magnifies an object by 45×, and the optical lens magnifies by 10×. By how much will the object be magnified to the viewer?
5. Which object is larger? An object with a diameter of 1500 micrometers (µm) or an object with a diameter of 15 millimeters (mm)?
6. Why is it important that scientists use common units of measurement?
7. Name three pieces of safety equipment that you should wear while carrying out an investigation in the lab.
8. What should you first do if an accident happens in the lab?
9. If you saw this hazard sign on a chemical container, what do you think it might mean?

10. How are computer models similar to the real world, and how do they differ?

Further Reading / Supplemental Links

- http://www.chem.unl.edu/safety/hslabcon.html
- http://en.wikibooks.org/wiki/Nanotechnology/Electron_microscopy

Vocabulary

aseptic technique Laboratory procedures that are carried out under sterile conditions.

compound microscope An optical microscopes that has a series of lenses, and have uses in many fields of science, particularly biology and geology.

electron microscope A microscope that uses electrons instead of light; allow a researcher to see things at very high magnification, far higher than an optical microscope can possibly magnify.

International System of Units (SI) The measurements that scientists use; a form of the metric system.

lab coat A knee-length overcoat that is usually worn while working in the lab; helps to protect the researcher's clothes from splashes or contamination.

laboratory A place that has controlled conditions in which scientific research, experiments, and measurement may be carried out.

lab techniques The procedures used in science to carry out an experiment.

magnification Enlarging an image of an object so that it appears much bigger than its actual size; also refers to the number of times an object is magnified.

microscopes Instruments used to view objects that are too small to be seen by the naked eye.

model A physical, mathematical, or logical representation of a system, phenomenon, or process; allow scientists to investigate a phenomenon in a controlled way.

optical microscope A microscope that uses visible light and lenses to magnify objects.

resolution A measure of the clarity of an image; it is the minimum distance two points can be separated and still be distinguished as two separate points.

scanning electron microscope (SEM) Electron microscope that scans an electron beam over the surface of an object and measures how many electrons are scattered back.

scientific modeling The process of making abstract models of natural phenomena.

simulation A model that runs over time; brings a model to life and shows how a particular object or phenomenon will behave.

stereo microscope A light microscope with two ocular lenses.

transmission electron microscope (TEM) Electron microscope that shoots electrons through the sample and measures how the electron beam changes because it is scattered in the sample.

Points to Consider

- Consider how much more difficult it would be to carry out investigations without the use of computers, and the types of models that have developed due to the development of computers.
- Consider reasons why eating and drinking are not allowed in the lab.
- What additional ethical considerations would there be if you were working with living organisms in the lab, such as mice, rats, or other mammals?

1.4 Lesson 1.4: Principles of Biology

Lesson Objectives

- List some of the different areas of study in biology.
- Identify the seven characteristics of living things.
- Identify the four unifying principles of modern biology.
- List two different types of interactions that organisms can have with each other.
- Outline the formation of modern evolutionary theory.

Introduction: Characteristics of Life

Biology examines the structure, function, growth, origin, evolution, and distribution of living things. It classifies and describes organisms, their functions, how species come into existence, and the interactions they have with each other and with the natural environment. Four unifying principles form the foundation of modern biology: cell theory, evolution, genetics and homeostasis.

Most biological sciences are specialized areas of study. Biology includes biochemistry, cell biology, microbiology, immunology, genetics, physiology, zoology, ecology, evolutionary biology, and botany. Biochemistry is the study of the chemicals that make up life. Cell biology is the study of life at the level of the cell. Microbiology is the study of microscopic organisms. Immunology is the study of an organism's resistance to disease. Genetics is the study of how organisms pass traits to their offspring. The study of how the human body works is called physiology. Zoology is the study of animals. The study of how organisms interact with their environment and each other is called ecology. Evolutionary biology is the study of how populations and species change over time. Botany is the study of plants. The four unifying principles are important foundations for each and every field of biology. Applied fields of biology such as medicine and genetic research involve many specialized areas of study.

What is Life?

Not all scientists agree exactly about what makes up life. Many characteristics describe most living things. However, with most of the characteristics listed below we can think of one or more examples that would seem to break the rule, with something non-living being classified as living or something living classified as non-living.

There is not just one distinguishing feature that separates a living thing from a non-living thing. A cat moves but so does a car. A tree grows bigger, but so does a cloud. A cell has structure, but so does a crystal. Biologists define life by listing characteristics that living things share. Something that has all of the characteristics of life is considered to be alive. The duck decoy in **Figure** 1.44 may look like a duck, act like a duck in that it floats about, but it is not alive. The decoy cannot reproduce offspring, respond to its environment, or breathe.

Figure 1.44: Is it a duck? Both of these objects move across the water's surface. But, how can you tell which one is alive and which is not? You can tell by seeing which of them have all of the characteristics of life. (34)

An individual living creature is called an **organism**. There are many characteristics that living organisms share. They all:

- respond to their environment
- grow and change
- reproduce and have offspring
- have a complex chemistry
- maintain homeostasis
- are built of structures called cells
- pass their traits onto their offspring

Responding to the Environment

If you step on a rock, it will just lie there, but if you step on a turtle, it may move or even snap at you. Living things know what is going on around them, and respond to changes in the environment. An **adaptation** refers to the process of becoming adjusted to an environment. Adaptations may include structural, physiological, or behavioral traits that improve an organism's likelihood of survival, and thus, reproduction.

Growth and Change

A seed may look like a pebble, but under the right conditions it will sprout and form a seedling that will grow into a larger plant. The pebble of course will not grow.

Reproduction

Living things make more organisms like themselves. Whether the organism is a rabbit, or a tree, or a bacterium, life will create more life.

Have Complex Chemistry

A flower has a complicated and beautiful structure. So does a crystal. But if you look closely at the crystal, you see no change. The flower, on the other hand, is transporting water through its petals, producing pigment molecules, breaking down sugar for energy, and undergoing a large number of other chemical reactions that are needed for living organisms to stay alive. We call the sum of the chemical reactions in a cell its **metabolism**.

Maintain Homeostasis

A human body has a temperature of 37° Celsius, (about 98.6° Fahrenheit). If you step outside on a cold morning, the temperature might be below freezing. Nevertheless, you do not become an ice cube. Your shiver and move your arms and legs about to stay warm. Eating food also gives your body the energy to keep warm. Living organisms keep their internal environments within a certain range (they maintain a stable internal condition), despite changes in their external environment. This process is called **homeostasis**.

Built of Cells

If you look closely at any organism you can see that it is made of structures called **cells**. Organisms that are very different such as ferns, and fish, and elephants all look very similar at the cellular level. All living organisms are made of one or more cells. Organisms are organized in the microscopic level from atoms up to cells. The matter is structured in an ordered way. Atoms are arranged into molecules, then into macromolecules, which make up organelles, which work together to form cells. Beyond this, cells are organized in higher levels to form entire multicellular organisms, as shown in **Figure** 1.45. Cells together form tissues, which make up organs, which are part of organ systems, which work together to form an entire organism. Of course, beyond this, organisms form populations which make up parts of an ecosystem. All of Earth's ecosystems together form the diverse environment that is Earth.

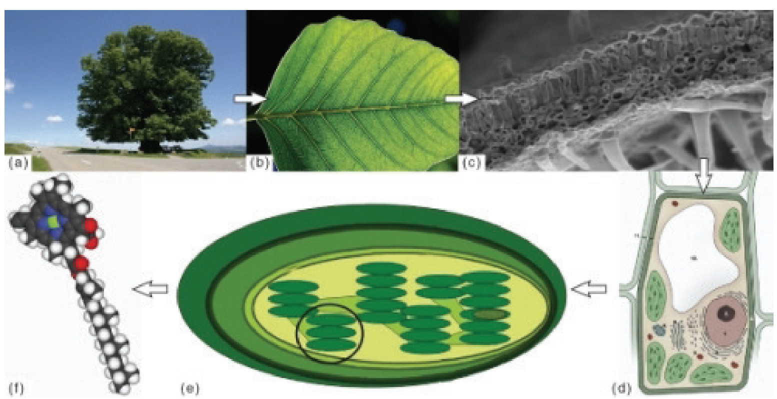

Figure 1.45: Levels of organization in a tree. (a)The tree is the organism; (b) a leaf is an organ, (c) a leaf tissue is made up of different types of cells; (d) a plant cell; (e) chloroplast is an organelle inside a plant cell; (f) chlorophyll is the photosynthetic molecule that is found in chloroplasts. (30)

Unifying Principles of Biology

There are four unifying principles of biology that are important for types of biology studies. These are:

The Cell Theory

The cell is the basic unit of life. The Cell Theory states that all living things are made of one or more cells, or the secretions of those cells, such as the organisms shown in **Figure** 1.46. For example, shell and bone are built by cells from substances that they secrete into their surroundings. Cells come from cells that already exist, that is, they do not suddenly appear from nowhere. In organisms that are made of many cells (called multicellular organisms), every cell in the organism's body derives from the single cell that results from a fertilized egg. You will learn more about cells and the Cell Theory in the *Cell Structure and Function* chapter.

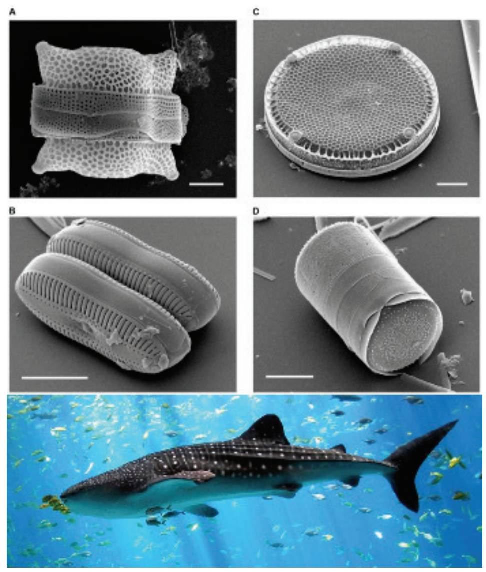

Figure 1.46: Tiny diatoms and whale sharks are all made of cells. Diatoms are about 20 µm in diameter and are made up of one cell, whereas whale sharks can measure up to 12 meters in length, and are made up of billions of cells. (20)

Gene Theory

A living organism's traits are encoded in their DNA, the large molecule, or macromolecule, that holds the instructions needed to build cells and organisms. DNA makes up the genes of an organism. Traits are passed on from one generation to the next by way of these genes. Information for how the organism appears and how its cells work come from the organism's genes. Although the appearance and cell function of the organism may change due to the organism's environment, the environment does not change its genes. The only way that genes can change in response to a particular environment is through the process of evolution in populations of organisms. You will learn more about DNA and genes in the *Molecular Genetics* chapter.

Homeostasis

Homeostasis is the ability of an organism to control its body functions in order to uphold a stable internal environment even when its external environment changes. All living organisms perform homeostasis. For example, cells maintain a stable internal acidity (pH); and warm-blooded animals maintain a constant body temperature. You will learn more about homeostasis in *The Human Body* chapter.

Homeostasis is a term that is also used when talking about the environment. For example, the atmospheric concentration of carbon dioxide on Earth has been regulated by the concentration of plant life on Earth because plants remove more carbon dioxide from the atmosphere during the daylight hours than they emit to the atmosphere at night.

Evolution

Evolution by natural selection, is the theory that maintains that a population's inherited traits change over time, and that all known organisms have a common origin. Evolutionary theory can explain how specialized features, such as the geckos sticky foot pads shown in **Figure** 1.47, develop in different species. You will learn more about evolution in the *Evolutionary Theory* and *Evolution in Populations* chapters.

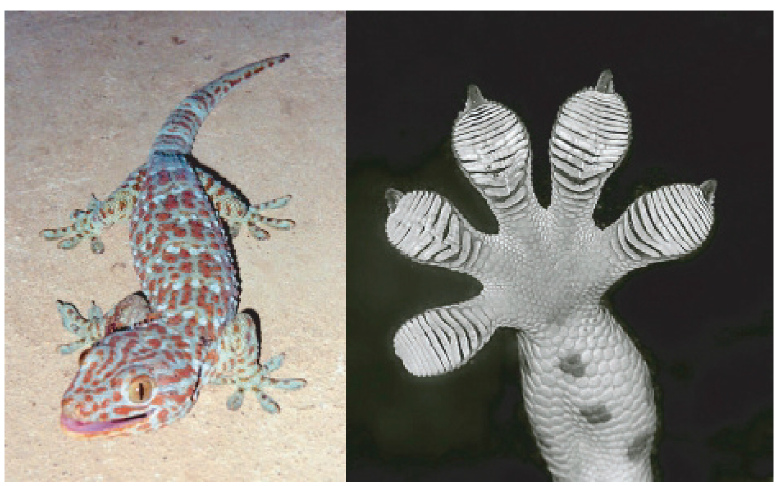

Figure 1.47: A Tokay Gecko. The pads at the tip of the Tokay gecko's foot are covered in microscopic hairs, each split into hundreds of tips that measure about 200 nanometers in diameter. By using these tiny hairs that can cling to smooth surfaces, the geckos are able to support their entire body weight while climbing walls, definately a product of evolution. (54)

Interdependence of Living Things

Biological interactions are the interactions between different organisms in an environment. In the natural world no organism is cut off from its surroundings. Organisms are a part of their environment which is rich in living and non-living elements that interact with each other in some way. The interactions of an organism with its environment are vital to its survival, and the functioning of the ecosystem as a whole.

These relationships can be categorized into many different classes. The interactions between two species do not necessarily need to be through direct contact. Due to the connected nature of ecosystems, species may affect each other through such relationships involving shared resources or common enemies.

The term **symbiosis** comes from a Greek word that means "living together." Symbiosis can be used to describe various types of close relationships between organisms of different species, such as **mutualism** and **commensalism**, which are relationships in which neither organism is harmed. Sometimes the term symbiosis is used only for cases where both organisms benefit, sometimes it is used more generally to describe all kinds of close relationships, even when one organism is killed by another, as shown in **Figure** 1.48. Symbiosis can also be used to describe relationships where one organism lives on or in another, called **parasitism**, or when one organism kills and eats another organism, called **predation**.

Competition

Competition is as an interaction between organisms or species, for the same resources such as water, food, or hunting grounds in an environment, shown in **Figure** 1.49. Eventually, the species that is less able to compete for resources will either adapt or die out. According to evolutionary theory, competition for resources plays an important role in natural selection.

Animals that eat decomposing organic material also have an important interaction with the environment. They help to decompose dead matter and assist with the recycling of nutrients. By burying and eating dung, dung beetles, such as the one shown in **Figure** 1.50, improve nutrient cycling and soil structure. They make the dead organic matter available to bacteria that break it down even further.

Levels of Organization

In studying how organisms interact with each other, biologists often find it helpful to classify the organisms and interactions into levels of organization. Similar to the way an organism itself has different levels of organization, the ways in which organisms interact with their environment and each other can also be divided in to levels of organization. For example:

The **biosphere** includes all living things within all of their environments. It includes every

Figure 1.48: There are many different types of symbiotic interactions between organisms. Clockwise from top left: *Escherichia coli* bacteria live inside your intestines in a mutualistic relationship; the bacteria produce Vitamin K for you, and they get their food from what you eat. Lions are predators that feed on other organisms such as this Cape buffalo. Similar to the E. *coli*, this bee has a mutualistic relationship with the flower, the bee feeds from the flower, and the flower gets pollinated by the bee. Clownfish that live among the tentacles of sea anemones protect the anemone from anemone-eating fish, and in turn the stinging tentacles of the anemone protect the clownfish from its predators (a special mucus on the clownfish protects it from the stinging tentacles). (23)

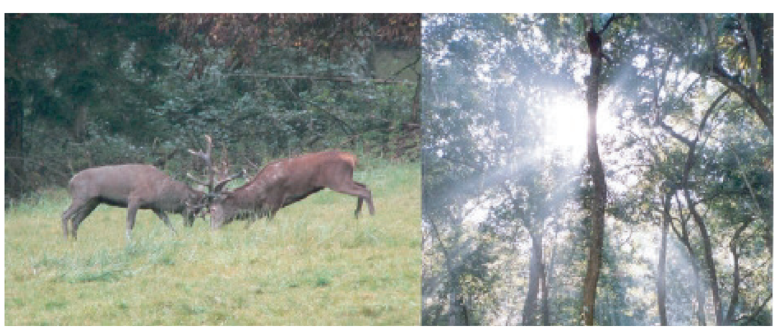

Figure 1.49: Competition between organisms and species. These male deer are competing for females during rutting (mating) season. Trees in this Bangladesh forest are in competition for light. (35)

Figure 1.50: Dung beetles have important interactions with the environment, through which many other organisms benefit. (17)

place that life occurs, from the upper reaches of the atmosphere to the top few meters of soil, to the bottoms of the oceans. An **ecosystem** is made up of the relationships among smaller groups of organisms with each other, and their environment. Scientists often speak of the interrelatedness of living things, because, according to evolutionary theory, organisms adapt to their environment, and they must also adapt to other organisms in that environment.

A **community** is made up of the relationships between groups of different species. For example, the desert communities consist of rabbits, coyotes, snakes, birds, mice and such plants as sahuaro cactus, ocotillo, and creosote bush. Community structure can be disturbed by such dynamics as fire, human activity, and over-population.

It is thus possible to study biology at many levels, from collections of organisms or communities, to the inner workings of a cell (organelle). To learn more about the interactions of organisms, you will read the *Biomes, Ecosystems and Communities* and *Populations* chapters.

The Diversity of Life

Evolutionary theory and the cell theory give us the basis for how and why, living things relate to each other. The diversity of life found on Earth today is the result of 4 billion years of evolution. Some of this diversity is shown in **Figure** 1.51. The origin of life is not completely understood by science, though limited evidence suggests that life may already have been well-established a few 100 million years after Earth formed. Until approximately 600 million years ago, all life was made up of single-celled organisms.

The level of biodiversity found in the fossil record suggests that the last few million years include the period of greatest biodiversity in the Earth's history. However, not all scientists support this view, since there is a lot of uncertainty as to how strongly the fossil record is biased by the greater availability and preservation of more recent fossil-containing rock layers. Some researchers argue that modern biodiversity is not much different from biodiversity 300 million years ago. Estimates of the present global species diversity vary from 2 million to 100 million species, with a best estimate of somewhere near 10 million species. All living organisms are classified into one of the six kingdoms: Archaebacteria (Archaea), Eubacteria (Bacteria), Protista (Protists), Fungi, Plantae (Plants), and Animalia (Animals).

New species are regularly discovered and many, though already discovered, are not yet classified. One estimate states that about 40 percent of freshwater fish from South America are not yet classified. Every year, scientists discover the existence of many hundreds more archaea and bacteria than were previously known about. Just a few of the many members of the animal kingdom are shown in **Figure** 1.51. The animal kingdom is just a tiny portion of the total diversity of life. To learn more about the diversity of living creatures, you will read the *Classification; Prokaryotes and Viruses; Protists; Fungi; Evolution and Classification of Plants; and Introduction to Animals and Invertebrates* chapters.

Evolution of Life

Evolution is the process by which populations of organisms change over time. These organisms acquire and pass on new traits from generation to the next generation. Its occurrence over large stretches of time explains the origin of new species and the great diversity of the biological world. **Extant** species are related to each other through common descent, and products of evolution over billions of years. Analysis of the DNA of different organisms indicate there is a similarity in the DNA genetic codes that help make proteins and other molecules in very different organisms. These genetic codes are used by all known forms of life on Earth, and are very similar. The theory of evolution suggests that the genetic code was established very early in the history of life and some studies suggest it was established soon after the formation of Earth. The timeline of the evolution of life, shown in **Figure** 1.52, outlines the major events in the development of life.

How do scientists know Earth is so old? The answer is in the rocks. Contained in rocks that were once molten, shown in **Figure** 1.53, are chemical elements that act like an atomic clock. The atoms of different forms of elements (called isotopes) break down at different rates over time. Parent isotopes within these rocks decay at a predictable rate to form daughter isotopes. By determining the relative amounts of parent and daughter isotopes, the age of these rocks can be calculated—forming the so-called atomic clock.

Thus, the results of studies of rock layers (stratigraphy), and of fossils (paleontology), along with the ages of certain rocks as measured by atomic clocks (geochronology), indicate that the Earth is over 4.5 billion years old, with the oldest known rocks being 3.96 billion years

Figure 1.51: Animal diversity. This figure shows just a fraction of the diversity of life. The diversity of organisms found in the five kingdoms of life, dwarf the number of organisms found in the animal kingdom. The other kingdoms of life are Eubacteria, Archaebacteria, Protista, Fungi, and Plantae. (21)

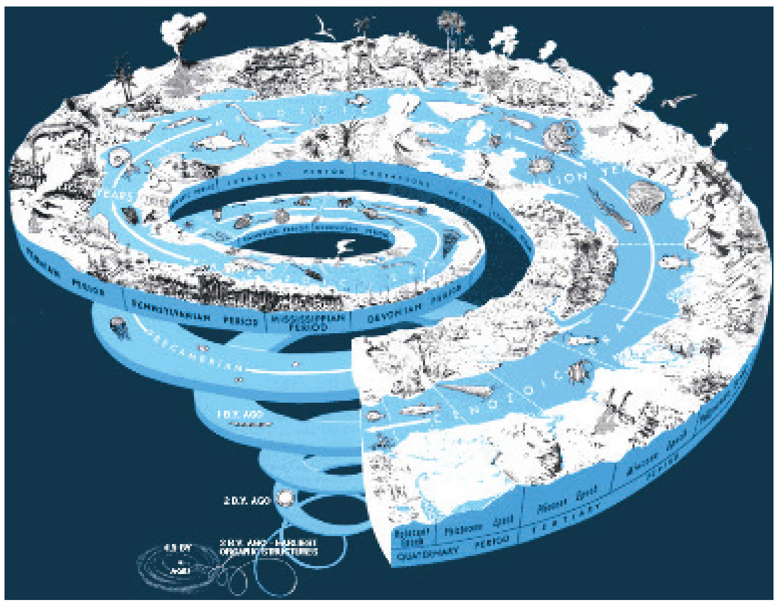

Figure 1.52: According to recent estimates, the Earth is about 4.5 billion years old. Most of the evidence for an ancient Earth is contained in the rocks that form the Earth's crust. The rock layers themselves, like pages in thick history book, record the surface shaping events of the past. Buried within them are traces of life, including the plants and animals that evolved from organic structures that existed perhaps as many as 3 billion years ago. (25)

old. To learn more about the history of life on Earth, you will read the History of Life chapter.

Figure 1.53: Molten rock, called *lava*, is expelled by a volcano during an eruption. The lava will eventually cool to become solid rock. When first expelled from a volcanic vent, it is a liquid at temperatures from 700 °C to 1,200 °C (1,300 °F to 2,200 °F). Not all types of rocks come from cooled lava, but many do. Additional images/videos of volcanic eruptions can be seen at Hawaii Volcanic Eruption with Lightning and USGS Kilauea Volcano (http://www.youtube.com/watch?v=y3aqFCT87_E and http://hvo.wr.usgs.gov/gallery/kilauea/volcanomovies/). (36)

History of Evolutionary Thought

The theory of evolution by natural selection was proposed at about the same time by both Charles Darwin and Alfred Russel Wallace, shown in **Figure** 1.54, and was set out in detail in Darwin's 1859 book *On the Origin of Species.* **Natural selection** is a process that causes heritable traits that are helpful for survival and reproduction to become more common, and harmful traits, or traits that are not helpful or advantageous for survival to become more rare in a population of organisms. This occurs because organisms with advantageous traits are more "fit" to survive in a particular environment and have "adapted" to the conditions of that environment. These individuals will have greater reproductive success than organisms less fit for survival in the environment. This will lead to an increase in the number of organisms with the advantageous trait(s) over time. Over many generations, adaptations occur through a combination of successive, small, random changes in traits, and natural selection of those variants best-suited for their environment. Natural selection is one of the cornerstones of modern biology.

The theory of evolution encountered initial resistance from religious authorities who believed humans were divinely set apart from the animal kingdom. There was considerable concern about Darwin's proposal of an entirely scientific explanation for the origin of humans. Many people found such an explanation to be in direct conflict with their religious beliefs. A caricature of Darwin as a monkey, shown in **Figure** 1.55, reflects the controversy that arose

Figure 1.54: Charles Darwin, left (1809-1882), and Alfred Russel Wallace, right (1823-1913). Both scientists proposed a process of evolution by natural selection at about the same time. However, Darwin was first to publish his findings. (2)

over evolutionary theory. In the 1930s, Darwinian natural selection was combined with Mendelian inheritance to form the basis of modern evolutionary theory.

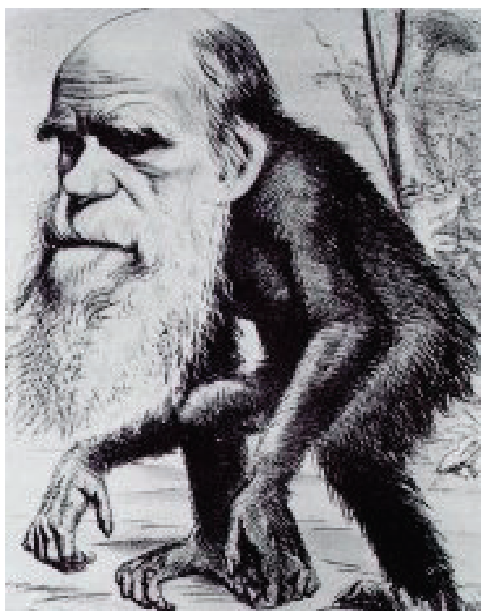

Figure 1.55: An 1871 caricature portraying Darwin with an ape body and the bushy beard he grew in 1866. Such satire reflected the cultural backlash against evolution. (3)

The identification of DNA as the genetic material by Oswald Avery and colleagues in the 1940s, as well as the publication of the structure of DNA by James Watson and Francis Crick in 1953, demonstrated the physical basis for inheritance. Since then, genetics and molecular biology have become core aspects of evolutionary biology.

Currently the study of evolutionary biology involves scientists from fields as diverse as biochemistry, ecology, genetics and physiology, and evolutionary concepts are used in even more distant disciplines such as psychology, medicine, philosophy and computer science.

Misconceptions About Evolution

The following list includes some common misconceptions about evolution.

- The term evolution describes the changes that occur in populations of living organisms over time. Describing these changes does not address the origin of life. The two are commonly and mistakenly confused. Biological evolution likewise says nothing about cosmology, the Big Bang, or where the universe, galaxy, solar system, or Earth came from.
- Humans did not evolve from chimpanzees or any other modern ape; instead they share a common ancestor that existed around 7 million years ago.
- The process of evolution is not necessarily slow. Millions of years are not required to see evolution in action. Indeed, it has been observed multiple times under both controlled laboratory conditions and in nature.
- Evolution is not a progression from ”lower” to ”higher” forms of life, and it does not increase in complexity. For example, bacteria have simpler structures and a smaller amount of genetic material than humans do. This does not mean however, that bacteria are “less evolved” than humans are. Bacteria have evolved over many millions of years and are well adapted to their own environments.

After Darwin

Since Darwin’s time, scientists have gathered a more complete fossil record, including microorganisms and chemical fossils. These fossils have supported and added more information to Darwin’s theories. However, the age of the Earth is now held to be much older than Darwin thought. Researchers have also uncovered some of the preliminary mysteries of the mechanism of heredity as carried out through genetics and DNA, which were areas unknown to Darwin. Another growing subject is the study of comparative anatomy, which looks at how different organisms have similar body structures. Molecular biology studies of slowly changing genes reveal an evolutionary history that is consistent with fossil and anatomical records.

Lesson Summary

- Biochemistry is the study of the chemicals that make up life. Cell biology is the study of life at the level of the cell. Microbiology is the study of microscopic organisms. Genetics is the study of how organisms pass traits to their offspring. The study of how the human body works is called physiology. Zoology is the study of animals. The study of how organisms interact with their environment and each other is called ecology. Evolutionary biology is the study of how populations and species of animals change over time. Botany is the study of plants.

- The seven characteristics of life include: responsiveness to the environment; growth and change; ability to reproduce; have a metabolism and breathe; maintain homeostasis; being made of cells; passing traits onto offspring.
- Four unifying principles form the foundation of modern biology: cell theory, evolution, genetics and homeostasis. These four principles are important to each and every field of biology.
- Symbiosis can be used to describe various types of close relationships between organisms of different species, such as mutualism and commensalism, which are relationships in which neither organism is harmed. Sometimes the term symbiosis is used only for cases where both organisms benefit, but sometimes it is used more generally to describe all kinds of close relationships, even when one organism is killed by another. Symbiosis can also be used to describe relationships where one organism lives on or in another, called parasitism, or when one organism kills and eats another organism, called predation. Competition is as an interaction between organisms or species for the same resources in an environment.
- Analysis of the DNA of different organisms indicate that there is a similarity in the DNA genetic codes that help make proteins and other molecules in very different organisms. These genetic codes are used by all known forms of life on Earth, and are very similar. The theory of evolution suggests that the genetic code was established very early in the history of life and some studies suggest it was established soon after the formation of Earth.

Review Questions

1. Identify three of the seven characteristics of living things.
2. Identify the four unifying principles of modern biology.
3. List two different types of interactions that organisms can have with each other.
4. Outline the formation of modern evolutionary theory.
5. Give an example of how you are interdependent from another organism.
6. You find an object that looks like a dead, brown leaf, but it also looks like it might have eyes and legs–features that leaves do not usually have. How would you go about determining if this object was a living creature.
7. What is the basic unit of life?
8. What is homeostasis?
9. How have more recent scientific findings fit with evolutionary theory since Darwin's time?
10. Large animals are more evolved than single-celled organisms such as bacteria. Do you agree with this statement?

Further Reading / Supplemental Links

- http://en.wikibooks.org/wiki/Biology%2C_Answering_the_Big_Questions_of_Life/Introduction
- http://thinkexist.com/quotations/education/
- http://www.ucmp.berkeley.edu/help/timeform.html

Vocabulary

adaptation Refers to the process of becoming adjusted to an environment; may include structural, physiological, or behavioral traits that improve an organism's likelihood of survival and reproduction.

biochemistry The study of the chemicals that make up life.

biological interactions The interactions between different organisms in an environment.

biology The study of life.

biosphere Every place that life occurs, from the upper reaches of the atmosphere to the top few meters of soil, to the bottoms of the oceans.

botany The study of plants.

cell The smallest unit of structure and function of living organisms.

cell biology The study of life at the level of the cell.

community Composed of the relationships between groups of different species.

competition An interaction between organisms or species, for the same resources such as water, food, or hunting grounds in an environment.

ecology The study of how organisms interact with their environment and each other.

ecosystem Made up of the relationships among smaller groups of organisms with each other, and their environment.

evolution The process by which populations of organisms change over time by acquiring and passing on new traits from generation to generation.

evolutionary biology The study of how populations and species change over time.

genetics The study of how organisms pass traits to their offspring (heredity).

homeostasis The ability to keep an internal environment within a certain range, despite changes in the external environment.

immunology The study of an organism's resistance to disease.

metabolism The sum of the chemical reactions in a cell.

microbiology The study of microscopic organisms.

natural selection A process that causes heritable traits that are helpful for survival and reproduction to become more common, and harmful traits, or traits that are not helpful or advantageous for survival to become more rare in a population of organisms.

organism An individual living creature.

physiology The study of how the human body works.

symbiosis Various types of close relationships between organisms of different species; comes from a Greek word that means "living together."

zoology The study of animals.

Points to Consider

- All modern scientific disciplines support the theory of evolution. Consider what type of hypothesis could be made that might challenge evolutionary theory. Likewise, consider what type of hypothesis could challenge the cell theory.
- As you read through other chapters in this book, it might help to remember that studying biology does not just mean learning facts by memory or repetition. By studying biology you are developing a knowledge and understanding of the world around you. And, combined with your study of other subjects such as literature, social studies, art, music, mathematics, and physical sciences, you will develop a fuller, deeper understanding of what it is to be a human being who interacts with and lives an interdependent life with other organisms (including other humans!) in your environment.

"Intellectual growth should commence at birth and cease only at death." - **Albert Einstein**

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(3) http://en.wikipedia.org/wiki/Image:Darwin_ape.jpg. Public Domain.

(4) William Rafti Institute. http://en.wikipedia.org/wiki/Image:Sharps_Container.jpg. GNU-FDL.

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(21) en:User:Justin. http://en.wikipedia.org/wiki/Image:Animal_diversity_October_2007.jpg. CC-BY-SA.

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