Welcome to AP Biology!

Advanced Placement Biology is designed to be the equivalent of a two-semester college biology lab course in its quality and sophistication. This course will contribute to the development of the student's ability to think clearly and to express their ideas, orally and in writing, with an emphasis on integrating inquiry, reasoning, and quantitative skills. Students will design and master plans for data collection and analysis, apply mathematical routines, and connect concepts in and across primary domains of science (biology, chemistry, physics). Curricular content is framed around "Four Big Ideas" which encompass core scientific principles, theories and processes governing living organisms and biological systems.

Big Idea 1 – EVOLUTION: The process of evolution drives the diversity and unity of life.

Big Idea 2 – CELLULAR PROCESSES: Biological systems utilize energy and molecular building blocks to grow, reproduce, and maintain homeostasis.

Big Idea 3 – GENETICS & INFORMATION TRANSFER: Living systems retrieve, transmit, and respond to information essential to life processes.

Big Idea 4 – ECOLOGY: Biological systems interact, and these interactions possess complex properties.

Primary emphasis will be on developing an understanding of concepts rather than on memorizing terms and technical details. Essential to this conceptual understanding are the following: a grasp of science as a process rather than as an accumulation of facts; personal experience in scientific inquiry; recognition of unifying themes that integrate the major topics of biology; and application of biological knowledge and critical thinking to environmental and social concerns.

Suggested Prerequisites: A strong passion for the life sciences, challenging and meaningful coursework, and college-level lab experiences. Grade equivalents of an A in Biology College Prep, or a B or better in Biology Honors is recommended.

AP Biology is a college-level introduction to the Biological Sciences. It is intended as a survey of the many fields of study that comprise "biology." At the end of the course, students take the AP Biology exam, administered by the College Board. **A sufficient score on this exam makes a student eligible for college credit.**

Being that this is a college-level course, students should expect a workload equal to what would be encountered in college. The typical college formula is that students will spend ~ 3 hours of their own time per hour spent in class. In this class, the amount of work you will need to do outside of class will vary depending on the day, your ability to balance your workload with the other aspects of your life, etc. Generally, you should expect to spend no less than 30 minutes per day doing work related to this class, and that may easily balloon up to as much as 90minutes. This may be very difficult for you if you are in multiple AP classes.

of this course. If you are legally absent, it is your responsibility to makeup all assignments and submit them upon your return (Schoology lists all assignments and is updated daily). "I was absent" is not an excuse for missing an assignment (unless I excuse you). Please discuss missed work with me as soon as you return to class. Work done during absences is due upon your return to class. In the case of multiple day absences, we will establish an acceptable due date for missed work upon your return to class. You must also make arrangements to make up any labs, quizzes or tests as soon as you return to school.

If your absence is unexcused, you will receive a "0" on any work that is assigned in class during your absence.

Late work policy - Work is considered "late" when it is submitted after the established collection time. Late work will receive a 10% penalty for every day it is late up to 5 days. After 5 days, work will be accepted for 50% of the grade.

Electronic Device Policy

No cell phones or hand-held gaming devices of any type are to be seen or heard in class unless permission has been granted during a lab. Students are to have their own set of earbuds to use during various lab exercises that include sound. A phone with camera capabilities is advised for microscopy labs.

Academic Honesty

A high level of integrity and academic honesty is expected in this course. Students should not do anything that would compromise their integrity. Collaboration and teamwork are encouraged, however, individual work must always be distinctly original from the lab partner's work and be authentic (i.e., a lab team may share data collected from an experiment, but each student's analysis and interpretation of the data should be their own). Not only is the act of reproducing someone else's work dishonest, but also a student who allows others to copy his or her work is equally dishonest. No points will be rewarded if cheating is discovered. Cheating will result in a zero for the assignment/quiz/test and given a discipline referral. See the student handbook for details.

In the Lab

Students will follow all safety rules as defined in the safety contract provided during the first week of classes. Unsafe practices during lab will result in a student first being warned, second will require a parent contacted, and then a third infraction will result in suspension from lab until the student can demonstrate proper safety procedures after school.

The AP Exam

At the end of this course you have the option of taking the AP exam (and you should take the exam). The AP Biology Exam consists of two sections: multiple choice and free response. Both sections include questions that assess students' understanding of the big ideas, enduring understandings, and essential knowledge and the ways in which this understanding can be applied through the science practices. These may include questions on the following:

Rules for Online Class

- All classes will be recorded.
- Camera must be turned on for attendance and turned off as instructed.
- All students should have their device on mute until instructed to turn on.
- Attendance will be taken randomly to ensure that you are present for duration of the class, and to get credit for the class.
- Students can be removed from the virtual platform for unacceptable behavior
  - Teachers are requesting students to think responsibly and act respectfully while participating with their peers in the virtual classroom.
  - Our School wide PBIS rules to "Expect Respect" remain in effect while at home.
  - Students who fail to follow the rules as outlined below can possibly be removed from the virtual classroom

- If you have a question please use the raise your hand icon or post it in the chat box.
- If you having technical difficulties please let your teacher know by email or any other instrument for communication (Remind, Class Tag).
- Tardy: virtual platforms records the time you log in/out.
- No Grooming/eating in front of camera.
- No profanity using virtual platforms.
- The same disciplinary actions will be handled the same as if you were in person inside the school.

Basic Rules:

- Identify a suitable workspace to work
- Log or dial in 5 minutes before the virtual classroom session begins
- Be respectful
- Listen actively
- Actively participate
- Complete and submit assignments
- Dress appropriately or turn off video feature

Student Responsibilities:

- Log in daily or assigned meeting times
- Ask/Answer questions
- Take turns participating daily in classroom discussions
- Complete packets and turn in work on time
- Work independently or in groups (when assigned)
- Be an active member of the virtual community

Unacceptable Behavior:

- Vulgarity (no cursing, vulgar language, or inappropriate gestures, memes)
- Negative feedback on other's work and /or comments
- Posting negativity, bully others in chats

Exam Overview

The AP Biology Exam assesses student understanding of the science practices and learning objectives outlined in the course framework. The exam is 3 hours long and includes 60 multiple-choice questions and 6 free-response questions. A four-function, scientific, or graphing calculator is allowed on both sections of the exam. The details of the exam, including exam weighting and timing, can be found below:

Section	Question Type	Number of Questions	Exam Weighting	Timing
I	Multiple-choice questions	60	50%	90 minutes
II	Free-response questions	6	50%	90 minutes
	Question 1: Interpreting and Evaluating Experimental Results (8–10 pts)			
	Question 2: Interpreting and Evaluating Experimental Results with Graphing (8–10 pts)			
	Question 3: Scientific Investigation (4 pts)			
	Question 4: Conceptual Analysis (4 pts)			
	Question 5: Analyze Model or Visual Representation (4 pts)			
	Question 6: Analyze Data (4 pts)			

The exam assesses content from each of four big ideas for the course:
1. Evolution
2. Energetics
3. Information Storage and Transmission
4. Systems Interactions

The exam also assesses each of the eight units of the course with the following exam weightings on the multiple-choice section of the AP Exam:

Unit	Exam Weighting
1: Chemistry of Life	**8–11%**
2: Cell Structure and Function	**10–13%**
3: Cellular Energetics	**12–16%**
4: Cell Communication and Cell Cycle	**10–15%**
5: Heredity	**8–11%**
6: Gene Expression and Regulation	**12–16%**
7: Natural Selection	**13–20%**
8: Ecology	**10–15%**

How Student Learning Is Assessed on the AP Exam

All six AP Biology science practices are assessed on every AP Exam in the multiple-choice and free-response sections as detailed below.

Science Practice	Multiple-Choice Section	Free-Response Section
1: Concept Explanation	Individual and/or set-based multiple-choice questions assess students' ability to explain biological concepts, processes, and models presented in written format. Students will need to describe and explain these concepts, processes, and models in both conceptual and applied contexts.	Free-response questions 1, 2, 3, 4, and 5 include one or two points per question that assess Science Practice 1.
2: Visual Representations	Individual and/or set-based multiple-choice questions will assess students' ability to analyze visual representations of biological concepts and processes. Students will need to describe characteristics of a biological concept, process, or model represented visually, as well as explain relationships between these different characteristics. Additionally, students will need to explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.	Free-response question 5 focuses primarily on Science Practice 2.
3: Questions and Methods	Individual and/or set-based multiple-choice questions will assess students' ability to determine scientific questions and methods. Students will need to identify or pose a testable question, state the null or alternative hypotheses or predict the results of an experiment, identify experimental procedures, and/or propose new investigations.	Free-response questions 1 and 3 focus on Science Practice 3, with approximately half of the points for each question assessing this practice.

continued on next page

Science Practice	Multiple-Choice Section	Free-Response Section
4: Representing and Describing Data	Individual and/or set-based multiple-choice questions will assess students' ability to describe data from a table or graph. Students will need to identify specific data points, describe trends or patterns, and describe relationships between variables	Free-response questions 2 and 6 focus on Science Practice 4, with approximately half of the points for each question assessing this practice. Free-response question 1 also assesses this practice in one or two points.
5: Statistical Tests and Data Analysis	Individual and/or set-based multiple-choice questions will assess students' ability to perform statistical tests and mathematical calculations to analyze and interpret data. Students will need to perform mathematical calculations, use confidence intervals, perform chi-square hypothesis testing, and use data to evaluate a hypothesis or prediction.	Free-response question 1 or 2 assess students' ability to perform a mathematical calculation. Free-response question 6 assesses students' ability to use data to evaluate a hypothesis or prediction.
6: Argumentation	Individual and/or set-based multiple-choice questions will assess students' ability to develop and justify scientific arguments using evidence. Students will need to make scientific claims, support claims with evidence, and provide reasoning to justify claims. Additionally, students will need to explain relationships between experimental results and larger biological concepts, processes, or theories. Finally, students will need to predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	Free-response questions 1, 2, 3, 4, and 6 include one, two, or occasionally three points per question that assess Science Practice 6.

Section I: Multiple-Choice

The first section of the AP Biology Exam includes 60 multiple-choice questions appearing either as individual questions or in sets of typically four to five questions per set. All six AP Biology science practices are assessed in the multiple-choice section with the following exam weightings:

Science Practice	Exam Weighting
1: Concept Explanation	**25–33%**
2: Visual Representations	**16–24%**
3: Questions and Methods	**8–14%**
4: Representing and Describing Data	**8–14%**
5: Statistical Tests and Data Analysis	**8–14%**
6: Argumentation	**20–26%**

Section II: Free-Response

The second section of the AP Biology Exam includes two long questions, and four short-answer questions. Each of the four short-answer questions will focus on a different big idea and a different unit of instruction.

Free-response question 1: Interpreting and Evaluating Experimental Results is an 8 to 10-point question that presents students with an authentic scenario accompanied by data in a table and/or graph. This question assesses student ability to do the following in four question parts:

- Part A (1 to 2 points): Describe and explain biological concepts, processes, or models.
- Part B (3 to 4 points): Identify experimental design procedures.
- Part C (1 to 3 points): Analyze data.
- Part D (2 to 4 points): Make and justify predictions.

Free-response 2: Interpreting and Evaluating Experimental Results with Graphing is an 8 to 10-point question that presents students with an authentic scenario accompanied by data in a table. This question assesses students' ability to do the following in four question parts:

- Part A (1 to 2 points): Describe and explain biological concepts, processes, or models.
- Part B (4 points): Construct a graph, plot or chart and use confidence intervals or error bars.
- Part C (1 to 3 points): Analyze data.
- Part D (1 to 3 points): Make and justify predictions.

Free-response question 3: Scientific Investigation is a 4-point question that presents students with a description of a lab investigation scenario. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe biological concepts or processes.
- Part B (1 point): Identify experimental procedures.
- Part C (1 point): Predict results.
- Part D (1 point): Justify predictions.

Free-response question 4: Conceptual Analysis is a 4-point question that presents students with an authentic scenario describing a biological phenomenon with a disruption. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe biological concepts or processes.
- Part B (1 point): Explain biological concepts or processes.
- Part C (1 point): Predict the causes or effects of a change in a biological system.
- Part D (1 point): Justify predictions.

Free-response question 5: Analyze Model or Visual Representation is a 4-point question that presents students with a description of an authentic scenario accompanied by a visual model or representation. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe characteristics of a biological concept, process, or model represented visually.
- Part B (1 point): Explain relationships between different characteristics of a biological concept or process represented visually.
- Part C (1 point): Represent relationships within a biological model.
- Part D (1 point): Explain how a biological concept or process represented visually relates to a larger biological principle, concept, process, or theory.

Free-response question 6: Analyze Data is a 4-point question that presents students with data in a graph, table, or other visual representation. This question assesses students' ability to do the following in four question parts:

- Part A (1 point): Describe data.
- Part B (1 point): Describe data.
- Part C (1 point): Use data to evaluate a hypothesis or prediction.
- Part D (1 point): Explain how experimental results relate to biological principles, concepts, processes, or theories.

Task Verbs Used in Free-Response Questions

The following **task verbs** are commonly used in the free-response questions:

Calculate: Perform mathematical steps to arrive at a final answer, including algebraic expressions, properly substituted numbers, and correct labeling of units and significant figures.

Construct/Draw: Create a diagram, graph, representation, or model that illustrates or explains relationships or phenomena. Labels may or may not be required.

Describe: Provide relevant characteristics of a specified topic.

Determine: Decide or conclude after reasoning, observation, or applying mathematical routines (calculations).

Evaluate: Judge or determine the significance or importance of information, or the quality or accuracy of a claim.

Explain: Provide information about how or why a relationship, process, pattern, position, situation, or outcome occurs, using evidence and/or reasoning to support or qualfiy a claim. Explain "how" typically requires analyzing the relationship, process, pattern, position, situation, or outcome; whereas explain "why" typically requires analysis of motivations or reasons for the relationship, process, pattern, position, situation, or outcome.

Identify: Indicate or provide information about a specified topic, without elaboration or explanation.

Justify: Provide evidence to support, qualify, or defend a claim, and/or provide reasoning to explain how that evidence supports or qualifies the claim.

Make a claim: Make an assertion that is based on evidence or knowledge.

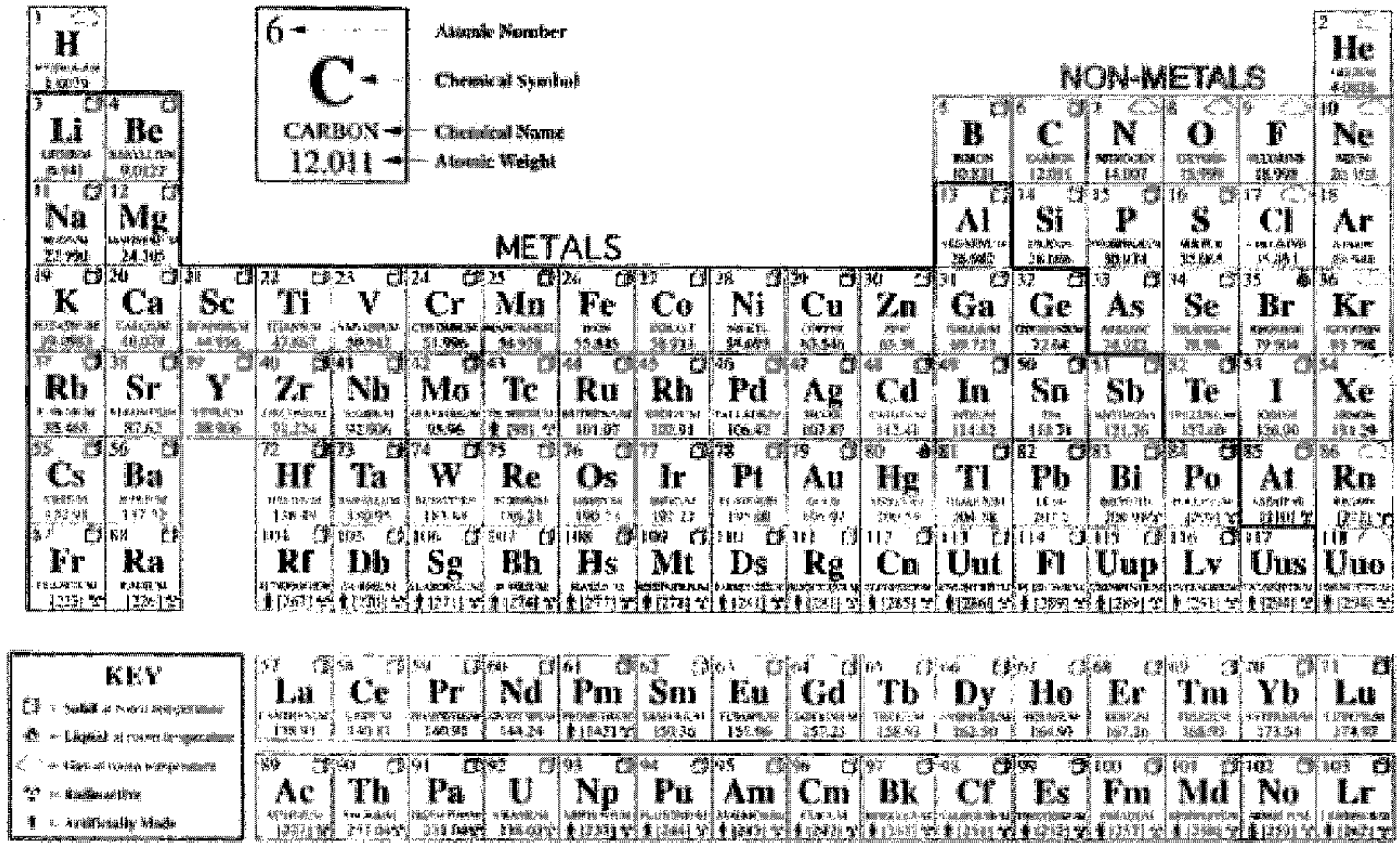
Predict/Make a prediction: Predict the causes or effects of a change in, or disruption to, one or more components in a relationship, pattern, process, or system.

Represent: Use appropriate graphs, symbols, words, illustrations, and/or tables of numerical values to describe biological concepts, characteristics, and/or relationships.

State (the null/alternative hypothesis): Indicate or provide a hypothesis to support or defend a claim about a scientifically testable question.

Support a claim: Provide reasoning to explain how evidence supports or qualifies a claim.

The Periodic Table of Elements



AP® BIOLOGY EQUATIONS AND FORMULAS

Statistical Analysis and Probability

Mean

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation

$$s = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n - 1}}$$

Standard Error of the Mean

$$SE_{\overline{x}} = \frac{s}{\sqrt{n}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o - e)^2}{e}$$

Chi-Square Table

p value	Degrees of Freedom							
	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.81	9.49	11.07	12.59	14.07	15.51
0.01	6.63	9.21	11.34	13.28	15.09	16.81	18.48	20.09

$\overline{x}$ = sample mean

n = sample size

s = sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population)

o = observed results

e = expected results

Σ = sum of all

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Laws of Probability

If A and B are mutually exclusive, then:

$$P(\text{A or B}) = P(\text{A}) + P(\text{B})$$

If A and B are independent, then:

$$P(\text{A and B}) = P(\text{A}) \times P(\text{B})$$

Hardy-Weinberg Equations

$p^2 + 2pq + q^2 = 1$ — p = frequency of allele 1 in a population

$p + q = 1$ — q = frequency of allele 2 in a population

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

Rate and Growth

Rate

$$\frac{dY}{dt}$$

dY = amount of change

dt = change in time

Population Growth

$$\frac{dN}{dt} = B - D$$

B = birth rate

D = death rate

Exponential Growth

$$\frac{dN}{dt} = r_{max}N$$

N = population size

K = carrying capacity

r_{max} = maximum per capita growth rate of population

Logistic Growth

$$\frac{dN}{dt} = r_{max}N\left(\frac{K-N}{K}\right)$$

Simpson's Diversity Index

$$\text{Diversity Index} = 1 - \Sigma\left(\frac{n}{N}\right)^2$$

n = total number of organisms of a particular species

N = total number of organisms of all species

Water Potential (Ψ)

$$\Psi = \Psi_P + \Psi_S$$

Ψ_P = pressure potential

Ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

The Solute Potential of a Solution

$$\Psi_S = -iCRT$$

i = ionization constant (1.0 for sucrose because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (°C + 273)

pH = $-\log[H^+]$

Surface Area and Volume

Surface Area of a Sphere

$SA = 4\pi r^2$

Volume of a Sphere

$V = \frac{4}{3}\pi r^3$

Surface Area of a Rectangular Solid

$SA = 2lh + 2lw + 2wh$

Volume of a Rectangular Solid

$V = lwh$

Surface Area of a Cylinder

$SA = 2\pi rh + 2\pi r^2$

Volume of a Cylinder

$V = \pi r^2 h$

Surface Area of a Cube

$SA = 6s^2$

Volume of a Cube

$V = s^3$

r = radius

l = length

h = height

w = width

s = length of one side of a cube

SA = surface area

V = volume

1 | THE STUDY OF LIFE

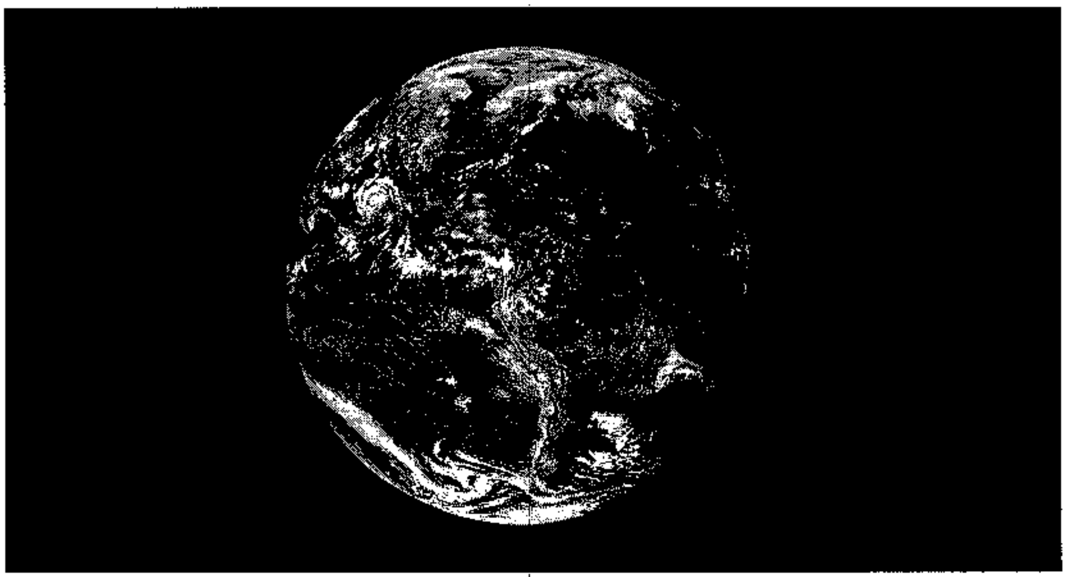


Figure 1.1 This NASA image is a composite of several satellite-based views of Earth. To make the whole-Earth image, NASA scientists combine observations of different parts of the planet. (credit: NASA/GSFC/NOAA/USGS)

Chapter Outline

Introduction

Viewed from space, Earth offers no clues about the diversity of life forms that reside there. Scientists believe that the first forms of life on Earth were microorganisms that existed for billions of years in the ocean before plants and animals appeared. The mammals, birds, and flowers so familiar to us are all relatively recent, originating 130 to 250 million years ago. The earliest representatives of the genus *Homo*, to which we belong, have inhabited this planet for only the last 2.5 million years, and only in the last 300,000 years have humans started looking like we do today.

1.1 | The Science of Biology

By the end of this section, you will be able to do the following:

- Identify the shared characteristics of the natural sciences
- Summarize the steps of the scientific method
- Compare inductive reasoning with deductive reasoning
- Describe the goals of basic science and applied science

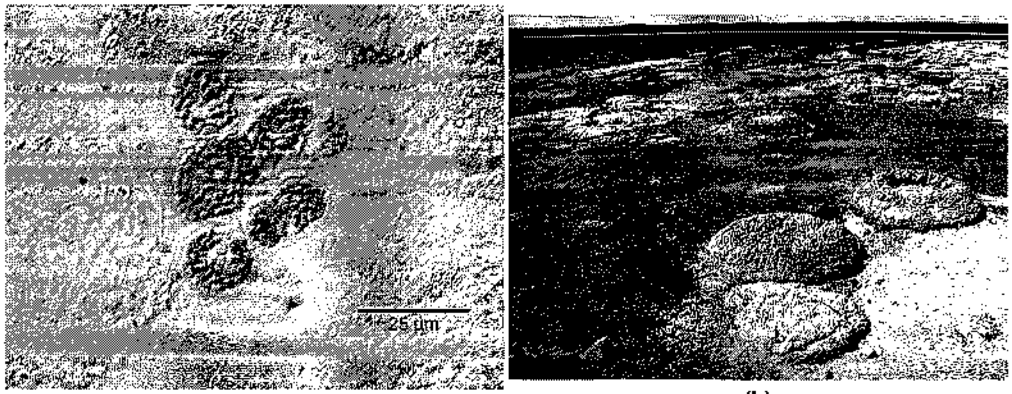


Figure 1.2 Formerly called blue-green algae, these (a) cyanobacteria, magnified 300x under a light microscope, are some of Earth's oldest life forms. These (b) stromatolites along the shores of Lake Thetis in Western Australia are ancient structures formed by layering cyanobacteria in shallow waters. (credit a: modification of work by NASA; credit b: modification of work by Ruth Ellison; scale-bar data from Matt Russell)

What is biology? In simple terms, **biology** is the study of living organisms and their interactions with one another and their environments. This is a very broad definition because the scope of biology is vast. Biologists may study anything from the microscopic or submicroscopic view of a cell to ecosystems and the whole living planet (**Figure 1.2**). Listening to the daily news, you will quickly realize how many aspects of biology we discuss every day. For example, recent news topics include *Escherichia coli* (**Figure 1.3**) outbreaks in spinach and *Salmonella* contamination in peanut butter. Other subjects include efforts toward finding a cure for AIDS, Alzheimer's disease, and cancer. On a global scale, many researchers are committed to finding ways to protect the planet, solve environmental issues, and reduce the effects of climate change. All of these diverse endeavors are related to different facets of the discipline of biology.

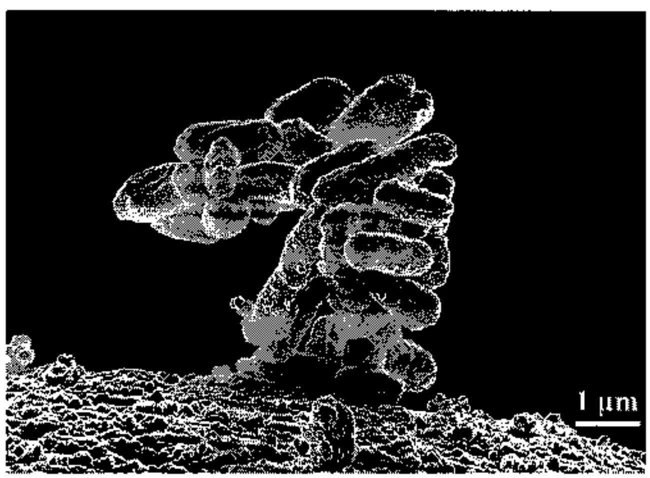


Figure 1.3 *Escherichia coli* (*E. coli*) bacteria, in this scanning electron micrograph, are normal residents of our digestive tracts that aid in absorbing vitamin K and other nutrients. However, virulent strains are sometimes responsible for disease outbreaks. (credit: Eric Erbe, digital colorization by Christopher Pooley, both of USDA, ARS, EMU)

The Process of Science

Biology is a science, but what exactly is science? What does the study of biology share with other scientific disciplines? We can define **science** (from the Latin *scientia*, meaning "knowledge") as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that applying scientific method plays a major role in science. The **scientific method** is a method of research with defined steps that include experiments and careful observation.

We will examine scientific method steps in detail later, but one of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A **hypothesis** is a suggested explanation for an event, which one can test. 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, psychology, and geology, the scientific method becomes less applicable as repeating experiments becomes more difficult.

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. He or she could make further hypotheses about various characteristics of this culture, which could be correct or false through continued support or contradictions from other findings. A hypothesis may become a verified theory. A **theory** is a tested and confirmed explanation for observations or phenomena. Therefore, we may be better off to define science as fields of study that attempt to comprehend the nature of the universe.

Natural Sciences

What would you expect to see in a museum of natural sciences? Frogs? Plants? Dinosaur skeletons? Exhibits about how the brain functions? A planetarium? Gems and minerals? Maybe all of the above? Science includes such diverse fields as astronomy, biology, computer sciences, geology, logic, physics, chemistry, and mathematics (**Figure 1.4**). However, scientists consider those fields of science related to the physical world and its phenomena and processes **natural sciences**. Thus, a museum of natural sciences might contain any of the items listed above.

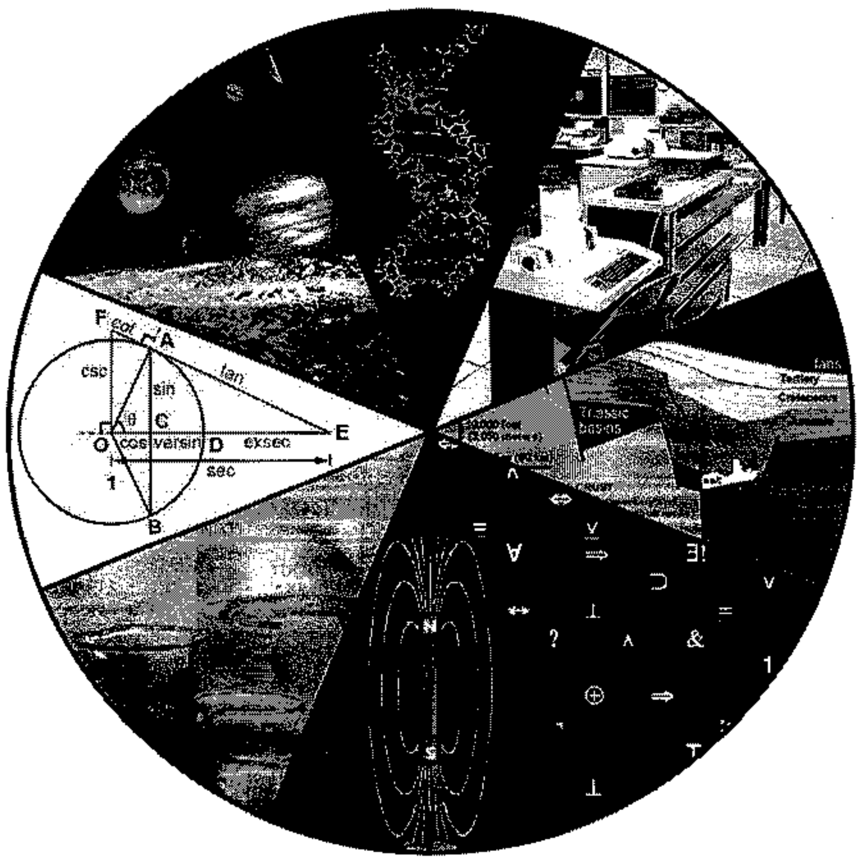


Figure 1.4 The diversity of scientific fields includes astronomy, biology, computer science, geology, logic, physics, chemistry, mathematics, and many other fields. (credit: "Image Editor"/Flickr)

There is no complete agreement when it comes to defining what the natural sciences include, however. For some experts, the natural sciences are astronomy, biology, chemistry, earth science, and physics. Other scholars choose to divide natural sciences into **life sciences**, which study living things and include biology, and **physical sciences**, which study nonliving matter and include astronomy, geology, physics, and chemistry. Some disciplines such as biophysics and biochemistry build on both life and physical sciences and are interdisciplinary. Some refer to natural sciences as "hard science" because they rely on the use of quantitative data. Social sciences that study society and human behavior are more likely to use qualitative assessments to drive investigations and findings.

Not surprisingly, the natural science of biology has many branches or subdisciplines. Cell biologists study cell structure and function, while biologists who study anatomy investigate the structure of an entire organism. Those biologists studying physiology, however, focus on the internal functioning of an organism. Some areas of biology focus on only particular types of living things. For example, botanists explore plants, while zoologists specialize in animals.

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.

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 one can supplement the raw data 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 analyzing a large amount of data. Brain studies provide an example. In this type of research, scientists observe many live brains while people are engaged in a specific activity, such as viewing images of food. The scientist then predicts the part of the brain that "lights up" during this activity to be the part controlling the response to the selected stimulus, in this case, images of food. Excess absorption of radioactive sugar derivatives by active areas of the brain causes the various areas to "light up". Scientists use a scanner to observe the resultant increase in radioactivity. 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.

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 one can test. 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. On closer inspection, he discovered that the burrs' gripping device was more reliable than a zipper. He eventually experimented to find the best material that acted similar, and produced the hook-and-loop fastener popularly known today as Velcro. Descriptive science and hypothesis-based science are in continuous dialogue.

The Scientific Method

Biologists study the living world by posing questions about it and seeking science-based responses. Known as scientific method, this approach is common to other sciences as well. The scientific method was used even in ancient times, but England's Sir Francis Bacon (1561–1626) first documented it (**Figure 1.5**). He set up inductive methods for scientific inquiry. The scientific method is not used only by biologists; researchers from almost all fields of study can apply it as a logical, rational problem-solving method.

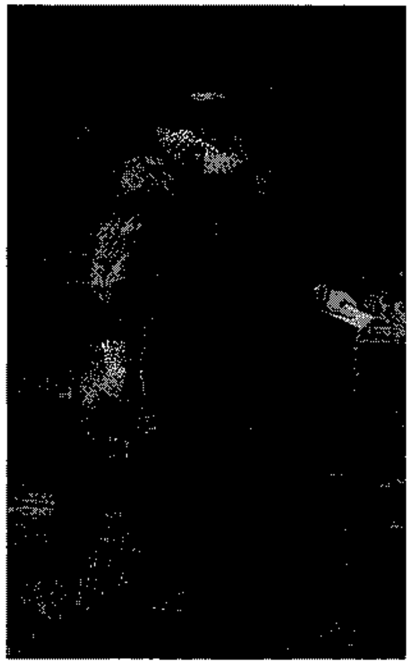


Figure 1.5 Historians credit Sir Francis Bacon (1561–1626) as the first to define the scientific method. (credit: Paul van Somer)

The scientific process typically starts with an observation (often a problem to solve) 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. One Monday morning, a student arrives at class and quickly discovers that the classroom is too warm. That is an observation that also describes a problem: the classroom is too warm. The student then asks a question: "Why is the classroom so warm?"

Proposing a Hypothesis

Recall that a hypothesis is a suggested explanation that one can test. To solve a problem, one can propose several hypotheses. For example, one hypothesis might be, "The classroom is warm because no one turned on the air conditioning." However, there could be other responses to the question, and therefore one may propose other hypotheses. A second hypothesis might be, "The classroom is warm because there is a power failure, and so the air conditioning doesn't work."

Once one has selected a hypothesis, the student can make a prediction. A prediction is similar to a hypothesis but it typically has the format "If . . . then . . . ." For example, the prediction for the first hypothesis might be, "*If* the student turns on the air conditioning, *then* the classroom will no longer be too warm."

Testing a Hypothesis

A valid hypothesis must be testable. It should also be **falsifiable**, meaning that experimental results can disprove it. 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 the researcher hypothesizes. Therefore, if the experimental group's results differ from the control group, the difference must be due to the hypothesized manipulation, rather than some outside factor. Look for the variables and controls in the examples that follow. To test the first hypothesis, the student would find out if the air conditioning is on. If the air conditioning is turned on but does not work, there should be another reason, and the student should reject this hypothesis. To test the second hypothesis, the student could check if the lights in the classroom are functional. If so, there is no power failure and the student should reject this hypothesis. The students should test each hypothesis by carrying out appropriate experiments. Be aware that rejecting one hypothesis does not determine whether or not one can accept the other hypotheses. It simply eliminates one hypothesis that is not valid (**Figure 1.6**). Using the scientific method, the student rejects the hypotheses that are inconsistent with experimental data.

While this "warm classroom" 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 observation to explain this occurrence might be, "When I eat breakfast before class, I am better able to pay attention." The student could then design an experiment with a control to test this hypothesis.

In hypothesis-based science, researchers predict specific results from a general premise. We call this type of reasoning deductive reasoning: deduction proceeds from the general to the particular. However, the reverse of the process is also possible: sometimes, scientists reach a general conclusion from a number of specific observations. We call this type of reasoning inductive reasoning, and it proceeds from the particular to the general. Researchers often use inductive and deductive reasoning in tandem to advance scientific knowledge **(Figure 1.7)**.

visual

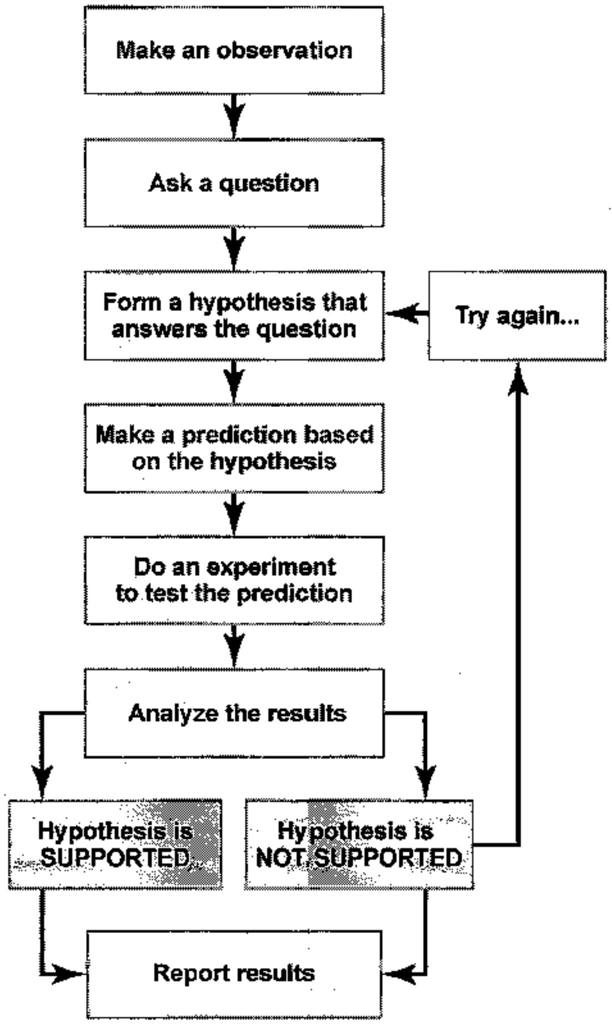


Figure 1.6 The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, one can propose a new hypothesis.

In the example below, the scientific method is used to solve an everyday problem. Order the scientific method steps (numbered items) with the process of solving the everyday problem (lettered items). Based on the results of the experiment, is the hypothesis correct? If it is incorrect, propose some alternative hypotheses.

1. Observation
2. Question
3. Hypothesis (answer)
4. Prediction
5. Experiment
6. Result

a. There is something wrong with the electrical outlet.
b. If something is wrong with the outlet, my coffeemaker also won't work when plugged into it.
c. My toaster doesn't toast my bread.
d. I plug my coffee maker into the outlet.

e. My coffeemaker works.
f. Why doesn't my toaster work?

visual

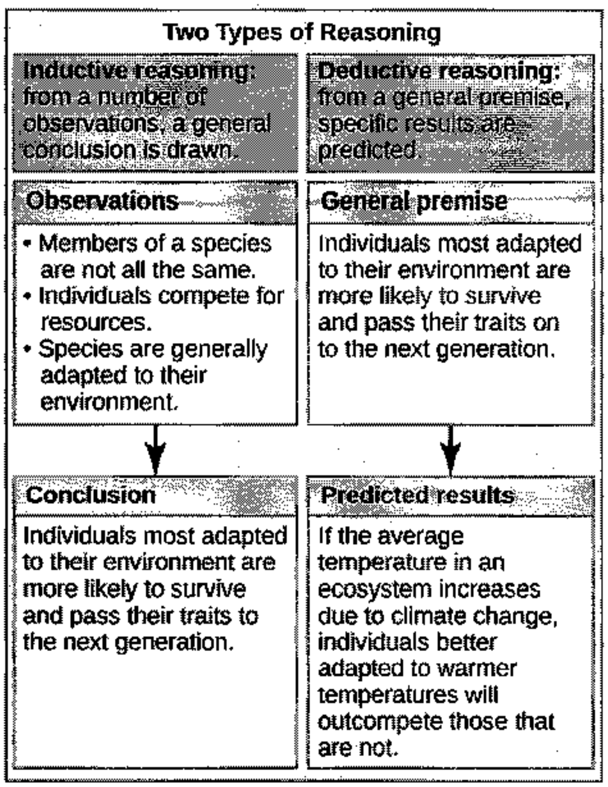


Figure 1.7 Scientists use two types of reasoning, inductive and deductive reasoning, to advance scientific knowledge. As is the case in this example, the conclusion from inductive reasoning can often become the premise for deductive reasoning.

Decide if each of the following is an example of inductive or deductive reasoning.

1. All flying birds and insects have wings. Birds and insects flap their wings as they move through the air. Therefore, wings enable flight.
2. Insects generally survive mild winters better than harsh ones. Therefore, insect pests will become more problematic if global temperatures increase.
3. Chromosomes, the carriers of DNA, are distributed evenly between the daughter cells during cell division. Therefore, each daughter cell will have the same chromosome set as the mother cell.
4. Animals as diverse as humans, insects, and wolves all exhibit social behavior. Therefore, social behavior must have an evolutionary advantage.

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. Sometimes an experiment leads to conclusions that favor a change in approach. Often, an experiment brings entirely new scientific questions to the puzzle. 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. Notice, too, that we can apply the scientific method to solving problems that aren't necessarily scientific in nature.

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 immediate goal of basic science is knowledge for knowledge's sake, although 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, making it possible, for example, to improve a crop yield, find a cure for a particular disease, or save animals threatened by a natural disaster (**Figure 1.8**). In applied science, the problem is usually defined for the researcher.

Figure 1.8 After Hurricane Irma struck the Caribbean and Florida in 2017, thousands of baby squirrels like this one were thrown from their nests. Thanks to applied science, scientists knew how to rehabilitate the squirrel. (credit: audreyjm529, Flickr)

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?" However, a careful look at the history of science 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 researchers develop an application therefore, applied science relies on the results that researchers generate through basic science. Other scientists think that it is time to move on from basic science in order to find solutions to actual problems. Both approaches are valid. It is true that there are problems that demand immediate attention; however, scientists would find few solutions without the help of the wide knowledge foundation that basic science generates.

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. DNA strands, unique in every human, are in our cells, where they provide the instructions necessary for life. When DNA replicates, it produces new copies of itself, shortly before a cell divides. Understanding DNA replication mechanisms enabled scientists to develop laboratory techniques that researchers now use 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 researchers analyzed and mapped each human chromosome to determine the precise sequence of DNA subunits and each gene's exact location. (The gene is the basic unit of heredity. An individual's complete collection of genes is his or her genome.) Researchers have studied other less complex organisms as part of this project in order to gain a better understanding of human chromosomes. The Human Genome Project (**Figure 1.9**) relied on basic research with simple organisms and, later, with the human genome. An important end goal eventually became using the data for applied research, seeking cures and early diagnoses for genetically related diseases.

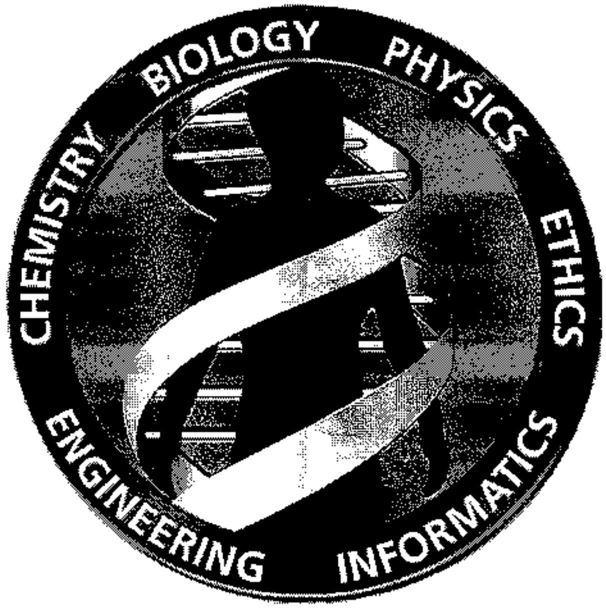


Figure 1.9 The Human Genome Project was a 13-year collaborative effort among researchers working in several different science fields. Researchers completed the project, which sequenced the entire human genome, in 2003. (credit: the U.S. Department of Energy Genome Programs **(http://genomics.energy.gov (http://openstax.org/l/genomics_gov))**

While scientists usually carefully plan research efforts in both basic science and applied science, note that some discoveries are made by **serendipity**, that is, by means of a fortunate accident or a lucky surprise. Scottish biologist Alexander Fleming discovered penicillin when he accidentally left a petri dish of *Staphylococcus* bacteria open. An unwanted mold grew on the dish, killing the bacteria. Fleming's curiosity to investigate the reason behind the bacterial death, followed by his experiments, led to the discovery of the antibiotic penicillin, which is produced by the fungus *Penicillium*. Even in the highly organized world of science, luck—when combined with an observant, curious mind—can lead to unexpected breakthroughs.

Reporting Scientific Work

Whether scientific research is basic science or applied science, 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, important aspects of a scientist's work are 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 a scientist's colleagues or peers review. 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 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.

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. First, scientific writing must be brief, concise, and accurate. A scientific paper 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 of the work. It justifies the work carried out and also briefly mentions the end of the paper, where the researcher will present the hypothesis or research question driving the research. 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 **plagiarism**.

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

Some journals require a results section followed by a discussion section, but it is more common to combine both. If the journal does not allow combining both sections, the **results** section simply narrates the findings without any further interpretation. The researchers present results with tables or graphs, but they do not present duplicate information. In the **discussion** section, the researchers 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, researchers include proper citations in this section as well.

Finally, the **conclusion** section summarizes the importance of the experimental findings. While the scientific paper almost certainly answers one or more scientific questions that the researchers stated, any good research should lead to more questions. Therefore, a well-done scientific paper allows the researchers 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 and typically include extensive reference sections.

1.2 | Themes and Concepts of Biology

By the end of this section, you will be able to do the following:

- Identify and describe the properties of life
- Describe the levels of organization among living things
- Recognize and interpret a phylogenetic tree
- List examples of different subdisciplines in biology

Biology is the science that studies life, but what exactly is life? This may sound like a silly question with an obvious response, but it is not always easy to define life. For example, a branch of biology called virology studies viruses, which exhibit some of the characteristics of living entities but lack others. Although viruses can attack living organisms, cause diseases, and even reproduce, they do not meet the criteria that biologists use to define life. Consequently, virologists are not biologists, strictly speaking. Similarly, some biologists study the early molecular evolution that gave rise to life. Since the events that preceded life are not biological events, these scientists are also excluded from biology in the strict sense of the term.

From its earliest beginnings, biology has wrestled with three questions: What are the shared properties that make something "alive"? Once we know something is alive, how do we find meaningful levels of organization in its structure? Finally, when faced with the remarkable diversity of life, how do we organize the different kinds of organisms so that we can better understand them? As scientists discover new organisms every day, biologists continue to seek answers to these and other questions.

Properties of Life

All living organisms share several key characteristics or functions: order, sensitivity or response to the environment, reproduction, adaptation, growth and development, regulation, homeostasis, energy processing, and evolution. When viewed together, these nine characteristics serve to define life.

Order

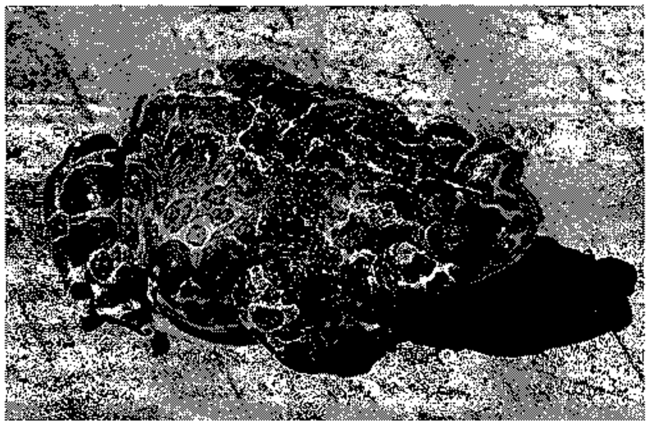


Figure 1.10 A toad represents a highly organized structure consisting of cells, tissues, organs, and organ systems. (credit: "Ivengo"/Wikimedia Commons)

Organisms are highly organized, coordinated structures that consist of one or more cells. Even very simple, single-celled organisms are remarkably complex: inside each cell, atoms comprise molecules. These in turn comprise cell organelles and other cellular inclusions. In multicellular organisms (**Figure 1.10**), similar cells form tissues. Tissues, in turn, collaborate to create organs (body structures with a distinct function). Organs work together to form organ systems.

Sensitivity or Response to Stimuli

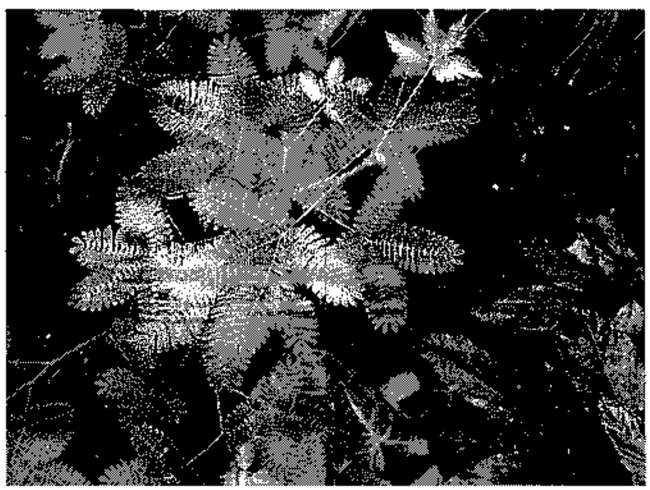


Figure 1.11 The leaves of this sensitive plant (*Mimosa pudica*) will instantly droop and fold when touched. After a few minutes, the plant returns to normal. (credit: Alex Lomas)

Organisms respond to diverse stimuli. For example, plants can bend toward a source of light, climb on fences and walls, or respond to touch (**Figure 1.11**). Even tiny bacteria can move toward or away from chemicals (a process called *chemotaxis*) or light (*phototaxis*). Movement toward a stimulus is a positive response, while movement away from a stimulus is a negative response.

LINK TO LEARNING

Watch **this video (http://openstaxcollege.org/l/movement_plants)** to see how plants respond to a stimulus—from opening to light, to wrapping a tendril around a branch, to capturing prey.

Reproduction

Single-celled organisms reproduce by first duplicating their DNA, and then dividing it equally as the cell prepares to divide to form two new cells. Multicellular organisms often produce specialized reproductive germline, gamete, oocyte, and sperm cells. After fertilization (the fusion of an oocyte and a sperm cell), a new individual develops. When reproduction occurs, DNA containing genes are passed along to an organism's offspring. These genes ensure that the offspring will belong to the same species and will have similar characteristics, such as size and shape.

Growth and Development

Organisms grow and develop as a result of genes providing specific instructions that will direct cellular growth and development. This ensures that a species' young (**Figure 1.12**) will grow up to exhibit many of the same characteristics as its parents.

Figure 1.12 Although no two look alike, these kittens have inherited genes from both parents and share many of the same characteristics. (credit: Rocky Mountain Feline Rescue)

Regulation

Even the smallest organisms are complex and require multiple regulatory mechanisms to coordinate internal functions, respond to stimuli, and cope with environmental stresses. Two examples of internal functions regulated in an organism are nutrient transport and blood flow. Organs (groups of tissues working together) perform specific functions, such as carrying oxygen throughout the body, removing wastes, delivering nutrients to every cell, and cooling the body.

Homeostasis

Figure 1.13 Polar bears (*Ursus maritimus*) and other mammals living in ice-covered regions maintain their body temperature by generating heat and reducing heat loss through thick fur and a dense layer of fat under their skin. (credit: "longhorndave"/Flickr)

In order to function properly, cells require appropriate conditions such as proper temperature, pH, and appropriate concentration of diverse chemicals. These conditions may, however, change from one moment to the next. Organisms are able to maintain internal conditions within a narrow range almost constantly, despite environmental changes, through **homeostasis** (literally, "steady state"). For example, an organism needs to regulate body temperature through the thermoregulation process. Organisms that live in cold climates, such as the polar bear (**Figure 1.13**), have body structures that help them withstand low temperatures and conserve body heat. Structures that aid in this type of insulation include fur, feathers, blubber, and fat. In hot climates, organisms have methods (such as perspiration in humans or panting in dogs) that help them to shed excess body heat.

Energy Processing

Figure 1.14 The California condor (*Gymnogyps californianus*) uses chemical energy derived from food to power flight. California condors are an endangered species. This bird has a wing tag that helps biologists identify the individual. (credit: Pacific Southwest Region U.S. Fish and Wildlife Service)

All organisms use a source of energy for their metabolic activities. Some organisms capture energy from the sun and convert it into chemical energy in food. Others use chemical energy in molecules they take in as food (**Figure 1.14**).

Levels of Organization of Living Things

Living things are highly organized and structured, following a hierarchy that we can examine on a scale from small to large. The **atom** is the smallest and most fundamental unit of matter. It consists of a nucleus surrounded by electrons. Atoms form molecules. A **molecule** is a chemical structure consisting of at least two atoms held together by one or more chemical bonds. Many molecules that are biologically important are **macromolecules**, large molecules that are typically formed by polymerization (a polymer is a large molecule that is made by combining smaller units called monomers, which are simpler than macromolecules). An example of a macromolecule is deoxyribonucleic acid (DNA) (**Figure 1.15**), which contains the instructions for the structure and functioning of all living organisms.

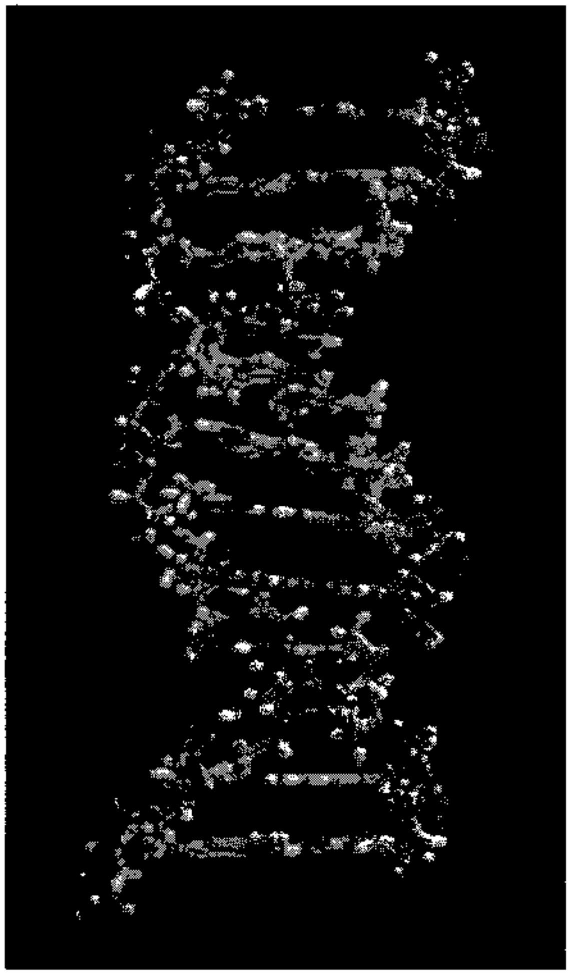


Figure 1.15 All molecules, including this DNA molecule, are comprised of atoms. (credit: "brian0918"/Wikimedia Commons)

LINK TO LEARNING

Watch **this video (http://openstaxcollege.org/l/rotating_DNA)** that animates the three-dimensional structure of the DNA molecule in **Figure 1.15**.

Some cells contain aggregates of macromolecules surrounded by membranes. We call these **organelles**. Organelles are small structures that exist within cells. Examples of organelles include mitochondria and chloroplasts, which carry out indispensable functions: mitochondria produce energy to power the cell, while chloroplasts enable green plants to utilize the energy in sunlight to make sugars. All living things are made of cells. The **cell** itself is the smallest fundamental unit of structure and function in living organisms. (This requirement is why scientists do not consider viruses living: they are not made of cells. To make new viruses, they have to invade and hijack the reproductive mechanism of a living cell. Only then can they obtain the materials they need to reproduce.) Some organisms consist of a single cell and others are multicellular. Scientists classify cells as prokaryotic or eukaryotic. **Prokaryotes** are single-celled or colonial organisms that do not have membrane-bound nuclei. In contrast, the cells of **eukaryotes** do have membrane-bound organelles and a membrane-bound nucleus.

In larger organisms, cells combine to make **tissues**, which are groups of similar cells carrying out similar or related functions. **Organs** are collections of tissues grouped together performing a common function. Organs are present not only in animals but also in plants. An **organ system** is a higher level of organization that consists of functionally related organs. Mammals have many organ systems. For instance, the circulatory system transports blood through the body and to and from the lungs. It includes organs such as the heart and blood vessels. **Organisms** are individual living entities. For example, each tree in a forest is an organism. Single-celled prokaryotes and single-celled eukaryotes are also organisms, which biologists typically call microorganisms.

Biologists collectively call all the individuals of a species living within a specific area a **population**. For example, a forest may include many pine trees, which represent the population of pine trees in this forest. Different populations may live in the same specific area. For example, the forest with the pine trees includes populations of flowering plants, insects, and microbial populations. A **community** is the sum of populations inhabiting a particular area. For instance, all of the trees, flowers, insects, and other populations in a forest form the forest's community. The forest itself is an ecosystem. An **ecosystem** consists of all the living things in a particular area together with the abiotic, nonliving parts of that environment such as nitrogen in the soil or rain water. At the highest level of organization (**Figure 1.16**), the **biosphere** is the collection of all ecosystems, and it represents the zones of life on Earth. It includes land, water, and even the atmosphere to a certain extent.

visual

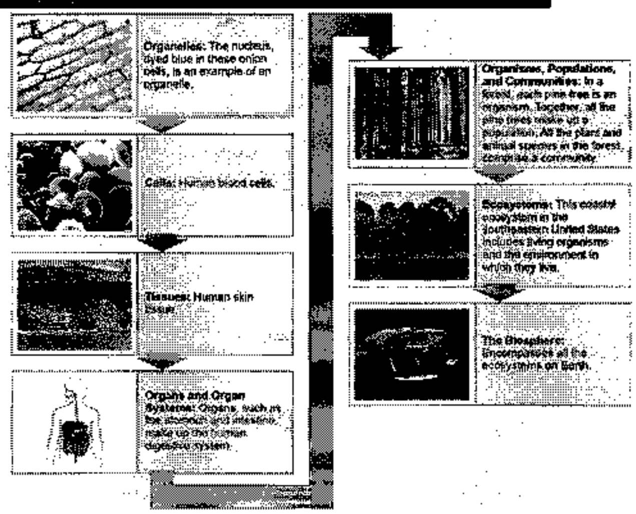


Figure 1.16 shows the biological levels of organization of living things. From a single organelle to the entire biosphere, living organisms are parts of a highly structured hierarchy. (credit "organelles": modification of work by Umberto Salvagnin; credit "cells": modification of work by Bruce Wetzel, Harry Schaefer/ National Cancer Institute; credit "tissues": modification of work by Kilbad; Fama Clamosa; Mikael Häggström; credit "organs": modification of work by Mariana Ruiz Villareal; credit "organisms": modification of work by "Crystal"/Flickr; credit "ecosystems": modification of work by US Fish and Wildlife Service Headquarters; credit "biosphere": modification of work by NASA)

Which of the following statements is false?

a. Tissues exist within organs which exist within organ systems.
b. Communities exist within populations which exist within ecosystems.
c. Organelles exist within cells which exist within tissues.
d. Communities exist within ecosystems which exist in the biosphere.

The Diversity of Life

The fact that biology, as a science, has such a broad scope has to do with the tremendous diversity of life on earth. The source of this diversity is **evolution**, the process of gradual change during which new species arise from older species. Evolutionary biologists study the evolution of living things in everything from the microscopic world to ecosystems.

A phylogenetic tree (**Figure 1.17**) can summarize the evolution of various life forms on Earth. It is a diagram showing the evolutionary relationships among biological species based on similarities and differences in genetic or physical traits or both. Nodes and branches comprise a phylogenetic tree. The internal nodes represent ancestors and are points in evolution when, based on scientific evidence, researchers believe an ancestor has diverged to form two new species. The length of each branch is proportional to the time elapsed since the split.

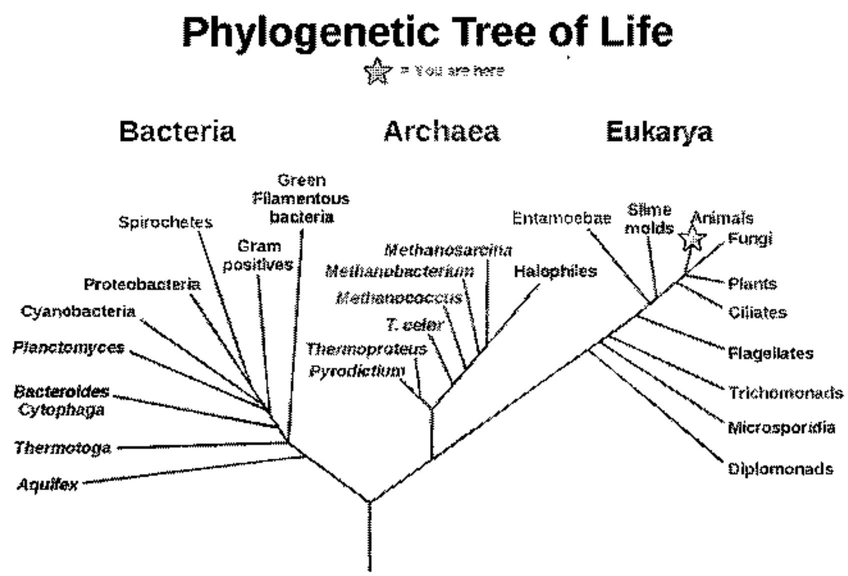


Figure 1.17 Microbiologist Carl Woese constructed this phylogenetic tree using data that he obtained from sequencing ribosomal RNA genes. The tree shows the separation of living organisms into three domains: Bacteria, Archaea, and Eukarya. Bacteria and Archaea are prokaryotes, single-celled organisms lacking intracellular organelles. (credit: Eric Gaba; NASA Astrobiology Institute)

evolution CONNECTION

Carl Woese and the Phylogenetic Tree

In the past, biologists grouped living organisms into five kingdoms: animals, plants, fungi, protists, and bacteria. They based the organizational scheme mainly on physical features, as opposed to physiology, biochemistry, or molecular biology, all of which modern systematics use. American microbiologist Carl Woese's pioneering work in the early 1970s has shown, however, that life on Earth has evolved along three lineages, now called domains—Bacteria, Archaea, and Eukarya. The first two are prokaryotic cells with microbes that lack membrane-enclosed nuclei and organelles. The third domain contains the eukaryotes and includes unicellular microorganisms (protists), together with the three remaining kingdoms (fungi, plants, and animals). Woese defined Archaea as a new domain, and this resulted in a new taxonomic tree (**Figure 1.17**). Many organisms belonging to the Archaea domain live under extreme conditions and are called extremophiles. To construct his tree, Woese used genetic relationships rather than similarities based on morphology (shape).

Woese constructed his tree from universally distributed comparative gene sequencing that are present in every organism, and conserved (meaning that these genes have remained essentially unchanged throughout evolution). Woese's approach was revolutionary because comparing physical features are insufficient to differentiate between the prokaryotes that appear fairly similar in spite of their tremendous biochemical diversity and genetic variability (**Figure 1.18**). Comparing homologous DNA and RNA sequences provided Woese with a sensitive device that revealed the extensive variability of prokaryotes, and which justified separating the prokaryotes into two domains: bacteria and archaea.

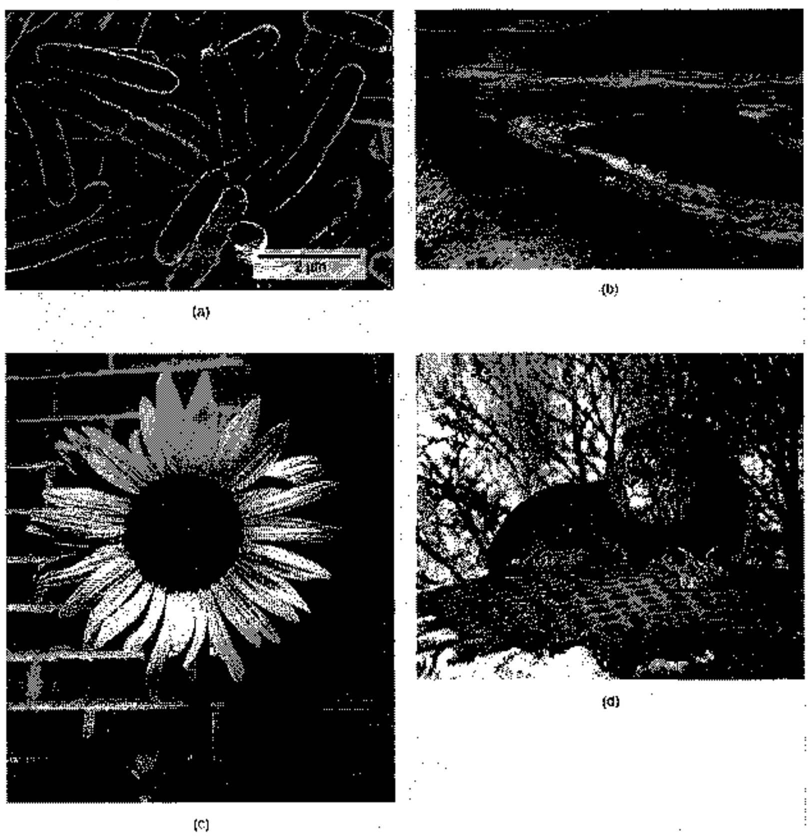


Figure 1.18 These images represent different domains. The (a) bacteria in this micrograph belong to Domain Bacteria, while the (b) extremophiles (not visible) living in this hot vent belong to Domain Archaea. Both the (c) sunflower and (d) lion are part of Domain Eukarya. (credit a: modification of work by Drew March; credit b: modification of work by Steve Jurvetson; credit c: modification of work by Michael Arrighi; credit d: modification of work by Leszek Leszczynski)

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. For instance, **molecular biology** and **biochemistry** study biological processes at the molecular and chemical level, 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.

ca eer CONNECTION

Forensic Scientist

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. Interest in forensic science has increased in the last few years, possibly because of popular television shows that feature forensic scientists on the job. Also, developing molecular techniques and establishing DNA databases have expanded the types of work that forensic scientists can do. 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 and also processing DNA (**Figure 1.19**) found in many different environments and materials. Forensic scientists also analyze other biological evidence left at crime scenes, such as insect larvae or pollen grains. Students who want to pursue careers in forensic science will most likely have to take chemistry and biology courses as well as some intensive math courses.

Figure 1.19 This forensic scientist works in a DNA extraction room at the U.S. Army Criminal Investigation Laboratory at Fort Gillem, GA. (credit: United States Army CID Command Public Affairs)

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

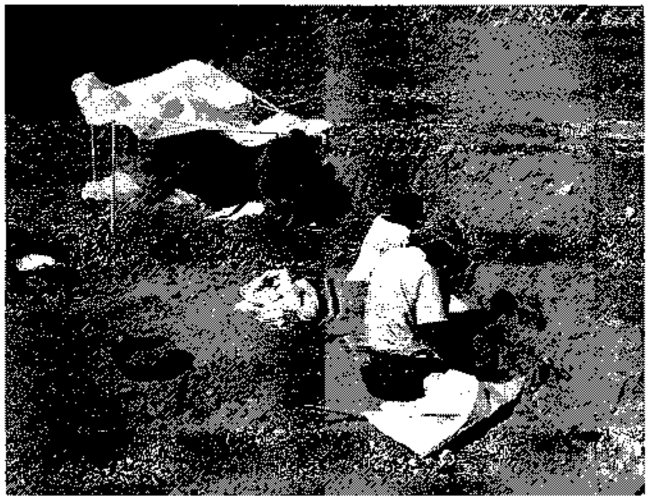


Figure 1.20 Researchers work on excavating dinosaur fossils at a site in Castellón, Spain. (credit: Mario Modesto)

Paleontology, another branch of biology, uses fossils to study life's history (**Figure 1.20**). **Zoology** and **botany** are the study of animals and plants, respectively. Biologists can also specialize as biotechnologists, ecologists, or physiologists, to name just a few areas. This is just a small sample of the many fields that biologists can pursue.

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 TERMS

abstract opening section of a scientific paper that summarizes the research and conclusions

applied science form of science that aims to solve real-world problems

atom smallest and most fundamental unit of matter

basic science science that seeks to expand knowledge and understanding regardless of the short-term application of that knowledge

biochemistry study of the chemistry of biological organisms

biology the study of living organisms and their interactions with one another and their environments

biosphere collection of all the ecosystems on Earth

botany study of plants

cell smallest fundamental unit of structure and function in living things

community set of populations inhabiting a particular area

conclusion section of a scientific paper that summarizes the importance of the experimental findings

control part of an experiment that does not change during the experiment

deductive reasoning form of logical thinking that uses a general inclusive statement to forecast specific results

descriptive science (also, discovery science) form of science that aims to observe, explore, and investigate

discussion section of a scientific paper in which the author interprets experimental results, describes how variables may be related, and attempts to explain the phenomenon in question

ecosystem all the living things in a particular area together with the abiotic, nonliving parts of that environment

eukaryote organism with cells that have nuclei and membrane-bound organelles

evolution process of gradual change during which new species arise from older species and some species become extinct

falsifiable able to be disproven by experimental results

homeostasis ability of an organism to maintain constant internal conditions

hypothesis suggested explanation for an observation, which one can test

hypothesis-based science form of science that begins with a specific question and potential testable answers

inductive reasoning form of logical thinking that uses related observations to arrive at a general conclusion

introduction opening section of a scientific paper, which provides background information about what was known in the field prior to the research reported in the paper

life science field of science, such as biology, that studies living things

macromolecule large molecule, typically formed by the joining of smaller molecules

materials and methods section of a scientific paper that includes a complete description of the substances, methods, and techniques that the researchers used to gather data

microbiology study of the structure and function of microorganisms

molecular biology study of biological processes and their regulation at the molecular level, including interactions among molecules such as DNA, RNA, and proteins

molecule chemical structure consisting of at least two atoms held together by one or more chemical bonds

natural science field of science that is related to the physical world and its phenomena and processes

neurobiology study of the biology of the nervous system

organ collection of related tissues grouped together performing a common function

organ system level of organization that consists of functionally related interacting organs

organelle small structures that exist within cells and carry out cellular functions

organism individual living entity

paleontology study of life's history by means of fossils

peer-reviewed manuscript scientific paper that a scientist's colleagues review who are experts in the field of study

phylogenetic tree diagram showing the evolutionary relationships among various biological species based on similarities and differences in genetic or physical traits or both; in essence, a hypothesis concerning evolutionary connections

physical science field of science, such as geology, astronomy, physics, and chemistry, that studies nonliving matter

plagiarism using other people's work or ideas without proper citation, creating the false impression that those are the author's original ideas

population all of the individuals of a species living within a specific area

prokaryote single-celled organism that lacks organelles and does not have nuclei surrounded by a nuclear membrane

results section of a scientific paper in which the author narrates the experimental findings and presents relevant figures, pictures, diagrams, graphs, and tables, without any further interpretation

review article paper that summarizes and comments on findings that were published as primary literature

science knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method

scientific method method of research with defined steps that include observation, formulation of a hypothesis, testing, and confirming or falsifying the hypothesis

serendipity fortunate accident or a lucky surprise

theory tested and confirmed explanation for observations or phenomena

tissue group of similar cells carrying out related functions

variable part of an experiment that the experimenter can vary or change

zoology study of animals

CHAPTER SUMMARY

1.1 The Science of Biology

Biology is the science that studies living organisms and their interactions with one another and their environments. Science attempts to describe and understand the nature of the universe in whole or in part by rational means. Science has many fields. Those fields related to the physical world and its phenomena are natural sciences.

Science can be basic or applied. The main goal of basic science is to expand knowledge without any expectation of short-term practical application of that knowledge. The primary goal of applied research, however, is to solve practical problems.

Science uses two types of logical reasoning. Inductive reasoning uses particular results to produce general scientific principles. Deductive reasoning is a form of logical thinking that predicts results by applying general principles. The common thread throughout scientific research is using the scientific method, a step-based process that consists of making observations, defining a problem, posing hypotheses, testing these hypotheses, and drawing one or more conclusions. The testing uses proper controls. Scientists present their results in peer-reviewed scientific papers published in scientific journals. A scientific research paper consists of several well-defined sections: introduction, materials and methods, results, and, finally, a concluding discussion. Review papers summarize the conducted research in a particular field over a period of time.

1.2 Themes and Concepts of Biology

Biology is the science of life. All living organisms share several key properties such as order, sensitivity or response to stimuli, reproduction, growth and development, regulation, homeostasis, and energy processing. Living things are highly organized parts of a hierarchy that includes atoms, molecules, organelles, cells, tissues, organs, and organ systems. In turn, biologists group organisms as populations, communities, ecosystems, and the biosphere. The great diversity of life today evolved from less-diverse ancestral organisms over billions of years. We can use a phylogenetic tree to show evolutionary relationships among organisms.

Biology is very broad and includes many branches and subdisciplines. Examples include molecular biology, microbiology, neurobiology, zoology, and botany, among others.

VISUAL CONNECTION QUESTIONS

1. Figure 1.6 In the example below, the scientific method is used to solve an everyday problem. Order the scientific method steps (numbered items) with the process of solving the everyday problem (lettered items). Based on the results of the experiment, is the hypothesis correct? If it is incorrect, propose some alternative hypotheses.

1. Observation
2. Question
3. Hypothesis (answer)
4. Prediction
5. Experiment
6. Result

a. There is something wrong with the electrical outlet.
b. If something is wrong with the outlet, my coffeemaker also won't work when plugged into it.
c. My toaster doesn't toast my bread.
d. I plug my coffee maker into the outlet.
e. My coffeemaker works.
f. Why doesn't my toaster work?

2. Figure 1.7 Decide if each of the following is an example of inductive or deductive reasoning.

1. All flying birds and insects have wings. Birds and insects flap their wings as they move through the air. Therefore, wings enable flight.
2. Insects generally survive mild winters better than harsh ones. Therefore, insect pests will become more problematic if global temperatures increase.
3. Chromosomes, the carriers of DNA, separate into daughter cells during cell division. Therefore, each daughter cell will have the same chromosome set as the mother cell.
4. Animals as diverse as humans, insects, and wolves all exhibit social behavior. Therefore, social behavior must have an evolutionary advantage.

3. Figure 1.16 Which of the following statements is false?

a. Tissues exist within organs which exist within organ systems.
b. Communities exist within populations which exist within ecosystems.
c. Organelles exist within cells which exist within tissues.
d. Communities exist within ecosystems which exist in the biosphere.

Name:______________________________ Date:________

Reading Guide: Chapter 1.2, Themes and Concepts of Biology (OpenStax Biology 2E)

1. From the beginning biology has wrestled with three questions:

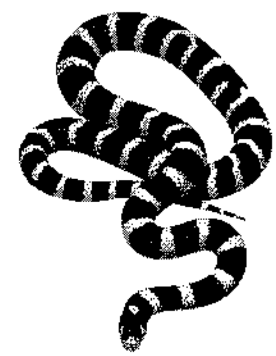
   What ______________ make something alive?

   How do we find meaningful levels of ______________ in its structure?

   How do we ______________ the different kinds of organisms?

2. Organisms are highly ______________ , coordinated structures that consist of one or more ______________.
3. Movement away or toward light is called ______________
4. When reproduction occurs, ______________ are passed to the offspring.

   Are two parents necessary for reproduction? ________



5. Genes provide instructions for organisms' growth and ______________
6. Regulation refers to mechanisms that:

   ______________ internal functions

   ______________ to stimuli

   cope with environmental ______________

7. What is homeostasis? ______________
8. All organisms require ______________ for their metabolic processes.
9. What is the smallest and most fundamental unit of matter? ______________
10. What is a macromolecule? ______________

    What is an example of a macromolecule? ______________

11. What is the difference between a prokaryote and a eukaryote? ______________
12. Cells combine to make ______________ which combine to make ______________
13. All the individuals of a species living in an area is a ______________
14. The source of the diversity of life is ______________
15. What is a phylogenetic tree? ______________

Evolution Connection: Carl Woese and the Phylogenetic Tree

16. The organization of organisms into the five kingdoms was based on ______________
17. Carl Woese proposed that life on earth evolved along three lineages, or domains. What are they?

    ____

18. What organisms belong to the domain Eukarya? ______________
19. Why was Woese's approach revolutionary? ______________

20. Briefly describe what each of the branches of science study:

    Microbiology ______________ Forensic Scientist ______________

    Neurobiology (neuroscience) ______________ Paleontology ______________

    Zoology ______________ Botany ______________

Name:____Date: _______

Reading Guide: Chapter 1.1, The Science of Biology (OpenStax Biology 2E)

1. What is the definition of biology? ____

2. What is the definition of science? ____

3. A suggested explanation for an event is called a(n): ______________________________________

4. A tested and confirmed explanation for observed phenomena is called a(n): _________________________

5. Science can be defined as fields of study that attempt to ______________________________ the nature of the ______________________________.

6. Fields of science related to the physical world are called ________________________ sciences.

7. What subjects would be part of this type of science? ___________________________________

Scientific Reasoning

8. ______________________________ reasoning uses related observations to arrive at a general conclusion.

9. How are brain studies an example of inductive reasoning? ____

10. Deductive reasoning is used in _____________________________ - based science.

11. Deductive reasoning uses a ____________________________________ to forecast specific results.

12. What is the goal of descriptive science? ____

13. How was velcro invented? ____

The Scientific Method

14. What scientist first documented the scientific method? __________________________________

15. The process starts with an _________________________ which leads to a ____________________

16. What is the typical format of a prediction? ____

17. A valid hypothesis must be testable and also be ____.

18. What distinguishes sciences from non-sciences? ____

19. Any part of the experiment that can vary or change is called the ______________________________

20. What is the control group? ____

21. Rejecting one hypothesis means that the other hypothesis is accepted. True / False

22. Deduction proceeds from the ____________________ to the ____________________

23. What type of reasoning has occurred when scientists reach a general conclusion from a number of specific observations? ____

24. Figure 1.6 The scientific method is used to solve an everyday problem. Match the scientific method steps (numbered items) with the process of solving the everyday problem (lettered items). Based on the results of the experiment, is the hypothesis correct? If it is incorrect, propose some alternative hypotheses.

____ observation	a) there is something wrong with the electrical outlet
____ question	b) if something is wrong with the outlet, the coffeemaker also won't work

when plugged into it

____ hypothesis	c) my toaster does not toast my bread
____ prediction	d) I plug my coffeemaker into the outlet
____ experiment	e) My coffeemaker works
____ result	f) Why doesn't the toaster work?

25. Figure 1.7 Decide if each of the following is an example of inductive (I) or deductive reasoning (D)

_____All flying birds and insects have wings. Birds and insects flap their wings as they move through the air. Therefore, wings enable flight.
_____Insects generally survive mild winters better than harsh ones. Therefore, insect pests will become more problematic if global temperatures increase.
_____Chromosomes, the carriers of DNA, separate into daughter cells during cell division. Therefore, each daughter cell will have the same chromosome set as the mother cell.
_____Animals as diverse as humans, insects, and wolves all exhibit social behavior. Therefore, social behavior must have an evolutionary advantage.

Two Types of Science: Basic Science and Applied Science

26. What is the goal of "basic science?" ______________________________

27. What is the goal of "applied science?" ______________________________

28. What is the Human Genome Project? ______________________________

29. What is serendipity? ______________________________

30. Where do scientists publish their works? ______________________________

31. A summary at the beginning of the scientific paper is called the ____________________

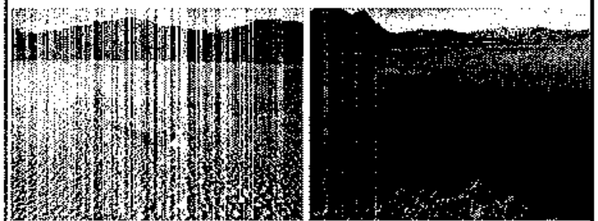
32. What other sections are included in a scientific paper (IMRaD)?
____

The Process of Science

Essential Questions

1. How does scientific inquiry answer questions about the living world?
2. How do scientific processes lead to a greater understanding of the natural world?
3. How can data be analyzed to determine the outcome of an experiment or set of observations?
4. How do scientists share information and build upon the work of others?

The Case of the Slithering Rocks



These rocks appear to move on their own, leaving "rock trails" behind them. What do you think causes the rocks to move?

All science assumes that observations have a natural cause, a principle known as

NATURAL CAUSALITY

by its nature it excludes supernatural phenomenon

What are some things that are considered "supernatural" and therefore cannot be studied scientifically?

Chapter 1.1 The Science of Biology

Biology is the study of living organisms

What is Science?

Knowledge that covers general truths or the operation of general laws, acquired and tested by scientific method

A **hypothesis** is a possible explanation for a natural event or a series of observations.

- to be valid, a hypothesis must be testable.
- observations can either confirm or refute hypothesis
  *avoid saying you've "proved" it

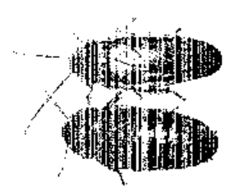
Observations are the main elements of scientific knowledge gathering.

Avoid using the word "fact." Instead, use the word "observation"

"Facts" depend on the perception of the observer. Is the sky really blue?

Observations → Hypothesis

Observe a laboratory specimen for a few minutes and practice writing down specific observations of what you see.



Discuss with your lab partner a hypothesis that can be tested with your specimen.

Scientific Reasoning

Inductive reasoning allows a person to combine isolated facts into a cohesive whole, reasoning makes broad generalizations from specific observations.

Observation 1: Snakes have tiny pelvic bones
Observation 2: Snakes and lizards have similar DNA sequences
Observation 3: Snakes appear after lizards in the fossil record.

Generalization: Snakes are related to lizards / Snakes evolved from lizards

A yellow-bellied three-toed skink carrying embryos, visible as light orbs inside its body.

Deductive reasoning involves "if, then" logic that predicts what will happen based on the hypothesis or theory.

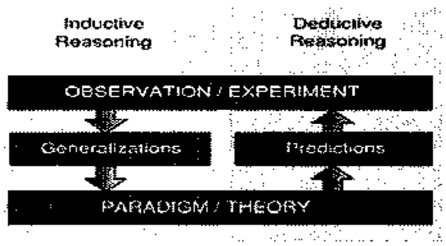
Involves general RULES to make predictions.

Start with a general idea or principle → make predictions.

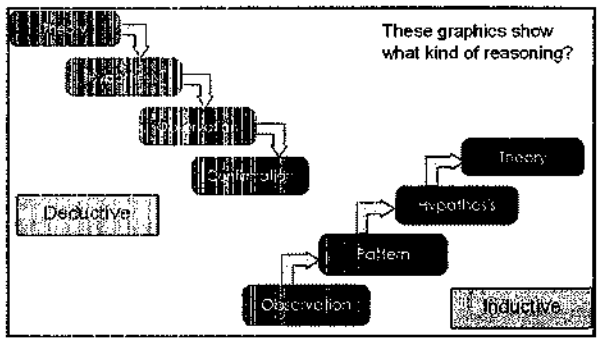
1. All living things require energy
2. Bacteria are living things
3. Bacteria require energy

Prediction: Bacteria deprived of an energy source will die.

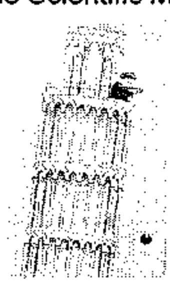
Comparing Inductive and Deductive Reasoning

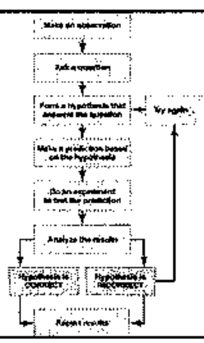


These graphics show what kind of reasoning?



The Scientific Method





Controlled Study

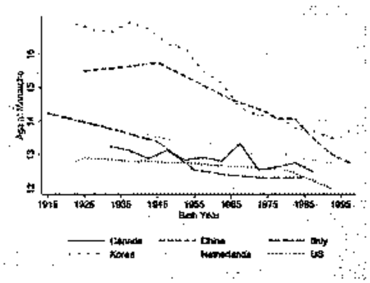
Independent Variable (What you did)
---- Manipulated Variable
---- Graph on X Axis
(this is time on many graphs)

Dependent Variable (What you measure)
----- Responding
----- Graph on Y axis

The control group is the group that is not changed and is used as a comparison.

DRY MIX

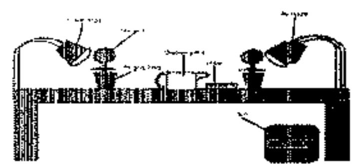
You don't always need to perform an experiment to analyze trends and data...



1. Identify the independent and dependent variables.
2. What is the (likely) experimental question being answered by this data set?
3. What new questions can be developed from this information?

Examples of independent and dependent variables

Question: Does colored light affect plant growth?
What is the experimental variable?
What is the dependent variable?



What variables must be kept constant - or controlled?

How would you graph this?

Data Gathering

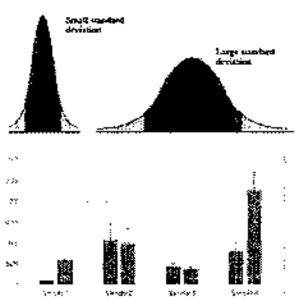
Organizing Data: Charts, Tables, Graphs

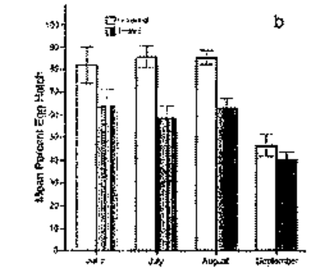
Sample Size

Mean versus Median

Standard Deviation

Standard Error / Error Bars





I² Strategy
What I SEE
What It MEANS

I² strategy Practice Wolbachia and Mosquitoes

CER Charts

Claim - a sentence that answers a question or draws a conclusion from a data set. It may also describe the relationship between independent and dependent variable.

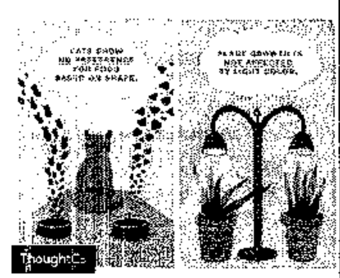
Evidence - sufficient and appropriate details that support the claim (qualitative or quantitative)

Reasoning - shows how or why the data count as evidence and may include scientific principles linked to the phenomenon.

"While We Sleep" - Article with CER

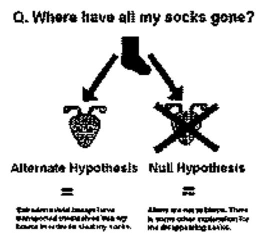
Null Hypothesis

The hypothesis that there is no significant difference between specified populations, or there is NO relationship between two measured variables. Sometimes your goal is to DISPROVE the null hypothesis.



FALSIFIABILITY

It is important than any statement or hypothesis is falsifiable - if there is no evidence out there that would prove the statement wrong, then there is no point in running any tests.



It is bad science to ask someone to **PROVE A NEGATIVE.**

For example:

Prove that ghosts don't exist.
Prove that cell phones don't cause cancer.
Prove that there are no aliens.
Prove that telepathy doesn't exist.

The burden of proof lies on the claimant. If you make a claim, then you must be the one to provide evidence for that claim. (It is not on other people to show it to be false.)

What is an anecdote?

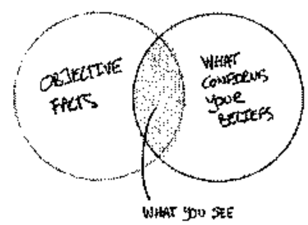
Anecdotes are singular observations, stories people tell, or things someone might have heard.

It is NOT data.

What is confirmation bias?

What are ways scientists can reduce bias?

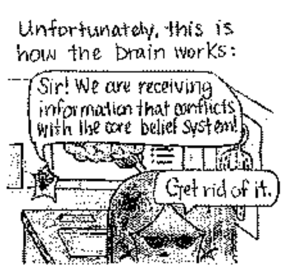
What is a double blind experiment?



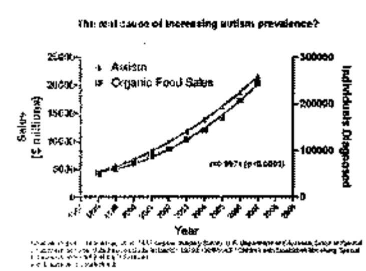
Cognitive dissonance = the state of having inconsistent thoughts, beliefs, or attitudes, especially as relating to behavioral decisions and attitude change.

How might cognitive dissonance make it difficult for scientists to change people's opinions and behaviors?

See also: Logical Fallacies



Correlation vs. Causation



The Importance of Publication

After scientists have conducted research, in order for the conclusions to be considered valid, they must publish their findings in a PEER-REVIEWED journal.

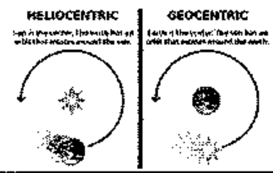
Check out PLOS for a source of open-source, peer reviewed science articles.

JAMA - Journal of the American Medical Association

The University of California, Berkeley defines a theory as "a broad, natural explanation for a wide range of phenomena.

Theories are concise, coherent, systematic, predictive, and broadly applicable, often integrating and generalizing many hypotheses."

*A theory explains *why* something happens*



Principles, Laws, Models

The terms "principle" and "law" and "model" are also used for generally accepted theories.

Basic theories of biology are:
a. Cell theory
b. Biogenesis theory
c. Evolution theory
d. Gene theory
e. Germ Theory

Other Theories
f. Heliocentric Theory
g. Theory of Gravity

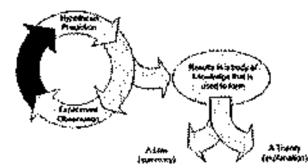
What is the difference between a theory and a law?

Theories do not become LAWS.

Theories explain sets of data. (WHY)

Laws provide general rules for what we expect to happen. (WHAT)

Scientific Method



TedEd - What is the difference between a theory and a law? (Video)

All Scientific Knowledge is Tentative!

When a law, theory, or hypothesis is shown to be wrong, it is modified or removed.

We don't worry about "PROOF" in science, we look at EVIDENCE and whether the evidence supports or refutes a particular claim. We look at whether our laws and theories are valuable for making predictions.

Theories and Laws are never technically "proven."

Chapter 1.1 The Process of Science

Essential Questions

- How does scientific **inquiry** answer questions about the living world?
- How do scientific processes lead to a greater understanding of the natural world?
- How can data be analyzed to determine the outcome of an experiment or set of observations?
- How do scientists share information and build upon the work of others?

1. The Case of the Slithering Rocks

2. What is biology? What is science in general?

3. Natural Causality and the limitations of science

4. Hypothesis / Observations / Facts

5. Observation Activity (What do you observe?)

6. Scientific Reasoning: Inductive vs Deductive Reasoning

7. Scientific method(s)

   Controls and Variables (Independent vs Dependent)

8. Data Gathering

   Sample Size / Mean / Median / Standard Deviation / Standard Error

9. I^2 Strategy for interpreting Graphs

10. Claim - Evidence - Reasoning (CER)

11. The Null Hypothesis

12. Falsifiability and Proving a Negative

13. Anecdotes

14. Confirmation bias and double blind experiments

15. Cognitive Dissonance

16. Correlation versus causation

17. Peer Review and Publications

18. Scientific Theories

19. Logical Fallacies (*See handout)

1.2 Themes and Concepts in Biology

Essential Question: How are living things identified and classified?

1. Properties of Life

    - Order
    - Response to Stimuli
    - Reproduction
    - Growth and Development
    - Regulation
    - Homeostasis
    - Energy Processing

2. Homeostasis and Feedback Loops

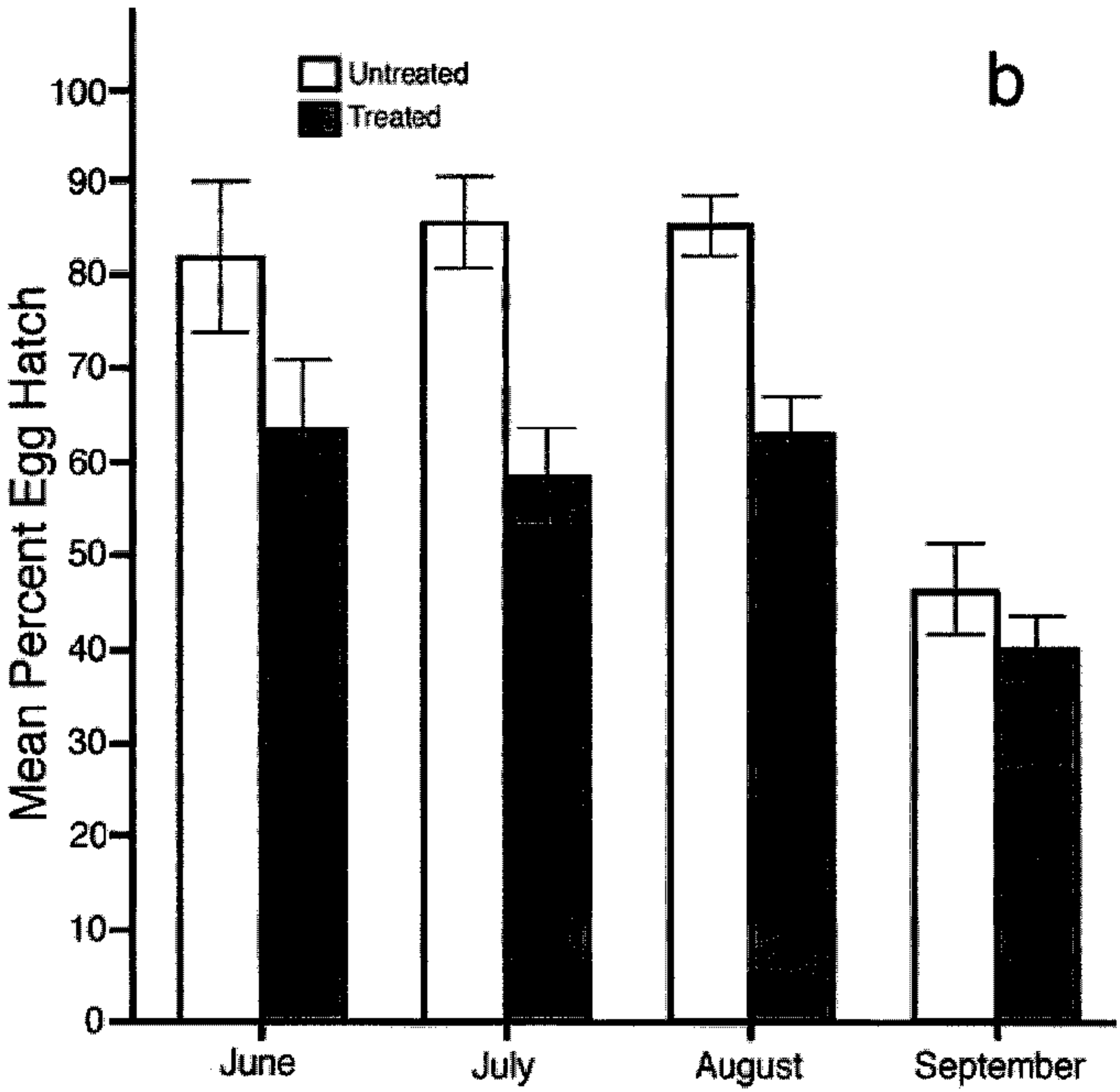
3. Levels of Organization

4. Taxonomy and the 6 Kingdoms

5. Homeostasis (Ch 33.3 referenced) and Feedback Loops

I² Strategy Data Point: Mosquito

https://www.hhmi.org/biointeractive/using-wolbachia-to-suppress-mosquito-fertility



BACKGROUND INFORMATION

Some mosquito-borne pathogens, like the dengue, chikungunya, and Zika viruses, cause diseases for which there are not yet effective treatments or vaccines. Zika virus in particular has spread to more than 80 countries to date, making it a global concern. Zika can cause a debilitating illness of the nervous system called Guillain-Barré syndrome and, when a pregnant woman is infected, severe birth defects including microcephaly. An increasingly common approach to preventing the spread of these diseases is to target mosquito fertility rather than use insecticides, which can have negative environmental effects. One of these techniques involves using the naturally occurring Wolbachia bacteria that infect mosquitoes, making them, in some cases, infertile. When male mosquitoes are infected with Wolbachia, they must mate with an infected female to produce viable embryos. If they mate with an uninfected female, their sperm are unable to go through mitosis after embryo formation. Consequently, in the field, after mating with a Wolbachia-infected male, an uninfected wild female will lay eggs that never hatch. This is called cytoplasmic incompatibility.

CLAIM:	
Evidence	Reasoning

Additional Discussion Questions (optional)

1. Describe the differences in the percentages of eggs hatched between treated and untreated sites.

2. During which months do you see the greatest impact of the treatment? Why do you think that is?

3. Why is it important to include untreated sites in this study?

4. Describe what the error bars mean in this figure. How do you interpret the differences between treated and untreated?

5. What type of statistical analysis would convince you that the decrease in the mean percentage egg hatch in the months of June, July, and August was statistically significant?

6. Why do you think the researchers chose to release only male mosquitoes instead of both males and females?

7. Why didn't the release of infected males result in zero eggs hatched at the treated site?

8. If this site was left untreated the following year, predict what this same graph might look like.

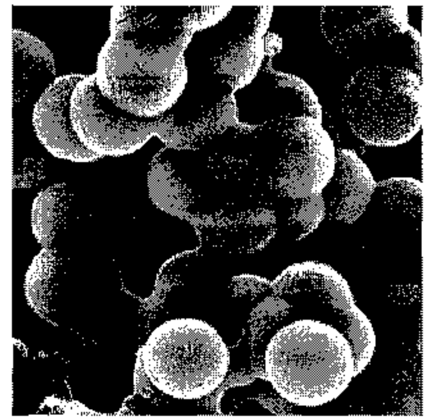
9. Based on these results, would you recommend treatment with Wolbachia as a way to reduce A.albopictus mosquito populations? Why or why not?

Name:______________________________________Team:________

Nanobacteria: Are They Alive?

A Case Study on What It Means to Be a Biological Organism

by **Merri Lynn Casem,** Department of Biological Science , California State University, Fullerton (Adapted from: National Center for Case Study Teaching in Science)



Part I—What Does It Mean To Be Alive?

Biology is the study of living things. Whether a single cell or a Sequoia tree, a humpback whale or a human being, you have an intuitive sense of what it means to be a biological organism. Sometimes, however, the designation of something as a living thing is not so obvious. A recent example of this is the discovery of *nanobacteria.*

Bacteria are *prokaryotic* cells. Prokaryotes lack the internal, membrane-bound structures associated with *eukaryotic* cells (your body is made up of eukaryotic cells). Bacteria are extremely abundant,, occurring in every environment on Earth (including inside and outside your body). Many bacteria can cause diseases.

Nanobacteria are very tiny, smaller than known prokaryotic cells. This class of bacteria was originally isolated from human and cow blood. It has been proposed that these bacteria function to stimulate a process called *biomineralization.* Biomineralization is the formation of inorganic crystalline structures in association with biological macromolecules. This process is responsible for the production of bone and dental enamel. Nanobacteria have been isolated from within human kidney stones, leading to the suggestion that these bacteria may be the cause of this disease.

Over the next several class meetings we will be considering the evidence for the existence of nanobacteria and their role in the process of biomineralization. We will seek to answer the question about whether nanobacteria should be considered living organisms.

Assignment for Part I: To answer this you need to think about the properties common to all living things.

1. Think of at least THREE properties of life and consider how you would design a test for this property.

Property of Life	How would you test for it?

2. As part of this study, you will be asked to read scientific text that may contain words you are unfamiliar with. Reread this introduction and underline words that might be difficult for some readers. Find at least three words and construct a definition for them. (Do not look it up, contextualize.)

Word	Definition / Explanation

Part II—What Is the Evidence that Nanobacteria Are Alive?

Nanobacteria were originally discovered by two researchers from Finland, Drs. E. Olavi Kajander and Neva Ciftcioglu. They isolated very small (0.2 to 0.5µm) coccoid (round) particles from human and cow blood. They found that they were very difficult to work with and did not behave like typical bacteria. They reported: "Nanobacteria are poorly disruptable, stainable, fixable and exceptionally resistant to heat" (i.e. none of these standard techniques worked on the nanobacteria).

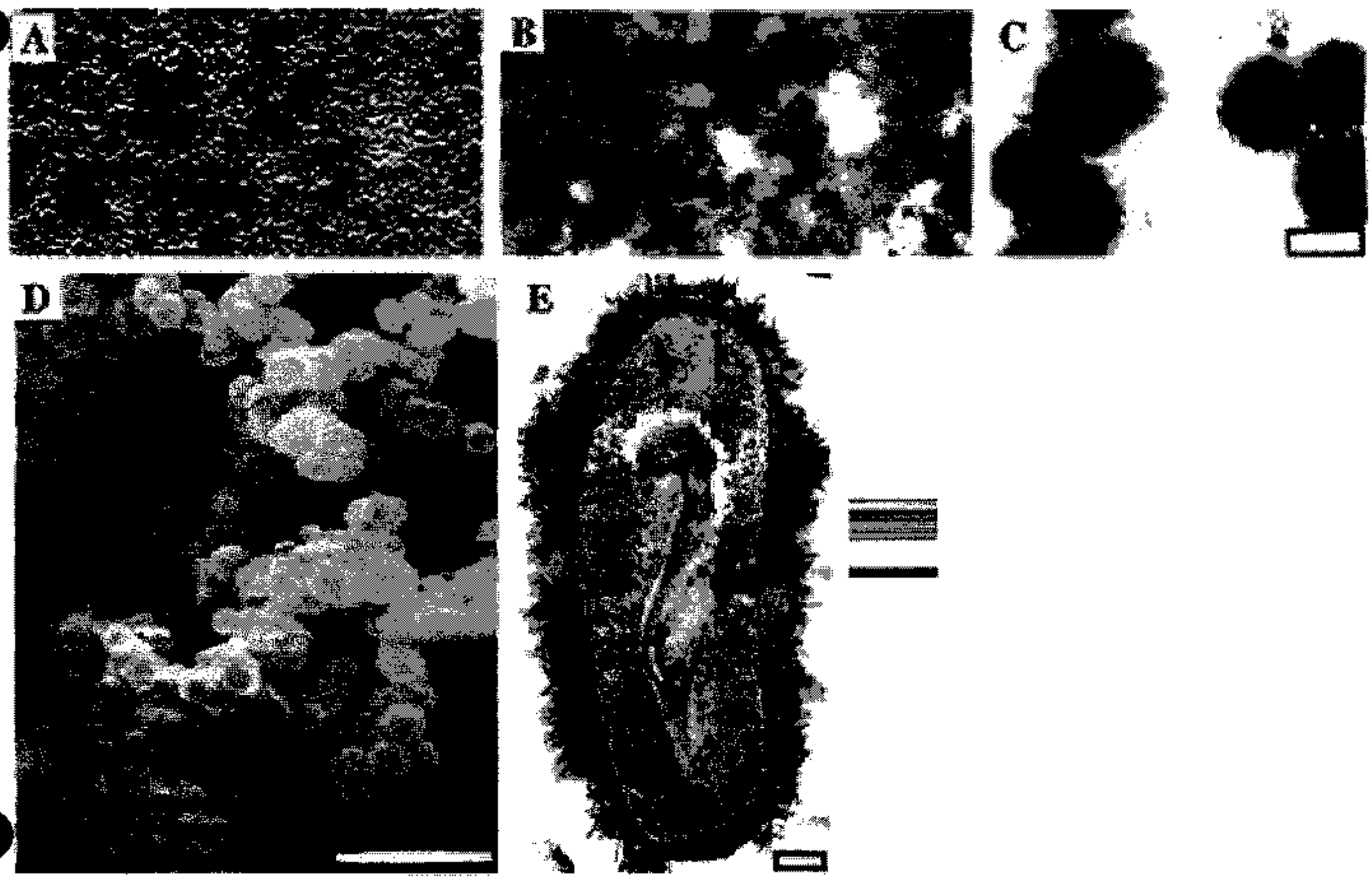
The researchers determined that a culture of nanobacteria will double in size in three days and high doses of gamma radiation or antibiotics will prevent this multiplication. They claim to have isolated a "gene sequence that falls within the subgroup of Proteobacteria," a class of bacteria that includes several human pathogens.

Carefully read the introduction above. What is the main point of paragraph 1?

What is the main point of paragraph 2?

Examine the data presented in Data Sheet 1 . Circle any words you are unfamiliar with. Discuss with your group what those words might mean and **annotate the margins.** You may need to use other resources to determine what these words mean.

Data Sheet 1 for Part II



Light and electron microscopic images of nanobacteria.

(A) DIC image of bottom-attached nanobacteria after a 2-month culture period.

(B) DNA staining of the same area (X1600) with the modified Hoechst method.

(C) Negative staining of nanobacteria isolated directly from FBS. (Bar = 200 nm.)

(D) SEM micrograph showing their variable size. (Bar = 1 μm.)

(E) A dividing nanobacterium covered with a "hairy" apatite layer. (Bar = 100 nm.)

Source: Kajander and Ciftcioglu 1998 (PNAS 95: 8274-8279).

Part III – More Evidence of Life

In their 1998 paper, Kajander and Ciftcioglu describe various experimental results to support their hypothesis that nanobacteria are living organisms. In addition to the evidence you have already considered, these authors describe three key experiments that they feel greatly strengthen their hypothesis.

Experiment 1—Transferability

When nanobacteria are cultured for a period of time (1 month), the process of biomineralization that they trigger results in the formation of a "biofilm" on the surface of the culture container - much like a hardwater deposit around a faucet. It is possible to scrape up this biofilm, dilute the components (1:10), and transfer the nanobacteria into a new culture container. After another month, the culture container is once again coated with a biofilm. They describe this property as "transferability."

Experiment 2—Gamma Radiation

Nanobacteria could be isolated from culture as described above. When these isolated cells were exposed to high energy, gamma radiation and then added to a culture container, it was observed that no growth of a biofilm was observed. Gamma radiation is known to disrupt the cell membrane which is fatal to living cells.

Experiment 3—Kidney Stones

Kidney stones were examined from 30 different human patients. When these stones were treated to slightly dissolve them, it was possible to isolate nanobacteria-like particles. When placed in culture, these particles behaved exactly like nanobacteria isolated from serum. That is, they formed a biofilm on the surface of the culture container.

Consider the results from each of the three experiments described above. What does each experiment tell you? How does the experiment support the hypothesis that nanobacteria are living? Use the table below to record your thoughts.

	What can you conclude from this experiment?	Does the experiment support the hypothesis?
Experiment 1		
Experiment 2		
Experiment 3		

Part IV—Corroborating Evidence

A key requirement in the process of scientific investigation is the repetition of experimental results by other scientists. If others can repeat your work, then it is likely (although not guaranteed) that your conclusions and hypotheses are correct. In October of 2000, Cisar et al. (et al. means "and others") published a paper that examined the original work of Kajander and Ciftciolglu.

Cisar's team repeated the experiments described by Kajander. They isolated and cultured the nanobacteria in the same way and observed many of the same behaviors. Despite this, Cisar et al. believe that their evidence does not support the hypothesis that nanobacteria are living and play a role in the development of kidney stones in humans.

One difference between the papers focuses on the evidence for DNA. DNA can be identified by its staining properties (Hoechst or ethidium bromide) or by its ability to absorb light at a wavelength of 260nm (ultraviolet). Another method is to use the technique of Polymerase Chain Reaction (PCR). This technique uses short sequences of DNA called primers to trigger a chemical reaction that increases the concentration of pieces of a specific region of DNA from a sample. (*The data from these and other experiments are presented on Data Sheet 1)*

The critical analysis of data becomes even more important when different groups reach conflicting conclusions. Scientific results are meaningless if they cannot be repeated and validated. The inability to repeat results could arise from unknown variables (quality of water, etc.), from minor changes in technique or procedure, from differences in interpretation (researcher bias), or from serious flaws with the original research.

1. What is Cesar et al's position on whether nanobacteria are alive or not? Find a sentence or phrase that identifies this position and highlight it.

2. Why might scientists NOT be able to repeat the results from a previous experiment?

3. Consider the evidence gathered by Kajander's team. What evidence would it take for your group to decide that the nanobacteria are NOT alive and that Kajander is wrong?

DATA SHEET 1

Experiment	Result of Cesar et al's research - repeating the work of Kajander	Supports hypothesis that nanobacteria are alive? (yes/no)
Culture of Nanobacteria	Nanobacteria maintained in culture generate a biofilm on the surface of the culture container within 3 weeks.	
Gamma Radiation	Exposure to gamma radiation prevents the formation of a biofilm.	
Transferability	When a biofilm (nanobacteria) isolated by scraping the surface of an established culture and transferred into a new culture container - generating a new biofilm. This could be repeated for several months.	
Cell-like appearance	The nanobacteria isolated from the biofilm has a coccoid (round) appearance.	
DNA Isolation	There is no evidence of DNA based on absorption at a wavelength of 260nm.	
PCR for DNA	The same PCR product was found in 2 samples that lacked the nanobacteria. 1) The sequence of the PCR product was 99% identical to that of *Pseudomonas*, a common bacterial contaminant. 2) The published sequences of rDNA from nanobacteria are 99% identical to rDNA from *Phyllobacterium*, another common contaminant.	

1. Consider the data from the work by Cisar et al. Which terms or techniques might be difficult for novice biologists to understand? Clarify them with your group and with other resources. Describe at least 2 concepts that might need clarification below.

2. Based on Cesar's data, do nanobacteria have DNA? Why would this be important for establishing that nanobacteria are living organisms?

Part V—Final Chapter (or is it?)

When Cisar *et al.* tried to repeat the experiments described by Kajander and Ciftciolglu, they did not feel that the results they obtained supported the hypothesis that nanobacteria were living. Cisar *et al.* claim to provide evidence that there is no DNA associated with the nanobacteria based on DNA staining and that evidence of nanobacterial rRNA is likely a result of contamination of the PCR results by other common bacteria.

While these results seemed to support the idea that nanobacteria are not biological organisms, there was a problem. Cisar *et al.* were able to repeat **some** of Kajander and Ciftciolglu's data. Specifically, Cisar *et al.* found that, nanobacteria could 1) generate a biofilm, 2)gamma radiation prevented the formation of the biofilm, and that 3)the biofilm could be transferred.

What could account for these results if nanobacteria were not alive? Cisar *et al.* needed to explain these results if they wanted their conclusion to be accepted by the scientific community. They attempted to do this by this by designing an additional set of experiments.

Assignment for Part V:

It is not enough to simply suggest that someone else's research is wrong. The finding of "negative evidence" (not finding something) is usually not sufficient. You must provide compelling, positive evidence that offers an alternative explanation of the published observations.

Look over the final set of experimental data provided by Cisar et al. and displayed on the chart. What conclusions can you make?

Experiment	Results of Cesar's new experiments	Conclusions based on this data
Energy Use by Nanobacteria	Cultures of nanobacteria were exposed to 0.1% *sodium azide* - a powerful inhibitor of cellular respiration. The formation of a biofilm continued even in the presence of this poison.	
"Growth of Dilute Cultures"	Cultures of nanobacteria were diluted to a higher degree than that used by Kajander. Dilutions of 1:100 or 1:1000 were cultured At these high dilutions there was no evidence of biofilm formation even after 8 weeks.	
Biofilm formation in the **absence** of nanobacteria	Sterile culture media will not form a biofilm on its own. When purified phosphotidyl inositol (a phospholipid common to biological membranes) was added to the culture, biofilm formation occurred within two weeks. The appearance of the particles was very similar to those found in nanobacterial cultures. This ability for a phospholipid to induce biofilm formation was prevented when the phospholipid was exposed to gamma radiation.	

Final Project

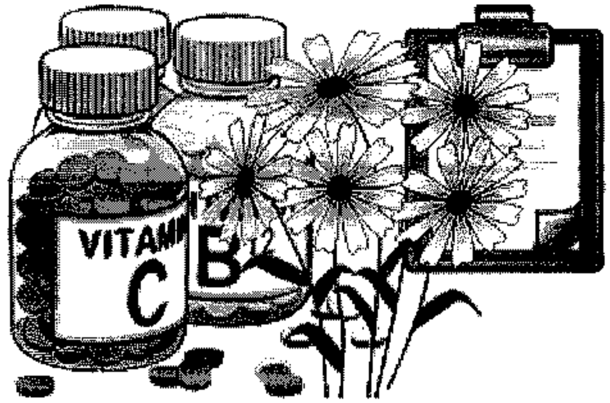
Discuss which set of evidence (Kajander and Ciftcioglu or Cisar et al.) you find most convincing. Decide whether you believe nanobacteria are alive or not!

Write a 1 page essay that states your position and discusses the evidence and reasoning for your choice. Use the CER model to help you develop your argument.

Rubric - Nanobacteria (CER)

Background Information included so that the author's CLAIM has context: __3 __2 __1 __0
<u>Claim</u> is clearly worded and takes a position regarding the central question of the case: __3 __2 __1 __0
Sufficient <u>evidence</u> is included that supports claim using data and observations from case: __3 __2 __1 __0
Scientific <u>reasoning</u> (deductive/inductive) is applied, leading to a **logical conclusion** __3 __2 __1 __0

Scientific Method Scenarios (AP Bio)



1. Design an experiment that would answer your experimental question.

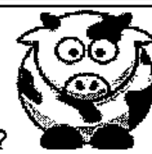
   a.Establish a hypothesis AND a null hypothesis.
   b. Identify the dependent and independent variables (may not apply to all).
   c. Propose ways to eliminate confirmation bias.
   d. Show a chart or graph that would depict what your data would look like.
   e. Be ready to share your experiment with the class.

2. Improve your question (Scientific Questioning)

Does the wavelength of light (R.O.Y.G.B.I.V.) affect a plant's growth? 

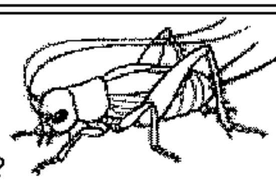
Do mosquitoes spread the Zika virus to humans? 

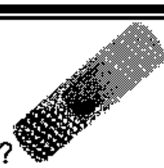
Will frogs exposed to the hormone estrogen lay more eggs? 

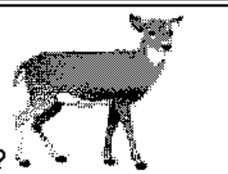
Does the hormone estrogen increase the milk yield of dairy cows? 

Does the size of a fish tank determine how large a fish will grow? 

Do phosphates cause algae growth? 

Will crickets chirp more if the temperature is warmer? 

Do wounds heal faster when they are covered by Band-Aids? 

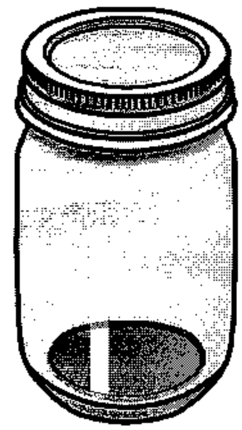
Do insecticides increase the yield of a corn crop? 
Do hyenas hunt by sight or by smell? 
Does lack of sunlight cause depression in humans? 
Are mosquitoes attracted to carbon dioxide? 
Are herbicides causing bee populations to decline? 
Will female deer urine attract male deer? 

Grading Rubric (1-2 pts for each, 10 pts total)

Hypothesis and Hull Hypothesis ____
Identified variables ____
Eliminated bias ____
Data table / chart suggestion ____
Question revision / improvement ____

Name(s):______________________________

Investigation: Heat Storage



Problem: Mammals and other **endotherms** need to regulate their temperatures. When the environment is extremely cold, animals have ways to stay warm, mammals have hair and birds have feathers. Even your house has some kind of insulation to keep the heat inside.

Question: What materials provide the best insulation? How can you find out?

Experimental Design

*Discuss with your group an experimental design that you can use to answer the question.

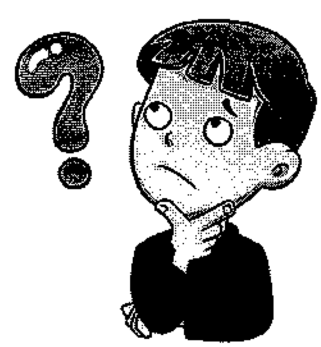
You will be provided with the following materials:

Hot water, thermometer, jars with plastic wrap covers, clock or stopwatch
Materials to test: cotton, polyester, styrofoam, newspaper, cardboard, bubble wrap

1. Sketch your experiment below, use annotations to explain your design.

2. How you will know which material was the best insulator.
   What kind of data will you need to collect?

   a) the temperature of the material
   b) how fast the temperature changes in the jar
   c) the size of the material being tested
   d) the time it takes to fill the jar with water



Testing the Materials

1. Fill a jar with hot water and place a thermometer in it and cover with saran wrap.
2. Set up another job with the same amount of water, thermometer and saran wrap. For this jar, use one of the insulating materials to wrap around the jar. Be sure you can still read the thermometer.

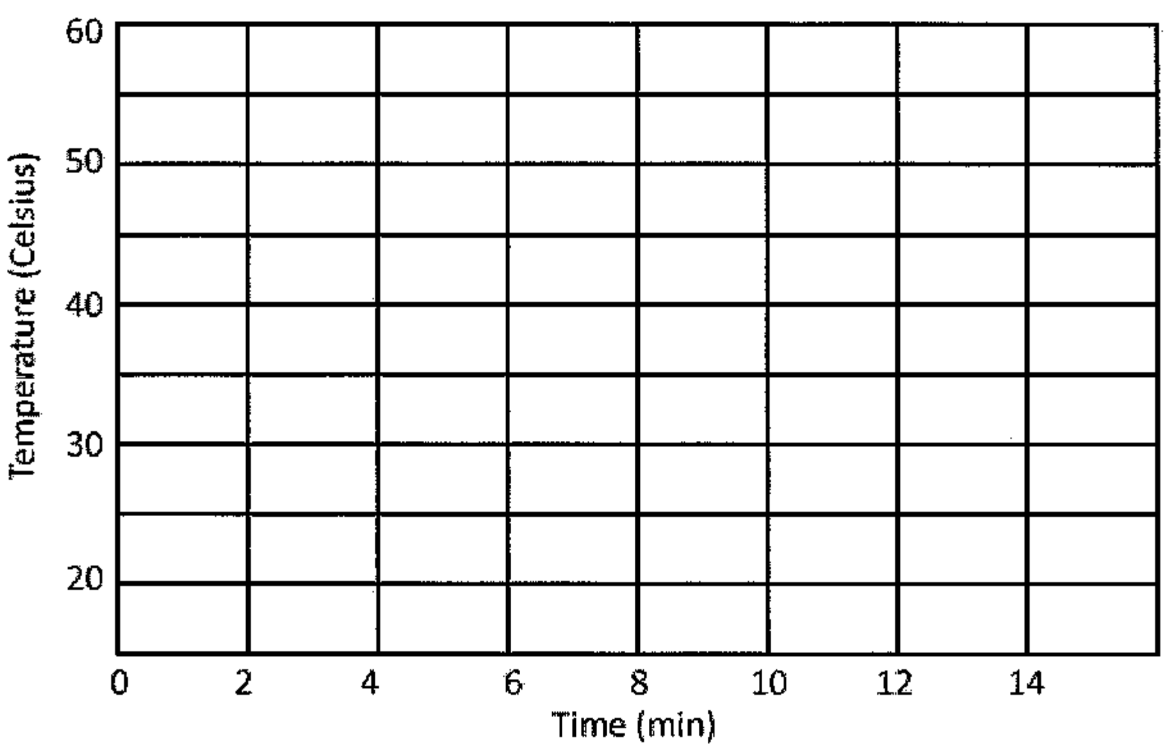
Your teacher will assign the material. **Which insulation does your group have?** ____________________

3. Take readings on the thermometer every two minutes for both jars and record in the data table.

Data Table

Time	Temperatures of Materials Being Tested (Celsius)	
	No insulation	With insulation
Starting temp		
2 minutes		
4 minutes		
6 minutes		
8 minutes		
10 minutes		
12 minutes		
14 minutes		

Graph the Data - Create two lines, one for the uninsulated jar and one for insulated jar



Analysis

1. In this experiment, what is the control?

   a) jar with no insulation   b) jar with insulation   c) the water

2. What is the independent (manipulated) variable? a) time   b) temperature   c) insulation

   What is the dependent (responding) variable? a) time   b) temperature   c) insulation

3. Which statement best summarizes what happened to the temperature in the jars over the 14 minute period?

   a) temperatures went up over time at about the same rate
   b) temperatures stayed the same in both jars
   c) temperatures went down over time, but at different rates
   d) temperatures went down over time at about the same rate

4. Compile the data from all the groups. (Your instructor will give you direction).

   Make a **CLAIM** about which material is the best insulator based on the data. This should be in a complete sentence. Use the term "heat" in your claim.

5.. How do you know? Provide **EVIDENCE** for your claim.

6. Use **REASONING** to connect the evidence and claim by completing the following sentence:

If [ ] is the best insulator, then... [ ]

(material)   (what will occur)

Name: ______________________________ Date: ________

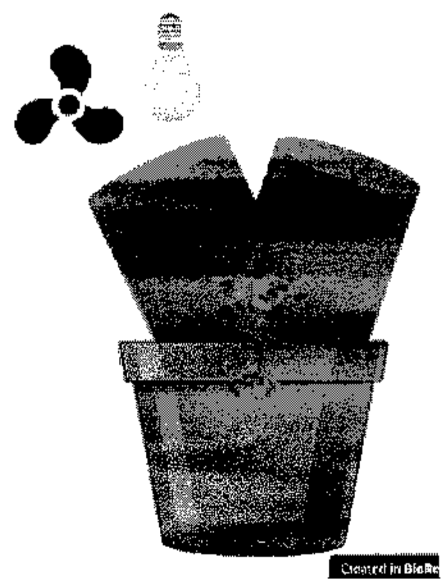
Scientific Method - Can Plants Learn?

https://youtu.be/LCvwyScn9jU

https://www.nature.com/articles/srep38427

Scientists set out to find the answer to the question: "Can plants learn?" Learning is a behavior normally attributed to animals, dependent on a central nervous system to sense and then **respond** to the environment. In early learning experiments, Ivan Pavlov, showed that dogs could be conditioned to respond to a bell when that bell was paired with a food reward. Every time he rang the bell, the dogs would get fed. Over time, he only needed to ring the bell and the dogs would drool and become excited because they were expecting food. You have probably seen this type of behavior with your own pets; does your dog get excited when he sees you with a leash or hears a can opener? That's because your dog has learned to **associate** these sounds with some kind of reward, such as food or a walk.

The Plant Experiment



But how can scientists do the same type of experiment on a plant? Plants seem to have limited senses about the external world. We do observe that plants respond to stimuli. Plants will grow toward light, and their roots seem to know which way is down. Scientists working for space programs must take these behaviors into consideration when developing ways to grow plants in space. These behaviors are not considered learning, they are simply responses to external **stimuli.**

In order to show that plants can learn, scientists would need to design an experiment similar to the one Pavlov performed on his dogs. They knew that plants could respond to light, so the idea was they could pair another stimulus with light, similar to how Pavlov paired food with the ringing of the bell.

The experimental set-up included a light and a fan, with a type of tube maze where the plant would grow. The plant could grow toward either side. The plants were "trained" by pairing the light with the wind from the fan. After a training period, the plant was placed in a maze and exposed to just the fan. In most cases, the plant grew toward the fan. It seemed as though the plants **learned** that if there was a fan, then there would be light in that direction.

---

1. What types of stimuli do plants naturally respond to?

2. In the experiment described, what is the independent (manipulated) variable?

   What is the dependent (responding) variable?

3. What evidence did the experiment provide that plants can learn?

4. The story does not mention a control group. Describe a set-up that could serve as the control group.

5. What is meant by the phrase "learning by association?" Provide an example from this story.

Name: ____ Date:_______

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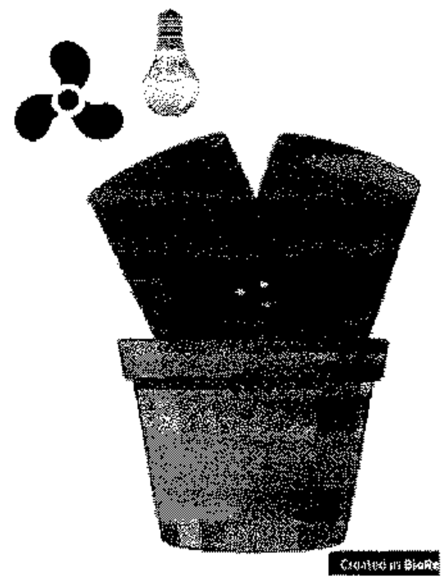

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___1. What types of stimuli do plants naturally respond to? a) light b) gravity c) wind d) light and gravity

___2. In the experiment described, what is the independent (manipulated) variable? a) wind b) tubes c) growth/

___3. What is the dependent (responding) variable? a) wind b) tubes c) growth

___4. What evidence did the experiment provide that plants can learn?
a) plants grew toward the light each time
b) plants grew toward the fan even when no light was present
c) plants grew toward the wind in some case, and toward the light in other cases

___5. The story does not mention a control group. Describe a set-up that could serve as the control group.
a) a plant that grown with wind on one side of light on the other
b) a plant that is grown in conditions with no light
c) a plant that is grown in space, with no gravity

___ 6. Scientists concluded that plants learn to _______ wind with light. a) respond b) associate c) stimulus