1.2: THE SCIENCE OF BIOLOGY - SCIENTIFIC REASONING

LEARNING OBJECTIVES

- Compare and contrast theories and hypotheses

THE PROCESS OF SCIENCE

Science (from the Latin scientia, meaning “knowledge”) can be defined as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. The steps of the scientific method will be examined in detail later, but one of the most important aspects of this method is the testing of hypotheses (testable statements) by means of repeatable experiments. Although using the scientific method is inherent to science, it is inadequate in determining what science is. This is because it is relatively easy to apply the scientific method to disciplines such as physics and chemistry, but when it comes to disciplines like archaeology, paleoanthropology, psychology, and geology, the scientific method becomes less applicable as it becomes more difficult to repeat experiments.

These areas of study are still sciences, however. Consider archaeology: even though one cannot perform repeatable experiments, hypotheses may still be supported. For instance, an archaeologist can hypothesize that an ancient culture existed based on finding a piece of pottery. Further hypotheses could be made about various characteristics of this culture. These hypotheses may be found to be plausible (supported by data) and tentatively accepted, or may be falsified and rejected altogether (due to contradictions from data and other findings). A group of related hypotheses, that have not been disproven, may eventually lead to the development of a verified theory. A theory is a tested and confirmed explanation for observations or phenomena that is supported by a large body of evidence. Science may be better defined as fields of study that attempt to comprehend the nature of the universe.

SCIENTIFIC REASONING

One thing is common to all forms of science: an ultimate goal “to know.” Curiosity and inquiry are the driving forces for the development of science. Scientists seek to understand the world and the way it operates. To do this, they use two methods of logical thinking: inductive reasoning and deductive reasoning.

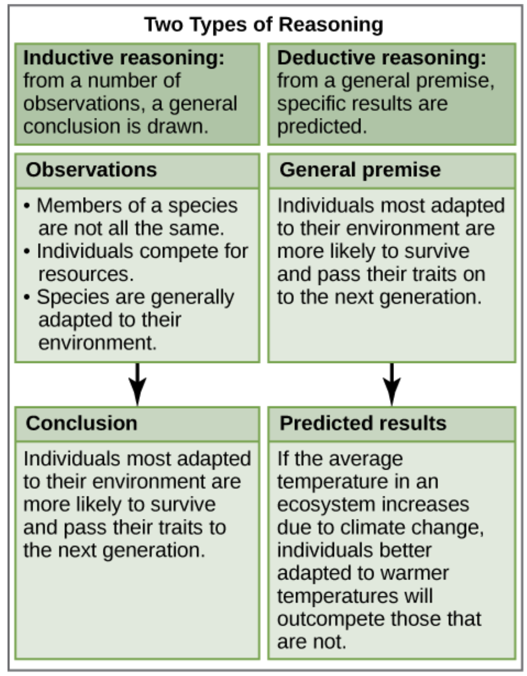

Figure 1.2.1: Scientific Reasoning: Scientists use two types of reasoning, inductive and deductive, to advance scientific knowledge.

Inductive reasoning is a form of logical thinking that uses related observations to arrive at a general conclusion. This type of reasoning is common in descriptive science. A life scientist such as a biologist makes observations and records them. These data can be qualitative or quantitative and the raw data can be supplemented with drawings, pictures, photos, or videos. From many observations, the scientist can infer conclusions (inductions) based on evidence. Inductive reasoning involves formulating generalizations inferred from careful observation and the analysis of a large amount of data. Brain studies provide an example. In this type of research, many live brains are observed while people are doing a specific activity, such as viewing images of food. The part of the brain that “lights up” during this activity is then predicted to be the part controlling the response to the selected stimulus; in this case, images of food. The “lighting up” of the various areas of the brain is caused by excess absorption of radioactive sugar derivatives by active areas of the brain. The resultant increase in radioactivity is observed by a scanner. Then researchers can stimulate that part of the brain to see if similar responses result.

Deductive reasoning or deduction is the type of logic used in hypothesis-based science. In deductive reason, the pattern of thinking moves in the opposite direction as compared to inductive reasoning. Deductive reasoning is a form of logical thinking that uses a general principle or law to forecast specific results. From those general principles, a scientist can extrapolate and predict the specific results that would be valid as long as the general principles are valid. Studies in climate change can illustrate this type of reasoning. For example, scientists may predict that if the climate becomes warmer in a particular region, then the distribution of plants and animals should change. These predictions have been written and tested, and many such predicted changes have been observed, such as the modification of arable areas for agriculture correlated with changes in the average temperatures.

Both types of logical thinking are related to the two main pathways of scientific study: descriptive science and hypothesis-based science. Descriptive (or discovery) science, which is usually inductive, aims to observe, explore, and discover, while hypothesis-based science, which is usually deductive, begins with a specific question or problem and a potential answer or solution that can be tested. The boundary between these two forms of study is often blurred and most scientific endeavors combine both approaches. The fuzzy boundary becomes apparent when thinking about how easily observation can lead to specific questions. For example, a gentleman in the 1940s observed that the burr seeds that stuck to his clothes and his dog's fur had a tiny hook structure. Upon closer inspection, he discovered that the burrs' gripping device was more reliable than a zipper. He eventually developed a company and produced the hook-and-loop fastener popularly known today as Velcro. Descriptive science and hypothesis-based science are in continuous dialogue.

Figure 1.2.1: A Burr: This fruit attaches to animal fur via the hooks on its surface to improve distribution. Velcro is an example of a biomimetic invention which has copied burrs and uses small flexible hooks to reversibly attach to fluffy surfaces.

KEY POINTS

- A hypothesis is a statement/prediction that can be tested by experimentation.
- A theory is an explanation for a set of observations or phenomena that is supported by extensive research and that can be used as the basis for further research.
- Inductive reasoning draws on observations to infer logical conclusions based on the evidence.
- Deductive reasoning is hypothesis-based logical reasoning that deduces conclusions from test results.

KEY TERMS

- **theory**: a well-substantiated explanation of some aspect of the natural world based on knowledge that has been repeatedly confirmed through observation and experimentation
- **hypothesis**: a tentative conjecture explaining an observation, phenomenon, or scientific problem that can be tested by further observation, investigation, and/or experimentation

1.3: THE SCIENCE OF BIOLOGY - THE SCIENTIFIC METHOD

LEARNING OBJECTIVES

- Discuss hypotheses and the components of a scientific experiment as part of the scientific method

THE SCIENTIFIC METHOD

Biologists study the living world by posing questions about it and seeking science -based responses. This approach is common to other sciences as well and is often referred to as the scientific method. The scientific method was used even in ancient times, but it was first documented by England's Sir Francis Bacon (1561–1626) who set up inductive methods for scientific inquiry. The scientific method can be applied to almost all fields of study as a logical, rational, problem-solving method.

Figure 1.3.1: Sir Francis Bacon: Sir Francis Bacon (1561–1626) is credited with being the first to define the scientific method.

The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. A teenager notices that his friend is really tall and wonders why. So his question might be, "Why is my friend so tall? "

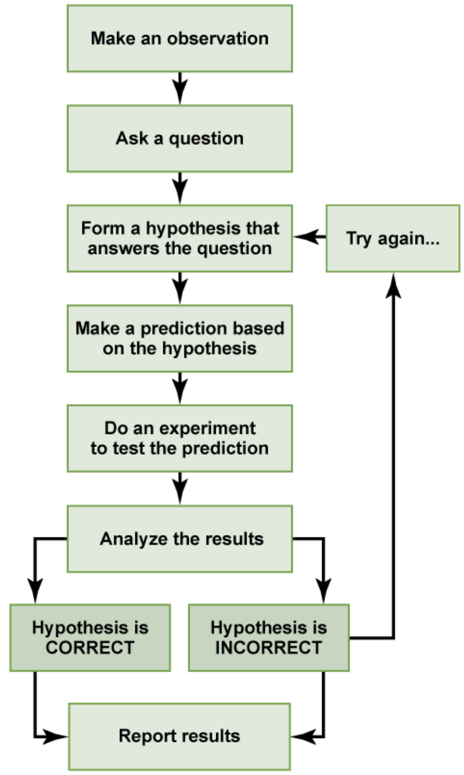

Figure 1.3.1: The Scientific Method: The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed.

PROPOSING A HYPOTHESIS

Recall that a hypothesis is an educated guess that can be tested. Hypotheses often also include an explanation for the educated guess. To solve one problem, several hypotheses may be proposed. For example, the student might believe that his friend is tall because he drinks a lot of milk. So his hypothesis might be "If a person drinks a lot of milk, then they will grow to be very tall because milk is good for your bones." Generally, hypotheses have the format "If… then…" Keep in mind that there could be other responses to the question; therefore, other hypotheses may be proposed. A second hypothesis might be, "If a person has tall parents, then they will also be tall, because they have the genes to be tall. "

Once a hypothesis has been selected, the student can make a prediction. A prediction is similar to a hypothesis but it is truly a guess. For instance, they might predict that their friend is tall because he drinks a lot of milk.

TESTING A HYPOTHESIS

A valid hypothesis must be testable. It should also be falsifiable, meaning that it can be disproven by experimental results. Importantly, science does not claim to "prove" anything because scientific understandings are always subject to modification with further information. This step—openness to disproving ideas—is what distinguishes sciences from non-sciences. The presence of the supernatural, for instance, is neither testable nor falsifiable. To test a hypothesis, a researcher will conduct one or more experiments designed to eliminate one or more of the hypotheses. Each experiment will have one or more variables and one or more controls. A variable is any part of the experiment that can vary or change during the experiment. The control group contains every feature of the experimental group except it is not given the manipulation that is hypothesized. For example, a control group could be a group of varied teenagers that did not drink milk and they could be compared to the experimental group, a group of varied teenagers that did drink milk. Thus, if the results of the experimental group differ from the control group, the difference must be due to the hypothesized manipulation rather than some outside factor. To test the first hypothesis, the student would find out if drinking milk affects height. If drinking milk has no affect on height, then there must be another reason for the height of the friend. To test the second hypothesis, the student could check whether or not his friend has tall parents. Each hypothesis should be tested by carrying out appropriate experiments. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted. It simply eliminates one hypothesis that is not valid. Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

While this "tallness" example is based on observational results, other hypotheses and experiments might have clearer controls. For instance, a student might attend class on Monday and realize she had difficulty concentrating on the lecture. One hypothesis to explain this occurrence might be, "If I eat breakfast before class, then I am better able to pay attention." The student could then design an experiment with a control to test this hypothesis.

The scientific method may seem too rigid and structured. It is important to keep in mind that although scientists often follow this sequence, there is flexibility. Many times, science does not operate in a linear fashion. Instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests.

KEY POINTS

- In the scientific method, observations lead to questions that require answers.
- In the scientific method, the hypothesis is a testable statement proposed to answer a question.
- In the scientific method, experiments (often with controls and variables) are devised to test hypotheses.
- In the scientific method, analysis of the results of an experiment will lead to the hypothesis being accepted or rejected.

KEY TERMS

- **scientific method**: a way of discovering knowledge based on making falsifiable predictions (hypotheses), testing them, and developing theories based on collected data
- **hypothesis**: an educated guess that usually is found in an "if… then…" format
- **control group**: a group that contains every feature of the experimental group except it is not given the manipulation that is hypothesized

1.4: THE SCIENCE OF BIOLOGY - BASIC AND APPLIED SCIENCE

LEARNING OBJECTIVES

- Differentiate between basic and applied science

TWO TYPES OF SCIENCE: BASIC SCIENCE AND APPLIED SCIENCE

The scientific community has been debating for the last few decades about the value of different types of science. Is it valuable to pursue science for the sake of simply gaining knowledge, or does scientific knowledge only have worth if we can apply it to solving a specific problem or to bettering our lives? This question focuses on the differences between two types of science: basic science and applied science.

Basic science or "pure" science seeks to expand knowledge regardless of the short-term application of that knowledge. It is not focused on developing a product or a service of immediate public or commercial value. The goal of basic science is knowledge for knowledge's sake; though this does not mean that, in the end, it may not result in a practical application.

In contrast, applied science or "technology" aims to use science to solve real-world problems such as improving crop yields, finding a cure for a particular disease, or saving animals threatened by a natural disaster. In applied science, the problem is usually defined for the researcher.

Figure 1.4.1: Example of Applied Science: After Hurricane Ike struck the Gulf Coast in 2008, the U.S. Fish and Wildlife Service rescued this brown pelican. Thanks to applied science, scientists knew how to rehabilitate the bird.

Some individuals may perceive applied science as "useful" and basic science as "useless." A question these people might pose to a scientist advocating knowledge acquisition would be, "What for?" A careful look at the history of science, however, reveals that basic knowledge has resulted in many remarkable applications of great value. Many scientists think that a basic understanding of science is necessary before an application is developed; therefore, applied science relies on the results generated through basic science. Other scientists think that it is time to move on from basic science and instead to find solutions to actual problems. Both approaches are valid. It is true that there are problems that demand immediate attention; however, few solutions would be found without the help of the wide knowledge foundation generated through basic science.

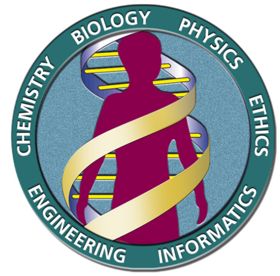

Figure 1.4.1: A Link Between Basic and Applied Science: The Human Genome Project was a 13-year collaborative effort among researchers working in several different fields of science. The project, which sequenced the entire human genome, was completed in 2003.

One example of how basic and applied science can work together to solve practical problems occurred after the discovery of DNA structure led to an understanding of the molecular mechanisms governing DNA replication. Strands of DNA, unique in every human, are found in our cells where they provide the instructions necessary for life. During DNA replication, DNA makes new copies of itself shortly before a cell divides. Understanding the mechanisms of DNA replication enabled scientists to develop laboratory techniques that are now used to identify genetic diseases, pinpoint individuals who were at a crime scene, and determine paternity. Without basic science, it is unlikely that applied science would exist.

Another example of the link between basic and applied research is the Human Genome Project, a study in which each human chromosome was analyzed and mapped to determine the precise sequence of DNA subunits and the exact location of each gene. (The gene is the basic unit of heredity; an individual's complete collection of genes is his or her genome.) Other less complex organisms have also been studied as part of this project in order to gain a better understanding of human chromosomes. The Human Genome Project relied on basic research carried out with simple organisms and, later, with the human genome. An important end goal eventually became using the data for applied research to seek cures and early diagnoses for genetically-related diseases.

While research efforts in both basic science and applied science are usually carefully planned, it is important to note that some discoveries are made by serendipity; that is, by means of a fortunate accident or a lucky surprise. Penicillin was discovered when biologist Alexander Fleming accidentally left a petri dish of *Staphylococcus* bacteria open. An unwanted mold grew on the dish, killing the bacteria. The mold turned out to be Penicillium and a new antibiotic was discovered. Even in the highly organized world of science, luck, when combined with an observant, curious mind, can lead to unexpected breakthroughs.

KEY POINTS

- The only goal of basic science research is to increase the knowledge base of a particular field of study.

- Applied science uses the knowledge base supplied by basic science to devise solutions, often technological, to specific problems.
- The basic science involved in mapping the human genome is leading to applied science techniques that will diagnose and treat genetic diseases.

KEY TERMS

- **basic science**: research done solely to expand the knowledge base
- **applied science**: The discipline dealing with the art or science of applying scientific knowledge to practical problems.

1.5: THE SCIENCE OF BIOLOGY - PUBLISHING SCIENTIFIC WORK

LEARNING OBJECTIVES

- Describe the role played by peer-reviewed scientific articles

REPORTING SCIENTIFIC WORK

Scientists must share their findings in order for other researchers to expand and build upon their discoveries. Collaboration with other scientists—when planning, conducting, and analyzing results—are all important for scientific research. For this reason, a major aspect of a scientist's work is communicating with peers and disseminating results to peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the select few who are present. Instead, most scientists present their results in peer-reviewed manuscripts that are published in scientific journals. Peer-reviewed manuscripts are scientific papers that are reviewed by a scientist's colleagues or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist's work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper or grant proposal is original, significant, logical, and thorough. Grant proposals, which are requests for research funding, are also subject to peer review. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings. The experimental results must be consistent with the findings of other scientists.

Figure 1.5.1: Scientific Journal: Scientific research is published in peer-reviewed scientific journals.

A scientific paper is very different from creative writing. Although creativity is required to design experiments, there are fixed guidelines when it comes to presenting scientific results. Scientific writing must be brief, concise, and accurate. It needs to be succinct but detailed-enough to allow peers to reproduce the experiments.

The scientific paper consists of several specific sections: introduction, materials and methods, results, and discussion. This structure is sometimes called the "IMRaD" format. There are usually acknowledgment and reference sections, as well as an abstract (a concise summary) at the beginning of the paper. There might be additional sections depending on the type of paper and the journal where it will be published; for example, some review papers require an outline.

The introduction starts with brief, but broad, background information about what is known in the field. A good introduction also gives the rationale and justification for the work. The introduction refers to the published scientific work of others and, therefore, requires citations following the style of the journal. Using the work or ideas of others without proper citation is considered plagiarism.

The materials and methods section includes a complete and accurate description of the substances and the techniques used by the researchers to gather data. The description should be thorough, yet concise, while providing enough information to allow another researcher to repeat the experiment and obtain similar results. This section will also include information on how measurements were made and what types of calculations and statistical analyses were used to examine raw data. Although the materials and methods section gives an accurate description of the experiments, it does not discuss them.

Journals may require separate results and discussion sections, or it may combine them in one section. If the journal does not allow the combination of both sections, the results section simply narrates the findings without any further interpretation. The results are presented by means of tables or graphs, but no duplicate information should be presented. In the discussion section, the researcher will interpret the results, describe how variables may be related, and attempt to explain the observations. It is indispensable to conduct an extensive literature search to put the results in the context of previously-published scientific research. Therefore, proper citations are included in this section as well.

Finally, the conclusion section summarizes the importance of the experimental findings. While the scientific paper almost certainly answered one or more scientific questions that were stated, any good research should lead to more questions. A well-written scientific paper leaves doors open for the researcher and others to continue and expand on the findings.

Review articles do not follow the IMRAD format because they do not present original scientific findings or primary literature. Instead, they summarize and comment on findings that were published as primary literature. They typically include extensive reference sections.

KEY POINTS

- The body of scientific knowledge is recorded in peer-reviewed science journals which allow other scientists to determine what has been done previously and where their own research fits in the larger field of study.
- A scientific article generally follows the steps of the scientific method: introduction (background, observations, question), materials and methods (hypothesis and experimental plan), results (analysis of collected data), and discussion (conclusions drawn from analysis).
- Peer reviewers are other researchers in that field of study who carefully dissect, analyze, and critique a research article

submitted for publication.
- Review articles (summaries and commentaries on prior research in a field of study) also go through the peer-review process.

KEY TERMS

- **peer review**: The scholarly process whereby manuscripts intended to be published in an academic journal are reviewed by independent researchers to evaluate the contribution, importance, and accuracy of the manuscript's contents.

1.6: THE SCIENCE OF BIOLOGY - BRANCHES AND SUBDISCIPLINES OF BIOLOGY

LEARNING OBJECTIVES

- Recognize the various subfields of biology; e.g. microbiology, genetics, evolutionary, etc.

BRANCHES OF BIOLOGICAL STUDY

The scope of biology is broad and therefore contains many branches and subdisciplines. Biologists may pursue one of those subdisciplines and work in a more focused field. The biological branches are divided according to the focus of the discipline and can even be divided based on the types of techniques and tools used to study that specific focus. However, with the increasing amount of basic biological information growing due to advances in technology and databases, there is often cross-discipline and collaboration between branches. For instance, molecular biology and biochemistry study biological processes at the molecular and chemical level, respectively, including interactions among molecules such as DNA, RNA, and proteins, as well as the way they are regulated. Microbiology, the study of microorganisms, is the study of the structure and function of single-celled organisms. It is quite a broad branch itself, and depending on the subject of study, there are also microbial physiologists, ecologists, and geneticists, among others.

BIOLOGICAL DISCIPLINES AND CAREERS

Forensic science is the application of science to answer questions related to the law. Biologists as well as chemists and biochemists can be forensic scientists. Forensic scientists provide scientific evidence for use in courts, and their job involves examining trace materials associated with crimes.Their job activities are primarily related to crimes against people such as murder, rape, and assault. Their work involves analyzing samples such as hair, blood, and other body fluids, including the processing of DNA found in many different environments and materials associated with the crime scenes.

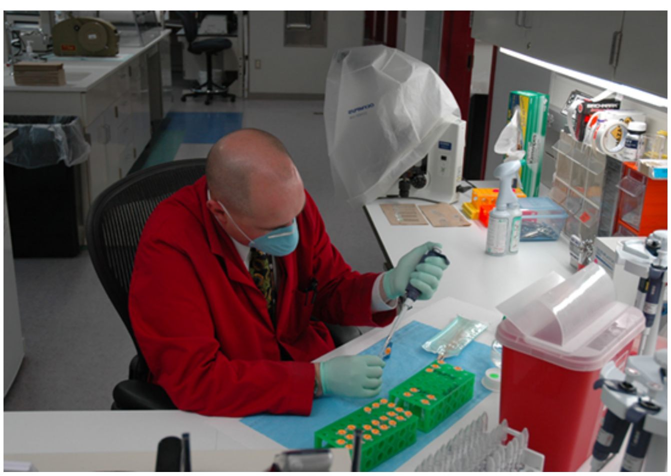

Figure 1.6.1: Forensic Science: This forensic scientist works in a DNA extraction room at the U.S. Army Criminal Investigation Laboratory at Fort Gillem, GA.

Another field of biological study, neurobiology, is the study of the nervous system, and although it is considered a branch of biology, it is also recognized as an interdisciplinary field of study known as neuroscience. Because of its interdisciplinary nature, this subdiscipline focuses on different functions of the nervous system using molecular, cellular, developmental, medical, and computational approaches.

Additional branches of biology include paleontology, which uses fossils to study life's history; zoology, which studies animals; and botany, which studies plants. Biologists can also specialize as biotechnologists, ecologists, or physiologists. This is just a small sample of the many fields that biologists can pursue.

Figure 1.6.1: Paleontology: Researchers work on excavating dinosaur fossils at a site in Castellón, Spain.

Biology is the culmination of the achievements of the natural sciences from their inception to today. Excitingly, it is the cradle of emerging sciences such as the biology of brain activity, genetic engineering of custom organisms, and the biology of evolution that uses the laboratory tools of molecular biology to retrace the earliest stages of life on earth. A scan of news headlines—whether reporting on immunizations, a newly discovered species, sports doping, or a genetically-modified food—demonstrates the way biology is active in and important to our everyday world.

KEY POINTS

- Biology is broad and focuses on the study of life from various perspectives.
- The branches and subdisciplines of biology, which are highly focused areas, have resulted in the development of careers that are specific to these branches and subdisciplines.
- Branches of biological study include microbiology, physiology, ecology and genetics; subdisciplines within these branches can include: microbial physiology, microbial ecology and microbial genetics.

KEY TERMS

- **genetic engineering**: the deliberate modification of the genetic structure of an organism
- **forensic**: Relating to the use of science and technology in the investigation and establishment of facts or evidence in a court of law.

CONTRIBUTIONS AND ATTRIBUTIONS