An Interactive Introduction to Organismal and Molecular Biology, 2nd ed.

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ANDREA BIEREMA

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East Lansing

Contents

Introduction

ANDREA BIEREMA

This “textbook” is interactive, meaning that although each chapter has text, they also have interactive HTML5 content, such as quizzes, simulations, interactive videos, and images with clickable hotspots. Students receive instant feedback when they complete the interactive content, and therefore, can learn and check their understanding all in one place. I still consider this textbook to be fairly text-heavy and will continue to make it even more interactive content!

The image on the cover and above represents the creation of this book. I pulled most of the content from open resources, modified them, added questions, and now offer them for you to use!

I chose the content to align with two courses that I teach: environmental and organismal applications and biomedical applications. Unit 1 introduces students to science, which both

courses use. Unit 2 covers content necessary for understanding conservation implications (the underlying theme of the course is de-extinction), and Unit 3 focuses on proteins so that students can understand the implications of modifying DNA (the underlying theme is CRISPR).

The 2nd edition includes many updates, such as

- Several more interactives in the "Nature of Science" and "Scientific Controversies" chapters.
- A "sexual selection" section in the "Evolution" chapter.
- Two new chapters: "Reproduction" (unit 2) and "Cell Signaling" (unit 3).
- Additional chapters updated include: "Information Communication," "Stakeholders," "Bibliographies," "Species Interactions," "Protein Structure and Function," "Gene Expression Overview," and "Genetic Engineering."
- More specific image alternative text and captions.

The sexual selection section and reproduction chapters were created while following inclusivity suggestions from Biodiversify.

Please use this book as you see fit for your classes. I look forward to hearing how to make this book even more useful in the future!

UNIT I

INTRODUCTION TO SCIENCE

CHAPTER 1

Nature of Science

ANDREA BIEREMA

Learning Objectives

- Identify aspects and misconceptions regarding the nature of science and scientific inquiry.
- Explain how the commonly-taught "scientific method" aligns with the setup of a research paper.
- Describe the processes of science.
- Identify scientific research questions.
- Explain and make scientific observations and inferences.
- Describe the main parts of a scientific argument.
- Given a description of an investigation, describe the type of study, the research question, and control and experimental variables, when appropriate.

AN INTRODUCTION TO THE NATURE OF

SCIENCE

To understand what ***science*** is, just look around you. What do you see? Perhaps your hand on the mouse, a computer screen, papers, ballpoint pens, the family cat, the sun shining through the window, etc. Science is, in one sense, our knowledge of all that: all the stuff that is in the universe from the tiniest subatomic particles in a single atom of the metal in your computer's circuits to the nuclear reactions that formed the immense ball of gas that is our sun, to the complex chemical interactions and electrical fluctuations within your own body that allow you to read and understand these words. But just as importantly, science is also a reliable process by which we learn about all that stuff in the universe. However, science is different from many other ways of learning because of the way it is done. Science relies on ***testing*** ideas with ***evidence*** gathered from the ***natural world***.

Given the way that science is often taught—memorizing facts from a thick textbook based on research done decades ago and completing lab activities in which there is one known answer—many students have ***misconceptions*** about what science is and how it works. Complete the following interactive to learn more about the real side of science!

Exercise

Before beginning the interactive element below, try this!

- Please see this interactive tool that contains a list of statements regarding the nature of science; some correct and some not. Click on a statement and hold down to move the statements around.
- The first thing to do on the website is to put the statements into three groups:

- Agree: Statements that you agree with
- Disagree: Statements that you disagree with
- In between: Statements that you believe to be true under some conditions, but not others.

- Second, once the statements are put into three groups, order the statements from those that you most agree to those that you least agree with. Discuss your list with your peers.

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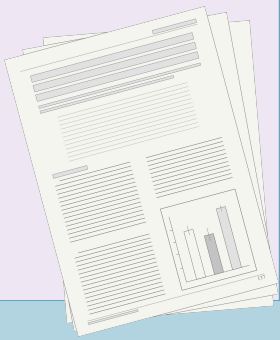
SCIENTIFIC PRACTICES

Exercise

The above quiz mentioned that there really is no one scientific method. So why is "the scientific method" so often taught?

Simply put, it is easier to follow something in an organized, familiar format than to follow along the actual process of any given investigation. This is why the standard setup of a scientific article is organized in a similar way as "the scientific method" and likely why it is often taught in grade school (and even college).



Graphic of a scientific article.

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See the chapter "Information Communication" to learn more about scientific articles.

SCIENCE FLOWCHART

As you learned from the activity above, scientists do not follow one Scientific Method. Rather, science is complex, but some shared practices among scientists (not just biologists, but all scientists) can be represented as a flowchart. Notice in the flowchart below, for instance,

- it is ***non-linear***; every study is unpredictable and follows a different path,
- the research is ***not "done" after one investigation***. Results often lead to new questions or new ways to investigate a

similar question, and

- one of the main elements is “Community Analysis and Feedback.” Science is a ***social endeavor*** and scientists talk to each other about their research before, during, and after an investigation is done and even published.

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Exercise

At first glance, scientific practices, as demonstrated in the science flowchart, might seem overwhelming. Even within the scope of a single investigation, science may involve many different people engaged in all sorts of different activities in different orders and at different points in time—it is simply much more dynamic, flexible, unpredictable, and rich than many other representations. Let’s break it down by looking at an example. The video below explains how an investigation of past climate change fits into the elements of the science flow chart.

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For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

TESTABLE RESEARCH QUESTIONS

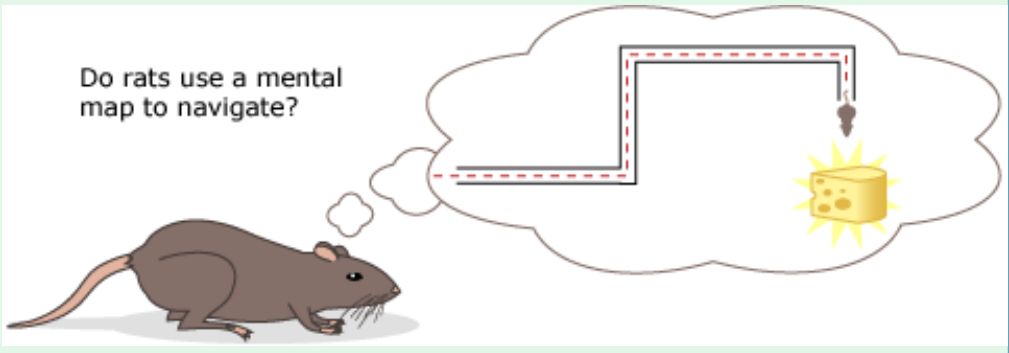
What makes something science? The checklist below provides a guide for which sorts of activities are encompassed by science, but because the boundaries of science are not clearly defined, the list should not be interpreted as all-or-nothing. Some of these characteristics are particularly important to science (e.g., all of science must ultimately rely on evidence), but others are less central. For example, some perfectly scientific investigations may run into a dead-end and not lead to ongoing research. Use this checklist as a reminder of the usual features of science. If something doesn't meet most of these characteristics, it shouldn't be treated as science.

- Science focuses on the natural world
- Science aims to explain the natural world
- Science uses testable ideas
- Science relies on evidence
- Science involves the scientific community

- Science leads to ongoing research
- Science benefits from scientific behavior

Example

Most of us have probably wondered how other animals think and experience the world (e.g., is Fido really happy to see me or does he just want a treat), but can that curiosity be satisfied by science? After all, how could we ever test an idea about how another animal thinks? In the 1940s, psychologist Edward Tolman investigated a related question using the methods of science. He wanted to know how rats successfully navigate their surroundings—for example, a maze containing a hidden reward. Tolman suspected that rats would build mental maps of the maze as they investigated it (forming a mental picture of the layout of the maze), but many of his colleagues thought that rats would learn to navigate the maze through stimulus-response, associating particular cues with particular outcomes (e.g., taking this tunnel means I get a piece of cheese) without forming any big picture of the maze.



Do rats use a mental map to navigate?

Here's how Tolman's investigation measures up against our checklist:

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https://openbooks.lib.msu.edu/isb202/?p=31#h5p-5

So is it science? Though less stereotypically scientific than splitting atoms, this psychological research is very much within the realm of science.

Exercise

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https://openbooks.lib.msu.edu/isb202/?p=31#h5p-7

As seen in the above exercise, only ***testable ideas*** that are regarding the ***natural world*** are within the purview of science.

Additional Example

Some topics initially appear to be scientific, but actually are not. For example, the Intelligent Design movement promotes the idea that many aspects of life are too complex to have evolved without the intervention of an intelligent cause—assumed by most proponents to be a **supernatural** being, like God. Promoters of this idea are interested in explaining what we observe in the natural world (the features of living things), which aligns well with science aims. However, because Intelligent Design relies on the action of an unspecified "intelligent cause," it is not a **testable idea**. The *Understanding Science* website has more information.

OBSERVATIONS AND INFERENCES

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https://openbooks.lib.msu.edu/isb202/?p=31#h5p-8

Figure. A collage of examples of how scientists can make observations. Hover over each image for a description. All images from pexels.com

We typically think of observations as having been seen "with our own eyes," but in science, ***observations ,*** humans cannot directly sense many of the phenomena that science investigates (no amount of staring at this computer screen will ever let you see the atoms that make it up or the UV radiation that it emits).

What are raw data? Raw data are unaltered observations. For example, an investigation of the evolutionary relationships among crustaceans, insects, millipedes, spiders, and their relatives might tell us the genetic sequence of a particular gene for each organism. This is raw data, but what does it mean? A long series of the As, Ts, Gs, and Cs that make up genetic sequences don't, by themselves, do not tell us whether insects are more closely related to crustaceans or to spiders. Instead, that data must be analyzed through statistical calculations, tabulations, and/or visual representations. In this case, a biologist might begin to analyze the genetic data by aligning the different sequences, highlighting similarities and differences, and performing calculations to compare the different sequences. Only then can she interpret the results and figure out whether or not they support the hypothesis that insects are more closely related to crustaceans than to spiders.

What do we do once we have these observations? The next thing is to infer what those observations could mean concerning our research question. This is where prior knowledge and creativity can come into play. What we believe the observations mean is called an "inference."

Exercise

Try this exercise to practice identifying observations, inferring what those observations mean, and developing conclusions. Although the "investigation" is not science-based, the skills that you will practice model what scientists do.

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SCIENTIFIC ARGUMENTS

We can extend this idea of observations and inferences to ***scientific arguments***.

In this case, the term *argument* refers not to a disagreement between two people, but to an evidence-based line of reasoning; so scientific arguments are more like the closing argument in a court case (a logical description of what we think and why we think it) than they are like the fights you may have had with siblings.

There are three main components to a scientific argument:

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https://openbooks.lib.msu.edu/isb202/?p=31#h5p-11

In the figure above, click on the information (“i”) icon to learn more about the main components of a scientific argument.

Example

Below is an article with the parts of the argument labeled.

PLOS | BIOLOGY

Fig 1. A female parasitoid wasp (*Leptopilina boulardi*) ovipositing in a *D. melanogaster* larva. Both larvae and adult vinegar flies detect and avoid some of the wasp odors including the wasp sex pheromone. *Image credit: Markus Knaden.*

SYNOPSIS

Odors Help Fruit Flies Escape Parasitoid Wasps

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Finding a spot for her babies to grow up can be perilous for a female fruit fly. The wrong choice can sentence most of them to death at the "hands" of another insect mother, a wasp that is like-wise searching for a nursery for her young (Fig 1). Wasps in the genus *Leptopilina*, which are the main parasitoids of *Drosophila*, lay their eggs in up to 80% of fruit fly larvae in the wild. As the wasp larvae grow, they consume their hosts from the inside. But fruit flies are far from defenseless against their wasp enemies. In this issue of *PLOS Biology*, Hansson, Knaden, and colleagues show that *Drosophila melanogaster* mothers and larvae have tightly-focused tactics for sniffing out and evading *Leptopilina*.

Claim

Insects rely on their keen sense of smell for everything from assessing food to finding mates, using olfactory neurons on their antennae and palps. To investigate whether fruit flies can escape parasitoid wasps by smelling them, the researchers washed *Leptopilina* to collect their odor and then tested it on fruit flies. They found that wasp body wash deterred both adult and larval flies: adults laid eggs in petri dishes with plain gel but not in those spiked with wasp body wash, while larvae crawled away from the side of a petri dish that was spiked with wasp body wash.

Next, the researchers identified the olfactory neuron that senses the wasp odor as well as the compounds that activate it. They did this by separating the compounds in wasp odor and test-ing how each one affected the activity of individual olfactory neurons in adult fruit flies. One olfactory neuron—ab10B—was activated by three compounds in wasp odor, and chemical analysis revealed them to be actinidine, nepetalactol, and iridomyrmecin. Wasps use the latter scent for defense and as a female sex pheromone.

Evidence

The researchers then confirmed that these wasp scents and the olfactory neurons that respond to them are enough to make fruit flies avoid their wasp parasitoids. Using temperature-sensitive mutants with the specific olfactory neurons being deactivated at 30°C, the researchers showed that wasp body wash repelled fruit fly adults and larvae at 23°C but not at 30°C. Moreover, by artificially activating the neurons that respond to wasp scents, the researchers showed that the activation of the neurons was sufficient to induce wasp avoidance in adults and larvae.

This is the first-known case of an olfactory circuit dedicated to detecting a life-threatening enemy in insects. It is also the second-known such case amongst all animals; the first of these was an olfactory circuit in mice dedicated to detecting cat urine.

This work presents several compelling lines of evidence—behavioral, chemical, and neural—that fruit flies thwart their main parasitoid by turning its own odor against it. This conclusion is further strengthened by additional findings: the fruit flies tested had not previously encountered parasitoids, showing that aversion to the scent of *Leptopilina* is innate, and the results also extend to the four other *Drosophila* species tested. Intriguingly, the wasps' dependence on their sex pheromone will likely curtail evolutionary countermeasures, suggesting that the fruit flies' strategy of co-opting this scent for an early warning system may be nearly foolproof.

Justification

Reference

1. Ebrahim SAM, Dweck HKM, Stökl J, Hofferberth JE, Trona F, Weniger K, et al. Drosophila Avoids Parasitoids by Sensing Their Semiochemicals via a Dedicated Olfactory Circuit. PLoS Biol. 2015; 13(12): e1002318. doi: 10.1371/journal.pbio.1002318

Modified Deritivie of: Meadows R (2015) Odors Help Fruit Flies Escape Parasitoid Wasps. PLoS Biol 13(12): e1002317. doi:10.1371/journal.pbio.1002317

This article titled "Odors Help Fruit Flies Escape Parasitoid Wasps" is a synopsis of a full research article. This image has the claim, evidence, and justification labeled. For an accessible version, see the PDF version of this image.

TESTING IDEAS

Ultimately, scientific ideas must not only be testable but must actually be tested—preferably with many different lines of **evidence** by many different people. This characteristic is at the heart of all science. Now that we have learned about the complexity of science as a process. let's explore some of the common ways in which scientists test ideas.

The table below describes some general aspects of the selected types of study: ***experimental studies***, ***observations studies***, and ***modeling studies***. "Experiment" is broken down into three main types: true experiments, quasi-experiments, and natural experiments. One of the main aspects that distinguish true experiments from all other studies is having an ***experimental group***) and a ***control group***).

Type of Study	Does it follow the nature of science tenants explained in this chapter (e.g., science is somewhat subjective)?	Does it examine possible treatment effects?	Does the investigator perform some type of manipulation (e.g., introduce an experimental variable)?	Does it use both a control group and experimental group(s)?	Does it test for cause and effect relationships?	Is the g the stu describ sample charact
True Experiment	Yes	Yes	Yes	Yes	It may	No
Quasi-Experiment	Yes	Yes	Yes	No	It may	No
Natural Experiment	Yes	Yes	No	It may have a control	It may	No
Observational Study	Yes	No	No	No	No	It may
Modeling Study	Yes	No	No	No	Yes	No

To learn more about these types of studies, click on the headings below:

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https://openbooks.lib.msu.edu/isb202/?p=31#h5p-12

Constants

Ideally, investigations also involve keeping as many other factors as ***constant*** as possible to better explain the outcome. This is particularly true in experiments. In experiments, ideally, just one variable will vary between the groups (the experimental variable), and everything else will remain constant (often referred to as "controlled variables"). For instance, if investigating the effects of temperature on honey bees, then the rest of the environment, such as the amount of space or sunlight, should remain the same across the groups. In a natural experiment, though, this is not possible for all variables and this lack of control needs to be considered when examining the results of the study (one of the downfalls of a natural experiment).

In modeling studies, the model is not an exact replica of the system of interest. Rather, it only focuses on the possible causes of the observed phenomenon (i.e., the effects of interest). Although the aspects of the system that are considered irrelevant are not true "controlled variables," it is, nonetheless, important to consider when developing models.

Controlling variables during an observational study is usually not possible, or even desired as the intention is to describe relationships or patterns.

Are model organisms scientific models?

A ***model organism*** is a non-human species that has been widely studied, usually because it is easy to maintain and breed in a laboratory setting and has particular experimental advantages. For example, they may have particularly robust embryos that are easily studied and manipulated in the lab, which is useful for scientists studying development. Or, they may occupy a pivotal position in the evolutionary tree; this is useful for scientists studying evolution.

If a study uses a model organism, is it a modeling study? The answer may seem like an obvious "yes", but consider how modeling organisms are used. For instance, what if the modeling organism is used in an experimental design in which some individuals are part of an ***experimental group*** and others are in a ***control group***. The purpose of doing the research may be ultimately to predict how the treatment may affect humans, but what is the research question? The research question is "how does treatment x affect this model species?" Scientists then use that information to ***infer*** how the treatment might affect humans, but it cannot by itself actually answer the question of how humans will be impacted. Instead, it is *inferred* that humans may be impacted by prior research that connects physiological similarities and differences between the model species and humans.

Therefore, when asking if a study is a modeling study, do not assume it is because it is using a model species. Rather, consider what the research question is, not just the general purpose of doing the research.

Exercise

Now try applying what you have learned about scientific research to an investigation!

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For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

Understanding Science. 2020. University of California Museum of Paleontology. 11 June 2020 <http://www.understandingscience.org>.

"What are Model Organisms?" by Yourgenome, Genome Research Limited is licensed under CC BY 4.0 License.

CHAPTER 2

Scientific Controversies

ANDREA BIEREMA

Learning Objectives

- Define and identify “scientific controversies.”
- Given a description of an investigation, identify possible sources of confirmation bias and ways to mitigate those biases.
- Describe how diversity in the scientific community allows for growth in scientific knowledge.
- Identify if a science topic is a scientific controversy.
- Distinguish between scientific hypotheses, theories, and laws.

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https://openbooks.lib.msu.edu/isb202/?p=38#h5p-13

WHAT IS A SCIENTIFIC CONTROVERSY?

The Merriam-Webster Dictionary defines *controversy* as "a discussion marked especially by the expression of opposing views." So, what does it mean for something to be a "scientific" controversy?

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So, what is a scientific controversy?

Exercise

The following activity is a series of scenarios. Determine if each one represents a scientific controversy or not. Each scenario is followed by which aspect of the science flowchart it represents. Below the interactive is a simplified flowchart (see the previous chapter for an in-depth version of the flowchart).

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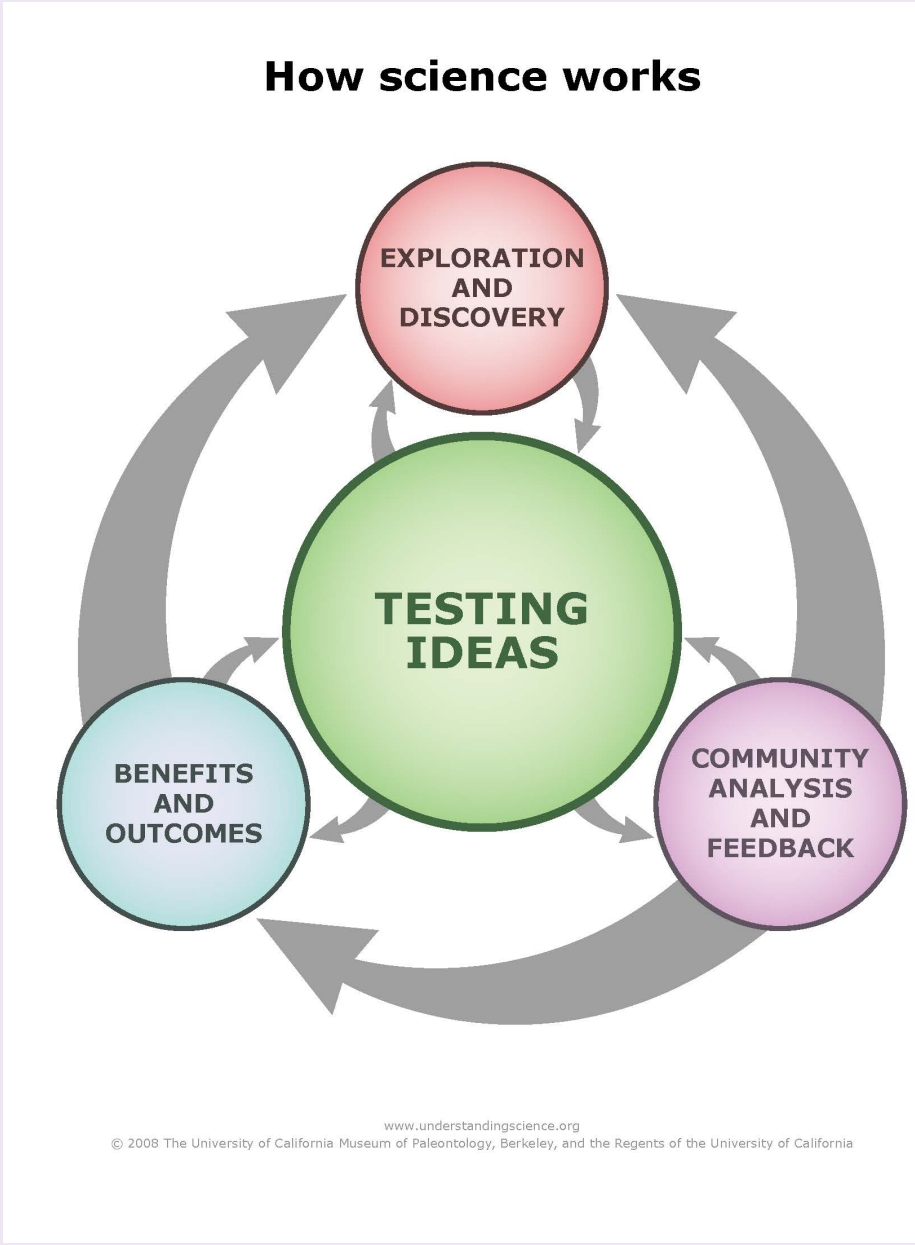
How science works
EXPLORATION AND DISCOVERY
TESTING IDEAS
BENEFITS AND OUTCOMES
COMMUNITY ANALYSIS AND FEEDBACK
www.understandingscience.org
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Four main elements to science: exploration and discovery, testing ideas, benefits and outcomes, and community analysis and feedback.

As you saw in the exercise above, ***controversies*** can take many forms, but many are not considered to be *scientific controversies*. For instance, ethical concerns are essential when society creates policy, but ***ethics do not use scientific evidence*** and so are not scientific controversies (reminder that science cannot answer all questions nor solve all of our problems).

Also, having ***unexpected results is very common in science***, and the fact that things may turn out different than what you expected does not mean that it is a controversy. Even having a single published article contradicting a widely accepted concept does not result in controversy. However, once the scientific community continues to research the concept and is ***identifying mounting evidence that counters the accepted conclusion, then the concept may be a scientific controversy***.

Also seen in the exercise, ***some ideas may appear to be controversial in science but really are not***. This may happen unintentionally. For instance, balanced reporting is generally considered good journalism, and balance does have its virtues. The public should be able to get information on all sides of an issue, but that doesn't mean that all sides of the issue deserve equal weight. Science works by carefully examining the evidence supporting different hypotheses and building on those that have the most support. Journalism and policies that falsely grant all viewpoints the same scientific legitimacy effectively undo one of the main aims of science: to weigh the evidence.

Comic illustrating an example in which viewpoints from a specialist and from someone with no experience have equal weight.

CONFIRMATION BIAS

Social Example

Confirmation bias affects multiple aspects of our lives- not just how we

In the last chapter, we were introduced to making inferences and how our prior knowledge can influence how we interpret data (or even which patterns we observe). ***Sometimes with scientific controversies, the evidence on one side is not particularly "strong," but if the conclusion aligns with our prior knowledge, we may defend that conclusion until there is overwhelming evidence for the other side of the debate.***

This is where confirmation bias comes into

play. Confirmation bias allows us to quickly interpret our surroundings. This will either help or hinder us: from an evolutionary standpoint it is beneficial as it allows us to make quick decisions (e.g., "I just spotted something really big that might eat me- run!"), but it also affects our ability to "see" things that are in front of us.

This can be especially true when new viewpoints with some evidence do not coincide with existing theories. For example, a major argument against the theory of evolution when Darwin first proposed it was that the theory didn't mesh with what was known about the age of the Earth at the time. Physicists had estimated the Earth to be just 100 million years old, a length of time that was deemed insufficient for evolution to account for the diversity of life on Earth today. However, as our understanding of geology and physics has improved, the age of the Earth has been more accurately pegged at several billion years old — a view that squares well with the idea that all life on Earth evolved from a common ancestor.

interpret data. It also affects our immediate views of people (i.e., implicit stereotypes). What are your biases or implicit stereotypes? *Project Implicit*, a non-profit organization, developed the I*mplicit Association Test*. One of the first steps to working to overcome our biases is to recognize what those biases are. Each test takes about 10 minutes. Take as many

Exercise

How does prior knowledge influence our observations and inferences? Complete the following activity to find out!

tests as you can!

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Social Examples

Confirmation bias affects multiple aspects of our lives- not just how we interpret data. It also affects our immediate views of people (i.e., implicit stereotypes). What are your biases or implicit stereotypes? *Project Implicit*, a non-profit organization, developed the I*mplicit Association Test*. One of the first steps to working to overcome our biases is to recognize what those biases are. Each test takes about 10 minutes. Take as many tests as you can!

The following TEDTalk by Chimamanda Ngozi Adichie discusses stereotype thinking by discussing “the dangers of a single story. ”

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https://openbooks.lib.msu.edu/isb202/?p=38

MITIGATING BIAS

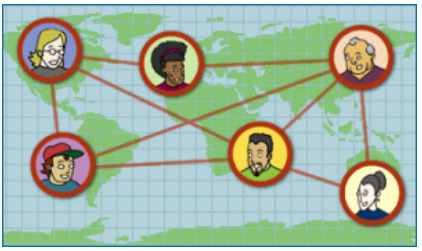
Check out this article from *Understanding Science* to learn about misconduct in science!

Although we cannot eliminate bias in research projects, there are ways to mitigate bias. One way is scrutinizing our methods before beginning the research and finding ways to reduce bias (see the exercise below for examples). The scientific community also balances biases.

The community evaluates evidence and ideas. Scientists describe their work at conferences, in journal articles, and in books. By disseminating their ideas, study methods, and test results in these ways, scientists allow other community members to review their work. This helps to ensure:

- that evidence meets high standards,
- that all relevant lines of evidence are explored,
- that judgments are not based on flawed reasoning, and hence,
- that science moves in the direction of more and more accurate explanations.

Moreover, the scientific community includes people from all over the world from all sorts of different cultures and backgrounds. At some points in history, science has largely been the domain of white males, but that is simply no longer true (although there is still room to continue increasing the diversity of the



Scientists from around the world working together.

scientific community). Increasing the community's diversity improves science in multiple ways:

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https://openbooks.lib.msu.edu/isb202/?p=38#h5p-134

Example

Before the 1970s, the field of primatology was dominated by men. Male scientists observed and recorded primate behavior in the wild, male scientists developed explanations to understand those behaviors, and male scientists read and evaluated each others' work. And at that time, observations suggested that primate social life was largely controlled by males, with females playing a more passive role. But that changed when women scientists began to work in the field in the 1970s. Because of their own gender experiences, these women paid more attention to subtleties in the female primates' behavior and revealed that female primates actually have elaborate sex lives and manipulate male behavior in many ways. So in this case, a diverse assemblage of scientists counterbalanced each others' biases, leading to a more complete and accurate understanding of primate societies.

So science depends on diversity. If scientists were all the same, scientific controversy would be rare, but so would scientific progress! Despite their diversity, all of those individual scientists are part of the same scientific community and contribute to the scientific enterprise in valuable ways.

Exercise

Some things can be done during research projects that help mitigate researcher bias. This exercise provides some examples.

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THEORIES, HYPOTHESES, AND LAWS

As explained in the previous section, our knowledge of currently accepted theories and laws can bias how we view the results of a study. But what are theories? To answer this question and better understand scientific controversies, it is essential to know the relationship between laws, theories, and hypotheses.

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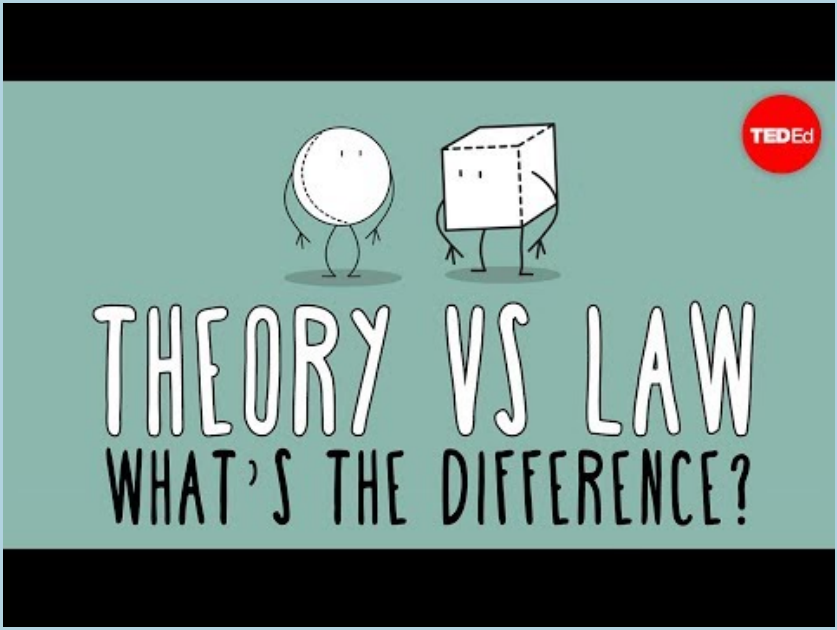
For an overview of the relationship between theories and laws, watch the following video:



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Are laws regarding only things that are directly observed?

Some laws are non-mechanistic statements about the relationship between observable phenomena. For example, the ideal gas law describes how the pressure, volume, and temperature of a particular amount of gas are related to one another. It does not describe how gases must behave; we know that gases do not precisely conform to the ideal gas law.

Other laws deal with phenomena that are not directly observable. For example, the second law of thermodynamics deals with entropy, which is not directly observable in the same way that volume and pressure are. Still, other laws offer more mechanistic explanations of phenomena. For example, Mendel's first law offers a model of how genes are distributed to gametes and offspring that help us make predictions about the outcomes of genetic crosses.

The term "law" may be used to describe many different forms of scientific knowledge, and whether or not a particular idea is called a law has much to do with its discipline and the time period in which it was first developed. ***For example, several laws within biology are not referred to as "the law of [...]" but are still observations of general phenomena.***

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CONTROVERSIES

Scientific controversies can occur regarding laws, theories, or hypotheses. Here are a couple of examples:

Fundamental scientific controversy: scientists disagreeing about a central hypothesis or theory. If you imagine scientific knowledge as a web of interconnected ideas, theories and hypotheses are at the center of the web and are connected to many, many other ideas—so, a controversy over one of these principal ideas has the potential to shake up the state of scientific knowledge. For example, physicists are currently in disagreement over the basic validity of string theory, the set of key ideas that have been billed as the next big leap forward in theoretical physics. This is a fundamental scientific controversy.

Secondary scientific controversy: scientists disagreeing about a less central aspect of a scientific idea. For example, evolutionary biologists have different views on the importance of punctuated equilibrium (a pattern of evolutionary change, characterized by rapid evolution interrupted by many years of constancy). This controversy focuses on an important aspect of the mode and rate of evolutionary change, but a change in scientists' acceptance of punctuated equilibrium would not shake evolutionary biology to its core. Scientists on both sides of the punctuated equilibrium issue accept the same basic tenets of evolutionary theory.

EXAMPLES

Let's look at some examples of science topics to determine if and to what extent they are scientific controversies.

VACCINES & AUTISM

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This is a podcast version of the text in this section titled "Vaccines and Autism." Feel free to listen to this podcast and/or follow along in the text.

Does vaccination cause autism, and is this a scientific controversy?

As emphasized by the World Health Organization and the Centers for Disease Control and Prevention, there is no evidence supporting that vaccination causes autism.

The idea of this possible link began by Wakefield and his research group when they published a paper in "The Lancet" journal in 1998 titled "Ileal-lymphoid-nodular hyperplasia, non-specific colitis, and pervasive developmental disorder in children" (see the original

article, which has since been retracted). In the article, Wakefield et al. (1998) claimed that "In eight children, the onset of behavioural problems had been linked, either by the parents or by the child's physician, with measles, mumps, and rubella vaccination."

After years of investigation and additional research studies—all of which found no link between autism and vaccination (Eggertson, 2010)—the General Medical Council held a hearing in 2010. During this hearing, Wakefield "admitted and found proved" that the research was funded by Mr. Barr, who "had the benefit of public funding from the Legal Aid Board in relation to the pursuit of litigation against manufacturers of the MMR vaccine" (p. 4).

Additionally, the children in the study were not randomly selected for the study. Rather, according to the General Medical Council (2010), each child in the study was carefully selected after conversations with the children's parents and doctors. For instance, the report described procedures for the selection of each child, and Child 3, for example, was referred by the child's general practitioner for having "behavioural problems of an autistic nature, severe constipation and learning difficulties all associated by his parents with his MMR vaccination" (p. 18). "In reaching its decision, the Panel concluded that [Wakefield's] description of the referral process as 'routine', when it was not, was irresponsible and misleading and contrary to [Wakefield's] duty as a senior author" (p. 46).

The General Medical Council (2010) also found other irresponsible measures such as telling assistants to increase the amount of medication without reporting it to the doctor and taking blood samples from children at his son's birthday party (documented on pages 50-56).

More Information

To learn more about vaccination and immunity, check out *OpenStax*'s chapter on Vaccines.

Wakefield and the so-called link between vaccination and autism are both discredited, and Wakefield is no longer a practicing physician. In 2016, Wakefield directed a propaganda movie called "Vaxxed: From Cover-Up to Catastrophe." The movie was supposed to air at the Tribeca Film Festival but was pulled (Ryzik, 2016). Robert De Niro, one of the founders of the festival, originally supported the movie but later denounced it (Ryzik, 2016). Although, as of August 2021, a video clip of him supporting it is still on the Vaxxed website.

So, is this a scientific controversy? The Wakefield article caused scientists to investigate the potential for a relationship. But, no additional evidence was found showing a link between vaccination and autism, making the only "evidence collected" based on a retracted article written by a discredited physician. Therefore, the idea of any link between vaccines and autism is not a scientific controversy.

CRISPR

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This is a podcast version of the text in this section titled “CRISPR.” Feel free to listen to this podcast and/or follow along in the text.

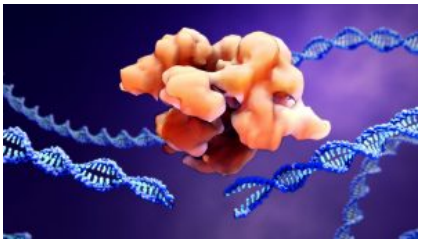
Genome editing technologies enable scientists to make changes to DNA, leading to changes in physical traits like eye color and disease risk. Scientists use different technologies to do this. These technologies act like scissors, cutting the DNA at a specific spot. Then scientists can remove, add, or replace the DNA where it was cut.

The first genome editing technologies were developed in the late 1900s. More recently, a new genome-editing tool called **CRISPR**, invented in 2009, has made it easier than ever to edit DNA. CRISPR is simpler, faster, cheaper, and more accurate than older genome editing methods. Many scientists who perform genome editing now use CRISPR.

One way that scientists use genome editing is to investigate different diseases that affect humans. They edit the genomes of animals, like mice and zebrafish, because animals have many of the same genes as humans. For example, mice and humans share

about 85 percent of their genes! By changing a single gene or multiple genes in a mouse, scientists can observe how these changes affect the mouse's health and predict how similar changes in human genomes might affect human health.

Scientists also are developing gene therapies—treatments involving genome editing—to prevent and treat diseases in humans. Genome editing tools have the potential to help treat diseases with a genomic basis, like cystic fibrosis and diabetes. There are two different categories of gene therapies: germline therapy and somatic therapy. Germline therapies change DNA in reproductive cells (like sperm and eggs). Changes to the DNA of reproductive cells are passed down from generation to generation. On the other hand, somatic therapies target non-reproductive cells, and changes made in these cells affect only the person who receives the gene therapy.



Cas-9 protein breaking a DNA molecule.

Even though CRISPR improved upon older genome editing technologies, it is not perfect. For example, sometimes genome editing tools cut in the wrong spot. Scientists are not yet sure how these errors might affect patients. Assessing the safety of gene therapies and improving genome editing technologies are critical steps to ensure that this technology is ready for use in patients.

There are also several ethical concerns that can emerge with genome editing, including safety. First and foremost, genome editing must be safe before it is used to treat patients. Some other ethical questions that scientists and society must consider are:

- Is it okay to use gene therapy on an embryo when it is

impossible to get permission from the embryo for treatment? Is getting permission from the parents enough?

- What if gene therapies are too expensive and only wealthy people can access and afford them? That could worsen existing health inequalities between the rich and poor.
- Will some people use genome editing for traits not important for health, such as athletic ability or height? Is that okay?
- Should scientists ever be able to edit germline cells? Edits in the germline would be passed down through generations.

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Most people agree that scientists should not edit the genomes of germline cells at this time because the scientific communities across the world are approaching germline therapy research with caution since edits to a germline cell would be passed down through generations. Many countries and organizations have strict regulations to prevent germline editing for this reason. The NIH, for example, does not fund research to edit human embryos.

There are many applications of CRISPR, including medical treatments (similar to gene therapy), agriculture (genetically

modified organisms), and conservation (adding genetic diversity to species or de-extincting species—described in the next section). Many of these applications have non-CRISPR alternatives that have been around longer. For instance, scientists are researching how CRISPR can be used to treat cancers rather than chemotherapy. Given the novelty of CRISPR, its effectiveness and safety are continually studied and compared to traditional approaches. Depending on the findings of the research, some of these applications may be a scientific controversy and will take time to solve.

DE-EXTINCTION

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This is a podcast version of the text in this section titled "De-extinction." Feel free to listen to this podcast and/or follow along in the text.

One of the more interesting conservation debates to have emerged in recent years involves efforts to reverse extinction. This field, known as de-extinction or resurrection biology aims to revive

extinct species, and eventually to reintroduce viable populations to their original locations (Seddon, 2017).

One possible method, called "breeding back", aims to produce individuals genetically similar to an extinct species by selective breeding of extant species that carry the genetic material of their extinct relatives. This is the main method currently being used to revive the aurochs (*Bos primigenius*), the ancestor of today's domestic cattle (Stokstad, 2015). Other "breeding back" projects place less emphasis on genetics and more on morphology, by selectively breeding individuals with certain traits to produce individuals that visually appear similar to the extinct species. Such is the case at The Quagga Project, where selectively breeding of plains zebras (*Equus quagga*) with quagga-like characteristics (reduced striping and brown hues) are resulting in animals that look increasingly like extinct quaggas (Harley et al., 2009).

The second popular method used for de-extinction is cloning. This involves the transfer of viable genetic material from an extinct species to the eggs (or embryo) of a closely related surrogate mother, who will hopefully give birth to an individual of the extinct species. Cloning has been used in the selective breeding of livestock for many years, and plans are also currently underway to use cloning to prevent the extinction of highly threatened species such as the northern white rhinoceros.

Spanish ibex

Despite the promise that cloning offers for reviving extant and recently extinct species, cloning species that went extinct many years ago has been more challenging. So far, attempts to clone Spain's Pyrenean ibex (*Capra pyrenaica pyrenaica*) and Australia's gastric-brooding frog (*Rheobatrachus silus*) have

produced individuals that lived for only a few minutes (Ogden, 2014).

Despite the progress made, de-extinction is one of the most controversial and polarising debates to emerge among conservation biologists in recent years. Proponents of de-extinction hope that the early work described above paves the way for the resurrection of extinct species once the threats that drove them to extinction have been managed. Many de-extinction biologists have even started establishing banks where the genetic material of threatened species is cryopreserved for future use.

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https://openbooks.lib.msu.edu/isb202/?p=38#h5p-18

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ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

"Extinction is Forever" by Wilson, J. W., & Primack, R. B., Conservation Biology in Sub-Saharan Africa, 2019, Cambridge, UK, Open Book Publishers, CC BY 3.0.

Understanding Science. 2020. University of California Museum of Paleontology. 11 June 2020 <http://www.understandingscience.org>.

"What is Genome Editing?" by National Human Genome Research Institute, National Institutes of Health, 2019, *Policy Issues in Genomics*, Public Domain.

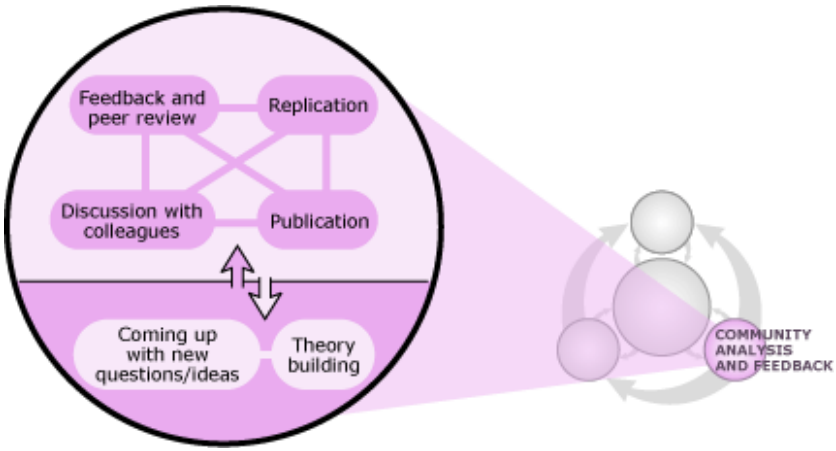
CHAPTER 3

Information Communication

ANDREA BIEREMA AND SARA MILLER

Learning Objectives

- Explain the peer review process for scientific articles.
- Describe the different types of information sources that describe scientific research.
- Recognize that information may be perceived differently based on the format in which it is packaged.
- Recognize that one's personal information and online interactions affect the information one receives and the information one produces or disseminates online.
- Evaluate an information source, including its heading and graphs, if present.



Scientific studies depend on community analysis and feedback. This chapter focuses on how the scientific community shares information.

COMMUNITY ANALYSIS AND FEEDBACK

One of the main elements of the science flowchart is "community analysis and feedback." Members of the scientific community play several essential and direct roles:

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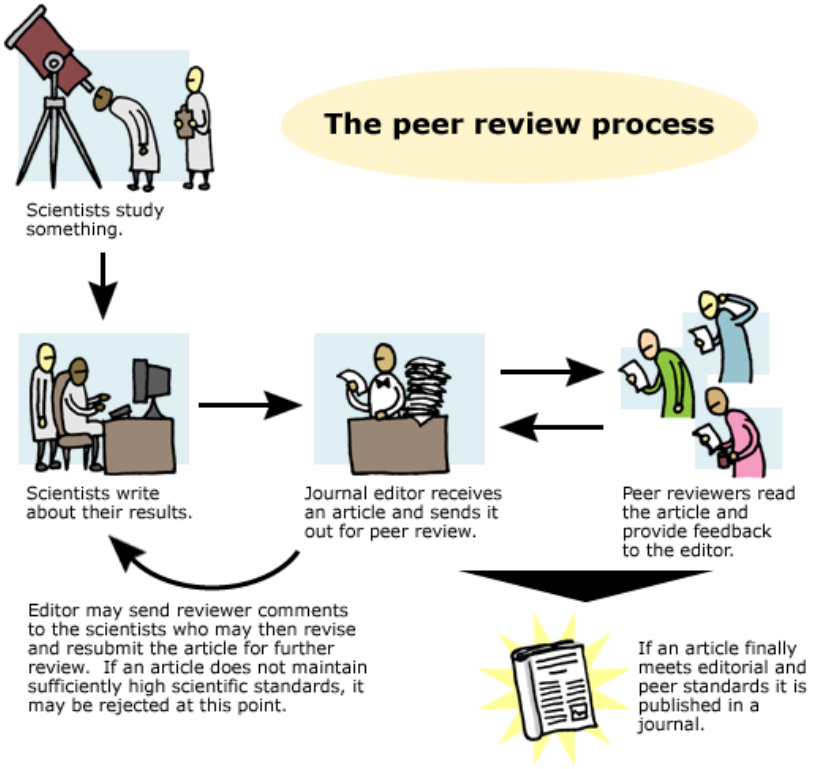
PEER REVIEW PROCESS

Peer review does the same thing for science that the "inspected by #7" sticker does for your t-shirt: provides assurance that someone who knows what they're doing has double-checked it. In science, peer review typically works something like this:

1. A group of scientists completes a study and writes it up in the form of an article. They submit it to a journal for publication.
2. The journal's editors send the article to several other scientists who work in the same field (i.e., the "peers" of peer review).
3. Those reviewers provide feedback on the article and tell the editor whether or not they think the study is of high enough quality to be published.
4. The authors may then revise their article and resubmit it for consideration.
5. Only articles that meet good scientific standards (e.g., acknowledge and build upon other work in the field, rely on logical reasoning and well-designed studies, back up claims with evidence, etc.) are accepted for publication.



A snapshot of the peer review process for scientific articles.

The scientific community provides a system of checks and balances that ensures the quality of scientific work, double-checks arguments, and makes sure that ideas are evaluated fairly. This scrutiny can serve a few different functions from fact-checking to whistleblowing.

Check out this article from Elsevier to learn more about the scientific article peer-review process!

ARTICLE TYPES

Scientists distribute information about their ideas in many ways (informally communicating with colleagues, making presentations at conferences, writing books, etc.), but among these different modes of communication, peer-reviewed journal articles are especially important.

A journal article is a formal, souped-up version of the standard high school lab report. In journal articles, scientists (usually a group of collaborators) describe a study and report any details one might need to evaluate that study: background information, data, statistical results, graphs, maps, explanations of how the study was performed and how the researchers drew their conclusions, etc. These articles are published in scientific journals, either in print or on the internet. Print journals look much like any magazine, except that they are chock full of firsthand reports of scientific research. Journals distribute scientific information to researchers all around the world so that they can keep current in their fields and evaluate the work of their peers. Journal articles neaten up the messy process of science by presenting ideas, evidence, and reasoning in a way that's easy to understand—in contrast to the often circuitous (and sometimes tedious) process of science (see the "Nature of Science" chapter for more information). Check out the video below to learn more about the different ways in which scientific research is published.

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can view it online here:

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For closed captioning or to view the full transcript of the above video, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

HEADLINES

- Trans-fat free!
- Ethanol production: an eco-nightmare?
- Cancer researchers discover new hope.
- Major petroleum company acknowledges the reality of global warming.
- Clinically proven to reduce the appearance of wrinkles!

The above statements aren't exactly the headlines you'd find in a scientific journal, but they are examples of the sorts of scientific messages that one might encounter every day. ***Because science is so critical to our lives, we are regularly targeted by media messages about science in the form of advertising or reporting from newspapers, magazines, the internet, TV, or radio***. Similarly, our everyday lives are affected by all sorts of science-related policies from what additives are allowed (or required) to be mixed in with gasoline, to where homes can be built, to how milk is processed, but you don't have to take these media messages and science policies at face value.

Understanding the nature of science can help you uncover the real meaning of media messages about science and evaluate the science behind policies.

Exercise

Let's practice!

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GRAPHS

Graphs (especially those that contain a reference) can be a great information source to use as evidence but sometimes they can be misconstrued to support a different claim to the untrained eye. Watch the video below to learn more about misleading graphs!

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For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Curious how statistics can be misleading? Check out this TED-Ed Talk to find out!

SOURCE EVALUATION

Headlines and graphs are attention grabbers that can quickly communicate the claims of an article (whether or not the claims are supported). What else do you need to consider when evaluating sources?

Every day, we are bombarded with messages based on science: the nightly news reports on the health effects of cholesterol in eggs, a shampoo advertisement claims that it has been scientifically proven to strengthen hair, or the newspaper reports on the senate's vote to restrict carbon dioxide emissions based on their

impact on global warming. ***Media representations of science and science-related policy are essential for quickly communicating scientific messages to the broad public. However, some important parts of the scientific message can easily get lost or garbled in translation.*** An original piece of scientific research may be interpreted many times over before it reaches you. First, the researchers will write up the research for a scientific journal article, which may then be adapted into a simplified press release, which will be read by reporters and translated yet again into a newspaper, magazine, or internet article and so on. Just as in a game of telephone, errors and exaggerations can sneak in with each adaptation.

Exercise

Before getting into the details on how to analyze information sources, let's consider the following hypothetical article. What are some things to consider while evaluating this article? In the image, click on the exclamation point icons to learn about some concerns regarding this article.

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For closed captioning or to view the full transcript of the above video, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

ATTRIBUTION

This chapter is a modified derivative of the following article:

Understanding Science. 2020. University of California Museum

of Paleontology. 11 June 2020 <http://www.understandingscience.org>.

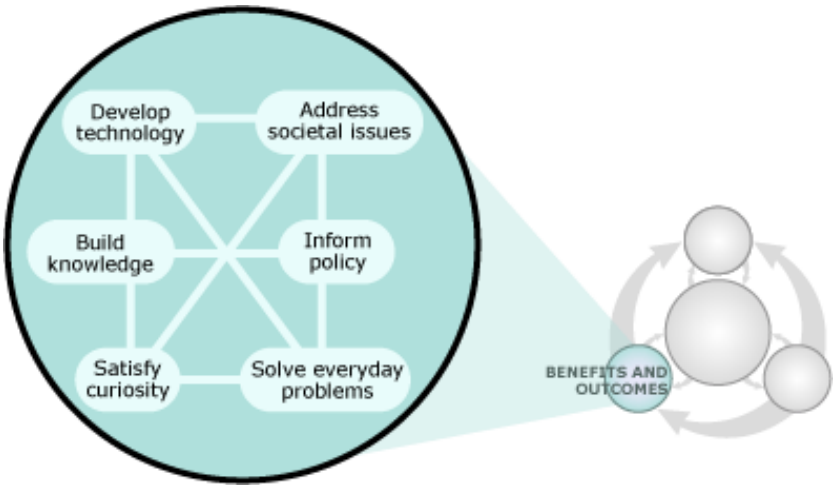
CHAPTER 4

Stakeholders and Authority

ANDREA BIEREMA

Learning Objectives

- Identify different types of authority, such as subject expertise, societal position, or individual experience.
- Identify why some groups/individuals may be underrepresented or systematically marginalized within the systems that produce and disseminate information.
- Recognize issues of access or lack of access to scientific information sources.
- Recognize that a given information source may not give voice to all—or even the majority— of stakeholders involved in and impacted by an issue, such as conservation.
- Identify and explain the roles of primary, secondary, opposition, and marginalized stakeholders in a given case study.



Scientific studies are used to address societal issues and inform policy, but who is impacted by these implications? This chapter addresses this question.

WHAT IS A STAKEHOLDER?

Note

Issues can affect more than just stakeholders. For instance, in conservation, policies include the impact on

Stakeholders are people, institutions, or social groups that are affected by, and/or involved in, a particular issue, such as the creation of policies. While this definition is seemingly straightforward, it is often difficult to answer fundamental questions such as:

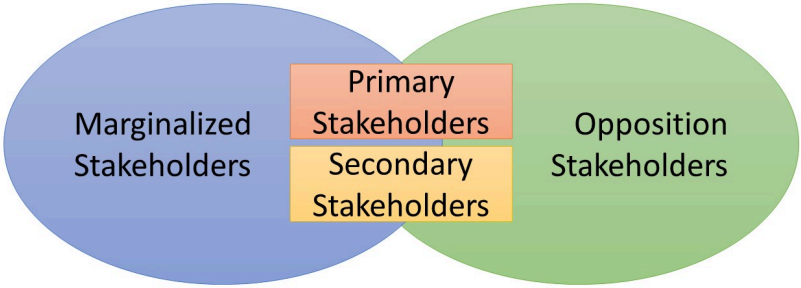
- Who are "the people?"
- What does "institution" mean?
- What are the limits of a "social group?"

Yet, these questions must be answered if the right **stakeholders** are to be identified and mobilized.

TYPES OF STAKEHOLDERS

There are stakeholders who directly influence, or are influenced by, outcomes (called "primary stakeholders") and others that indirectly affect, or are affected by, outcomes (called "secondary stakeholders"). Some of these stakeholders may be marginalized stakeholders or opposition stakeholders. See below for definitions.

wildlife. Wildlife are part of the ecosystem rather than a stakeholder. Stakeholders are only people or representatio ns for people



There are stakeholders who directly influence or are influenced by outcomes (called "primary stakeholders") and others that indirectly affect or are affected by outcomes (called "secondary stakeholders"). Some of these stakeholders may be marginalized stakeholders or opposition stakeholders.

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Exercise

Answer the following questions after reading through the different types of stakeholders.

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STAKEHOLDER INFLUENCE ON DECISION-MAKING

In some cases, stakeholders are easy to identify. In other cases, a more in-depth understanding of the issues involved in a particular situation is needed to determine who should be included in the early phases of the process. For a variety of reasons, stakeholders

may disagree about who should be included in the dialogue. It may be that a group is perceived as too combative, or is not thought to have the appropriate skills to participate effectively. ***These objections may or may not be justifiable and may often be the result of historic biases held by stakeholder groups.*** While assumptions are inevitable, it is important that the initial stakeholder identification process avoids reaching premature conclusions about which stakeholders should, or should not, be involved.

Initially, dialogue should be as open and participatory as possible, ***encouraging stakeholders from a variety of backgrounds and perspectives to contribute to the identification and framing of collaboration goals and objectives.*** If the process is not participatory, there is a risk that it will quickly become dominated by the strongest, loudest, or best-resourced groups who seek to shape the process for their own objectives. Over time, it may be determined that additional interests must be brought into the dialogue and the process needs to be open enough to facilitate this.

In some instances, initial dialogue may lead to consortiums, alliances, or coalitions. While this approach can provide for a strong and coherent voice, there are associated risks. These include the premature establishment of partnerships before issues, opportunities, and appropriate stakeholder roles and responsibilities have been fully defined. ***When alliances with only like-minded groups are formed, the risk of generating negative reactions among other stakeholders can increase due to perceived "exclusivity."*** Effective information sharing, communication, and public education can help alleviate these risks. Development of a strategic plan for progressively bringing in other key stakeholders—primary, secondary, or opposition—will also be essential.

DIFFERENCES IN POWER

Power differentials exist in all forms of social organizations and between social groups. ***The source of these differences may be based on the heredity rights that leaders enjoy in certain cultural settings, or the power differences earned through channels that economic and political opportunity afford individuals and groups.***

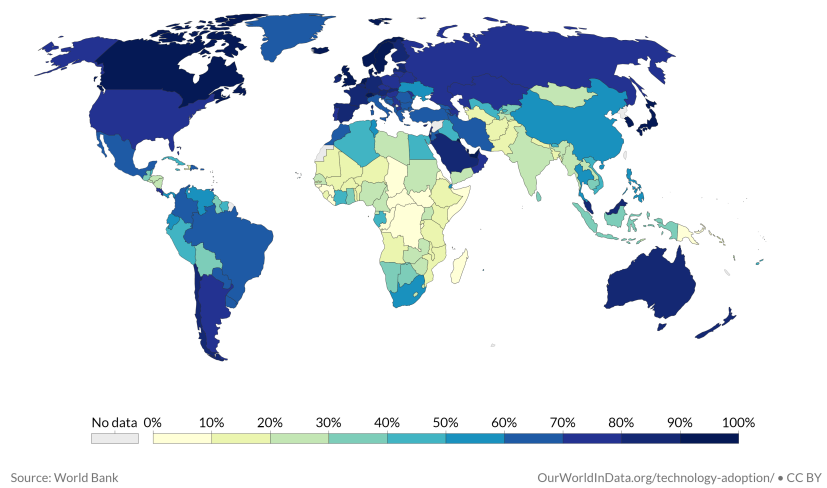
Two power issues are particularly relevant to facilitators of stakeholder collaboration:

- addressing power inequalities between key parties so that adequate representation and collaboration can be achieved, and
- reaching agreements among parties on how a disagreement over issues will be resolved.

Conflicts involving core group values and identity are difficult to resolve. For example, less politically powerful stakeholders may fear that a powerful outsider will impose its views on a process. This may provoke them to withdraw from a given negotiation process even if they stand to benefit from staying involved. Similarly, distrust can make it particularly difficult for the parties to begin constructive talks. Therefore, facilitators are involved to work toward removing this distrust, such as adapting the meeting structure and enabling constructive cross-stakeholder learning.

Information privilege is another issue with power differentials. Who has access to which information sources? For one, still, not everyone has

internet access. The graph below is from 2017, but it became unequal access to the internet became very apparent during the COVID-19 pandemic when schools and work switched to online modalities.



Share of the population using the Internet in 2017. All individuals who have used the internet in the last 3 months are counted as internet users. The internet can be used via a computer, mobile phone, personal digital assistant, games machines, digital TV, etc.

Additionally, most scholarly research is not freely available. If you are reading this chapter, you are likely a member of a college or university, and therefore, also are likely to have access to database subscriptions that are paid for by the library at your university or college. What about those that do not belong to a university or college? Subscriptions are expensive, and therefore, only certain people are privileged to have access to scientific information. This limits access to information that may be vital to making decisions as a stakeholder. There is a push to make

scientific articles"open" but this often means that the authors are paying to publish their research. ***What do you think? Should access to information be a human right? If so, to what extent?*** This "choose your own scenario" tutorial might help you think about this question further.

STAKEHOLDER SCENARIOS

The following is a series of scenarios that illustrate the stakeholder concepts described above.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=48#h5p-27

ATTRIBUTIONS

This chapter is a modified derivative of the following article:
"Stakeholder Collaboration: Building Bridges for Conservation" by Ecoregional Conservation Strategies Unit, World Wildlife Fund, 2000, Washington, D.C.: World Wildlife Fund, Public Domain.

CHAPTER 5

Bibliographies

ANDREA BIEREMA AND SARA MILLER

Learning Objectives

- Give credit to the original ideas of others through paper attribution and citation.
- Explain the rationale for citing information sources.
- Identify instances of plagiarism and copyright infringement, including with the use of images.
- Identify interested parties, such as scholars, organizations, governments, and industries, who might produce information about a topic and then determine how to access that information.
- Match information needs and search strategies to appropriate search tools.
- Manage searching processes and results effectively.
- Correctly cite an information source.
- Characterize common citation styles.

CITING SOURCES

Citation is something that we do almost every day, whether or not we're aware of it. We may think of citation as a requirement for papers and assignments, which is one function of citation, but it has several purposes. In the sciences, what does it really mean to **cite** your sources and why bother?

The rationale for citing carefully is to:

- Show you have read widely and creatively as per the expectations of the discipline
- Demonstrate you've learned from the work of people who studied the topic before you
- Give credit to your sources of information (definitions, other scholars' concepts, statistics) and avoid plagiarism
- Provide the details of your research path for others to follow so that they can find the materials and read/learn/think for themselves
- Actively participate in the scholarly conversation. Go you!

LOCATING INFORMATION

Whenever we share a story or link on social media, we're citing—including information about the source—such as where it can be found online. Very simply, this information allows others to find the original source and identify where it came from. If someone is curious about the story you shared, they can read the original post and possibly follow links in that story (citations) which will lead to other discoveries. Citation helps us to find information. If you're reading a news article about a scientific study, check to see if the article provides a link to the scholarly journal article where

the study was published. This link is a form of citation that will help lead you to the original information.

SCIENTIFIC CONVERSATION

Citation also serves to show a record of how other sources impacted the current source. Scientific research articles published in **scientific journals** always provide a list of citations, which show where the ideas, techniques, and studies were built upon by the current research came from. This reference creates a sort of paper trail that helps other scientists better evaluate the new study and see how it fits with previous research. By providing a list of references, an author invites other scientists to see for themselves if the ideas the author cites are supported by evidence, if the assumptions he or she makes are justified, and if the techniques described by others have been properly implemented. In this way, citation functions as a record of a conversation: how other scientists' work speaks to and informs new work.

COPYRIGHT INFRINGEMENT AND CREDIT

Another important function of citation is to identify the original creators of information and to give them credit. In science, credit matters. A magazine or newspaper article only sometimes acknowledges the sources of its arguments—the books the author read or the interviews conducted. Science, on the other hand, is scrupulous about giving credit where credit is due. The bibliography or list of citations that you find in scientific research articles serves to credit other scientists for ideas, techniques, and studies that were built upon by the current research.

Legally and ethically, It's important to not give the direct or indirect impression that someone else's work or ideas were written or created by you. When you hear the term plagiarism, it refers

to this phenomenon. For example, some of the content in this chapter was created by people other than the listed authors, and to avoid plagiarism, we've given credit to the original authors through citation at the end of the chapter in the "References" section. It's crucial to use proper citation to indicate where that source material or idea originated. I***f you use copyrighted work in your own creations without citation, it's a copyright infringement—a legal issue—in addition to the ethical issue of plagiarism***.

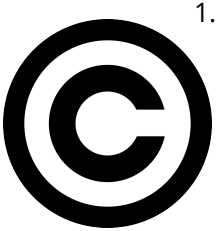
Exercise

Take this quiz from Turnitin to learn more about plagiarism and copyright infringement!

THE USE OF IMAGES

Images are easily available for download, but when can you use images in your own works? For text, a brief quote can be used in your work, but images do not work this way. Using an image that is protected by copyright is similar to taking an entire article, adding a citation, and then putting your name on the work.

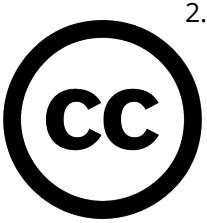
There are two main types of licenses that images (and text) can have:



Copyright logo

1. **Copyright** is a legal term that refers to the person (or people) who own and distribute a piece of information. The copyright holder has rights to that material, and if others use the material without getting permission first, they may be in violation of copyright. This isn't good (!) and can result in fines. ***What's the most important thing you need to know about copyright? Simple: If something is copyrighted,***

you can't use it without getting permission; this may involve paying for permission.



Creative Commons logo

2. **Creative Commons** is a not-for-profit organization that collects all sorts of materials and makes them available to the public for free use. When a user creates a piece of content (writing, art, photography, or just about anything), they may choose to put a Creative Commons license on the material. The license explains how people share, remix, repurpose, or in other ways use the material. ***As a student, the Creative Commons has made a world of materials available to you. If you use any of the materials in your work, you should include the Creative Commons in your source citation.***

Tip: To find images with creative commons licenses, search in Google Image, select "Tools," "Usage Rights" and then "Creative Commons." Or, try CC Search.

FINDING SOURCES

There are many ways to find both popular and scholarly sources, including Google and Google Scholar. You also have the option of beginning your search through your school's Library website (e.g., MSU Libraries). There are two main advantages to using the

Libraries' search as your starting point, especially for scholarly or journal articles. The Libraries' search can make it easier to narrow and sort your searches by type of article or subject. You will also have automatic access to articles for which the library subscribes. Often when you're using Google or Google Scholar, you may be asked to pay or log in to view the whole article (full-text). If you start at the Libraries' page, you typically just need to enter your school ID and password to get access.

Exercise

Watch this linked video about searching the MSU Libraries and answer the questions.

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https://openbooks.lib.msu.edu/isb202/?p=51#h5p-28

CITATION GUIDELINES

For each source that you use, you will want to keep track of certain types of bibliographic information to include in your citations, including the authors, the year it was published, the title of the work, and the publisher (and/or the URL). The order of the bibliographic elements is prescribed by the citation style, which is a convention for the sequence of information and punctuation used. People write for different purposes and different audiences. Citation styles reflect these differences by specifying:

1. How to structure the elements (such as date and title) within a citation and
2. All of the details that should be included in the bibliography, which goes at the end of your essay with the header “References,” “Works Cited,” or “Bibliography,” depending on the citation style.

Citation styles force researchers to standardize the content and format of their citations and references. When the title and date are always found in the same place in every citation, research is a bit easier because the information is presented in a consistent way. Whether you are citing print books or YouTube videos, this protocol of scholarly conversation is an efficient way to discuss and share sources.

Style	Organization	Fields where used	Features
AP	Associated Press	Print journalism, public relations	Quotations and paraphrases are integrated using signal words but without citations or reference list
APA	American Psychological Association	Academics, business, education research, social sciences, some engineering	In-text citations with publication date focus (Author, year); reference list alphabetical by authors' surnames
Chicago (CMOS) or Turabian	University of Chicago Press	Humanities, sciences, social sciences	2 systems: (i) notes and bibliography (footnotes /endnotes with superscript numbers); and (ii) author-date (in-text citations similar to APA)
CSE	Council of Science Editors	natural science, mathematics, physical science	3 systems: name-year (like APA); citation-sequence (like IEEE with superscript numbers); and citation-name (citations and reference list alpha by authors' surnames with superscript numbers)
IEEE	Institute for Electrical and Electronics Engineers	Technical fields such as computer science and some engineering,	In-text citations with bracketed numbers referencing bibliography entries; numeric reference list in order sources appear in text
MLA	Modern Language Association	Humanities, especially language and literature	Author-page in-text citations; works cited list alphabetical by authors' surnames

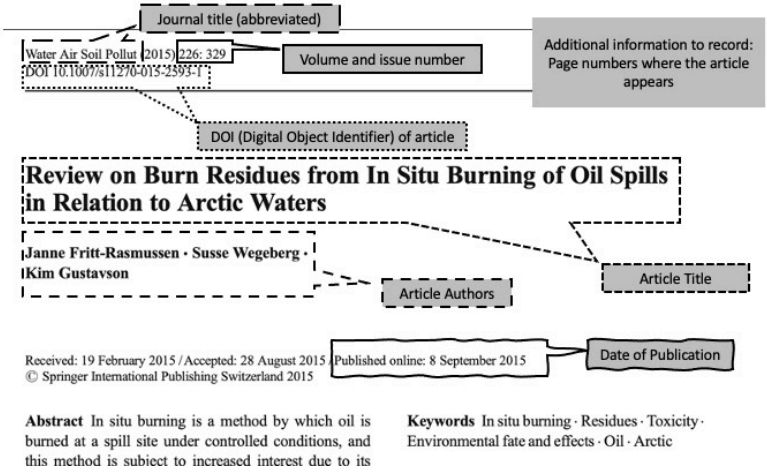
In science, the most common sources are scholarly journal articles written by scientists (see the "Information Communication" chapter for details on the types of media). The following is an example of a scholarly journal article with the pieces of information that you'll need to create the citation listed and highlighted. The example comes from Marcyk and Moll's Information Literacy Badges.

SCHOLARLY JOURNAL ARTICLE

To cite a scholarly journal article, you'll need to collect the following pieces of information:

- Author(s)
- Date when the article was published
- Title of the article
- Title of the journal
- Volume and issue number
- Page numbers where the article appears
- DOI (alphanumeric code) or URL (website address) of the article

These pieces of information are highlighted in the following image, and the completed APA-style citation is listed beneath the image.



A screenshot of an article with all of the citation information labeled. Original article source: https://link.springer.com/article/10.1007/s11270-015-2593-1

Completed APA Style Citation:

Fritt-Rasmussen, J., Wegeberg, S., & Gustavson, K. (2015). Review on burn residues from in situ burning of oil spills in relation to arctic waters. Water, Air and Soil Pollution, 226(329), n.p. https://doi-org.proxy1.cl.msu.edu/10.1007/s11270-015-2593-1

For more practice with citations, you can go through the Information Literacy Badges' self-guided lesson.

Exercise

For the following citation, match the different parts to their descriptor.

Colla, S. R., & Packer, L. (2008). Evidence for decline in eastern North American bumblebees (hymenoptera: Apidae), with special focus on *bombus affinis* cresson. *Biodiversity and Conservation, 17*(6), 1379-1391. doi:10.1007/s10531-008-9340-5

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=51#h5p-29

DOCUMENT YOUR RESEARCH AS YOU GO! (OR, HOW NOT TO CRY WHEN CREATING A BIBLIOGRAPHY)

Writing an essay begins with gathering evidence — reading, looking for themes and patterns, following leads to other texts, and taking notes. As you read the work of other scholars and think about your approach to the topic, make it a habit to keep track of where you found the ideas

and themes that spark your interest. Always note the ***author, date, and title*** in your notes to ensure you can find that source again. Keeping careful track also reduces errors in your final bibliography, which is a key part of your essay. Details are important. Citations include names of people, titles, dates, and volume numbers. Formatting styles including punctuation.

These details are easy to keep track of when you use a ***citation manager***. Citation managers (a.k.a. reference managers) are software programs that allow you to save and organize your citations, and quickly create bibliographies for your assignments. Using a digital tool will save you so much time when referring back to your sources and writing your paper and preparing your bibliography.

REFERENCES

Marcyk, E. & Moll, E. *Citation as conversation*. Information Literacy Badges. https://informationliteracybadges.org/

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

The Word on College Reading and Writing by Carol Burnell, Jaime Wood, Monique Babin, Susan Pesznecker, and Nicole Rosevear is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Understanding Science. 2020. University of

California Museum of Paleontology. 11 June 2020 <http://www.understandingscience.org>.

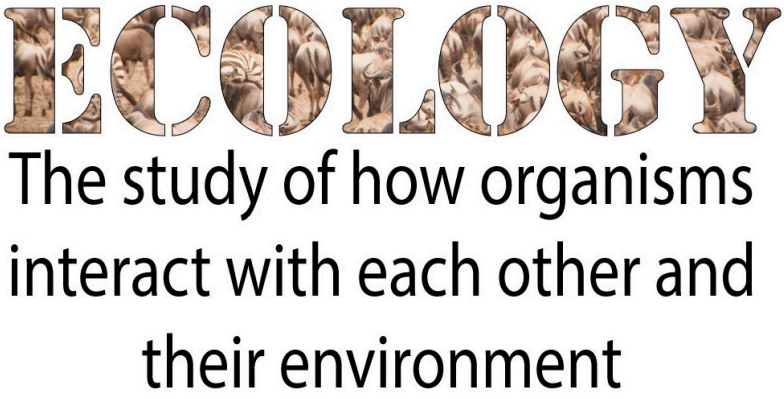
UNIT II

ORGANISMAL BIOLOGY

CHAPTER 6

Introduction to Ecology

ANDREA BIEREMA



ECOLOGICAL LEVELS

Ecology is studied at different levels. For instance, it can focus on the interaction of individuals within the same species (population ecology) or individuals of different species (community ecology).

See the figure below for all of the levels and click on the plus hotspots for definitions and more information.

The original version of this chapter contained H5P content. You may want to remove or replace this element.

In this unit, we will examine ecology at these various levels. First, we examine biodiversity, which addresses all of the ecological levels. Next, we consider the broad levels of biosphere and ecosystem ecology by learning about nutrient cycling and climate change. Then we focus on community ecology, learning about the various ways that species interact with one another. We consider population ecology, focusing on how population sizes change over time and the factors that influence those changes. We learn about evolution and modeling evolution using phylogenetic trees, which evolution occurs at the population level but is often influenced by biotic and abiotic factors. Lastly, we consider reproductive strategies.

CHAPTER 7

Biodiversity

ANDREA BIEREMA

Examples of the diversity of life. From left to right: Row 1: frogfish, moss, sea urchin, woodland crocus, and a flatworm; Row 2: alien lizard, archean cell infected with a virus, monarch butterfly, and platypus; Row 3: weevil, salmonella, hornbill, garden spider, and mushroom.

Learning Objectives

Students will be able to:

- Define biodiversity.
- Use visual models to characterize the scope of biodiversity on earth.
- Describe efforts to conserve threatened and endangered species.
- Explain the Red List of Threatened Species.
- Recognize types of protected areas.
- Describe the benefits of biodiversity.

- Characterize the threats to biodiversity.
- Explain ways in which organizations are working to save biodiversity.

INTRODUCTION TO BIODIVERSITY

Earth's biodiversity includes the entire range of living species, including single-celled and multicellular organisms. View the following interactive video to learn more!

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https://openbooks.lib.msu.edu/isb202/?p=58#h5p-30

For closed captioning or to view the full transcript for the video above, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

The previous video showed how to measure biodiversity and examples of how the amount of biodiversity varies throughout the world. Another aspect of biodiversity is that it is studied at different levels:

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https://openbooks.lib.msu.edu/isb202/?p=58#h5p-31

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=58#h5p-32

The relationship between species, genetic, and ecosystem diversities is complex and interdependent. That is, a species cannot exist without genetic diversity or ecosystem diversity and vice versa. For that reason, it is virtually impossible to affect one aspect of diversity without affecting the other. We can, therefore, think of species, genetic, and ecosystem diversities simply as different ways to measure the variety of life.

Let's dive deeper into ecosystem biodiversity:

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https://openbooks.lib.msu.edu/isb202/?p=58#h5p-33

For closed captioning or to view the full transcript for the video above, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

BENEFITS OF BIODIVERSITY

How do humans benefit from biodiversity? Watch the interactive video to find out!

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https://openbooks.lib.msu.edu/isb202/?p=58#h5p-34

For closed captioning or to view the full transcript for the video above, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

THREATS TO BIODIVERSITY

Despite humans obtaining several benefits from high biodiversity, there are several things that we are doing that limit biodiversity.

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https://openbooks.lib.msu.edu/isb202/?p=58#h5p-35

For closed captioning or to view the full transcript for the video above, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

SAVING BIODIVERSITY

Although many of our actions threaten biodiversity, there are things that people are doing to minimize our impact and save biodiversity.

Further Information

Curious what you can do to help save biodiversity? Check out the

World Wildlife Fund's guide!

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=58#h5p-36

For closed captioning or to view the full transcript for the video above, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

SPECIES RICHNESS AND THREAT LEVEL COMPARISON

The following is a series of maps illustrating global species richness as well as the number of threatened species for various taxa. Slide the white vertical line to see the threatened species map and to compare the two maps.

Further Information

If you would like to see maps for additional species, check out the Biodiversity Mapping website!

TERRESTRIAL SPECIES

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version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=58#h5p-37

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=58#h5p-38

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=58#h5p-39

MARINE SPECIES

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https://openbooks.lib.msu.edu/isb202/?p=58#h5p-40

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=58#h5p-41

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=58#h5p-42

Discussion Question

How do the species-richness and threatened-species maps compare? Are there consistent trends across the different taxa? Why do you think these patterns or lack of patterns exist?

ATTRIBUTIONS

The maps in this chapter are from "Biodiversity Mapping" by Jenkins, C. N. Used with permission.

This chapter is a modified derivative of "What is Biodiversity?" by Wilson, J. W., & Primack, R. B., Conservation Biology in Sub-Saharan Africa, Cambridge, UK, Open Book Publishers, 2019.

FIGURE 1 ATTRIBUTIONS

(in order from left to right, starting in row 1)

"Antennarius pictus- Painted frogfish" by Steve Childs is licensed under CC BY 2.0.

"Aloe-moss (Polytrichaceae) at Philip Edward Island in Killarney, Ontario, Canada" by Ryan Hodnett is licensed under CC BY-SA 4.0.

"Tripneustes ventricosus (West Indian sea egg-top) and Echinometra viridis (reef urchin – bottom)" by Nick Hobgood is licensed under CC BY-SA 3.0.

"Flowering woodland crocus in the garden reserve Jonkervallei, Joure, Netherlands" by Dominicus Johannes Bergsma is licensed under CC BY-SA 4.0.

"Lembeh, Indonesia – flatworm – Eurylepta sp." by Rickard Zerpe is licensed under CC BY-SA 2.0.

"The alien lizard" by Kalablink is licensed under CC BY-SA 4.0.

"Sulfolobus infected with the DNA virus STSV1" by Xiangyux is licensed under Public Domain.

CHAPTER 8

Systems Thinking and the Carbon Cycle

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Describe systems thinking.
- Identify and describe a system that is observed in the natural world.
- Apply systems terminology (e.g., closed and open system, reservoir, and flux) to the structure of a systems model, including the carbon cycle.
- Identify the characteristics of positive (reinforcing) and negative (balancing) feedbacks in systems model output.
- Convert information into a carbon cycle model to illustrate the relationships of components within a system.
- Use a carbon cycling system model to predict how a carbon molecular travels

through the earth's four spheres.

- Estimate residence time for a system in equilibrium.

SYSTEMS THINKING

A system is a set of components that are linked through interconnections and functions to create an outcome. The interconnections of ***components*** and their ***interactions*** create ***system*** behavior. This is a broad definition and it describes systems in biology (like the circulatory system or nutrient cycling), a game system (like chess, cards, or football), and even a social system (such as 4H or Girl Scouts).

Example

For example, a football team is a system with:

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https://openbooks.lib.msu.edu/isb202/?p=66#h5p-43

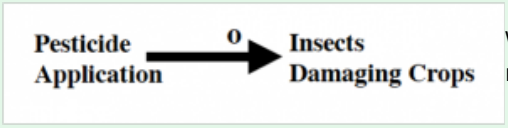
Systems thinking is one way of cognitively framing how we examine the world around us. In contrast to the more common mechanistic or deterministic model that analyzes and understands the whole as

the sum of its parts, systems thinking moves the focus of analysis away from the parts themselves and instead concentrates on understanding how the different parts interact with each other.

This is a fundamental difference from traditional analysis (analysis means to break into constituent parts); systems thinking works "by expanding its view to take into account larger and larger numbers of interactions" as a system is being studied (Aronson 1996).

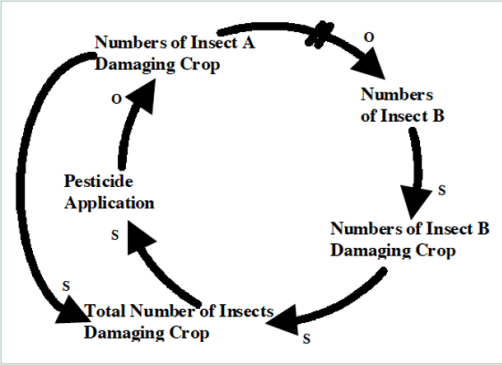
Example

Here is a classic example to show the difference between traditional analysis and systems thinking.



"If you apply pesticide, it will kill insect A which is damaging the crops. If you get more insects, apply more pesticide..."

A simplified diagram of how pesticide impacts insects that damage crops.



A cyclic diagram of insects, crops, and pesticides.

If it were that simple, as the top figure to the left suggests, we'd have no crop losses. Looking at the problem from a broader perspective, we can see one reason why the application of more pesticide doesn't have the expected outcome. As seen in the second figure, the total numbers of insect A are competing with insect B and keeping the population in check. When Insect A is exterminated, insect B's population explodes, and they fill the niche of insect A.

Systems thinking is a modality of thinking that keeps a focus on interactions between parts, with special vigilance to identify unintended consequences of changes that take place in a system because of these interactions.

The components and interactions in a system are referred to by the scientific terms used in system analysis

Now to introduce some important system science concepts. Scientists describe the "container" that holds an Earth material as a reservoir and the interactions as fluxes.

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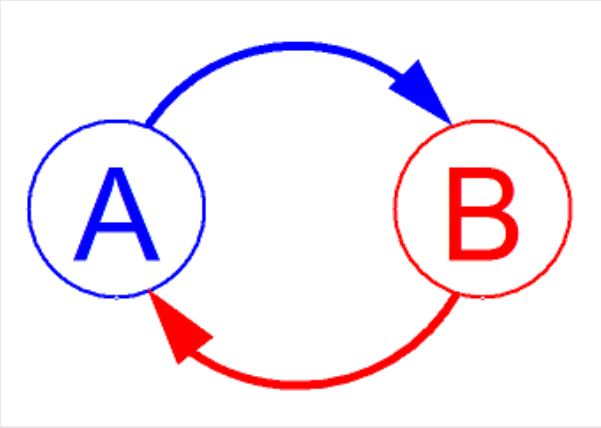
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-44

Exercise

A feedback loop exists between two components/reservoirs of a system (labeled “A” and “B” below) when each affects the other.



A simple feedback model.

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https://openbooks.lib.msu.edu/isb202/?p=66#h5p-45

Let's look at this concept closer with an example. The following is a slideshow—move the slides with the arrows at the bottom of the slideshow.

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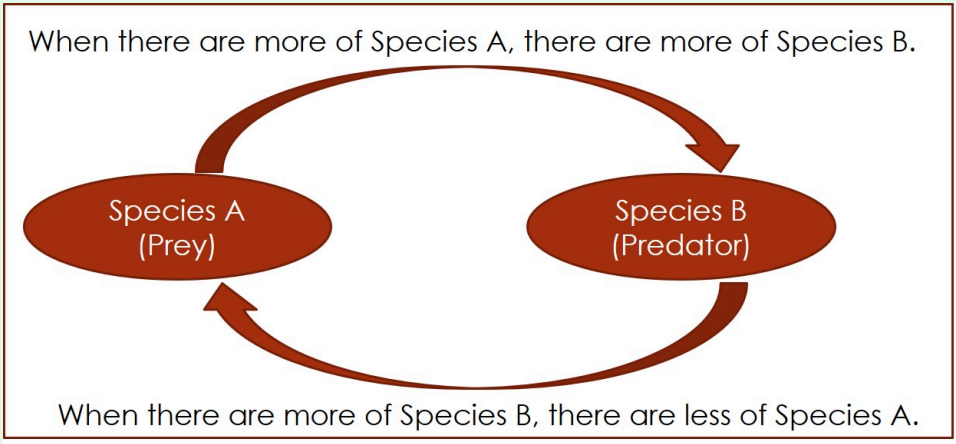
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-46

Example



A simple species interaction feedback model of predator and prey.

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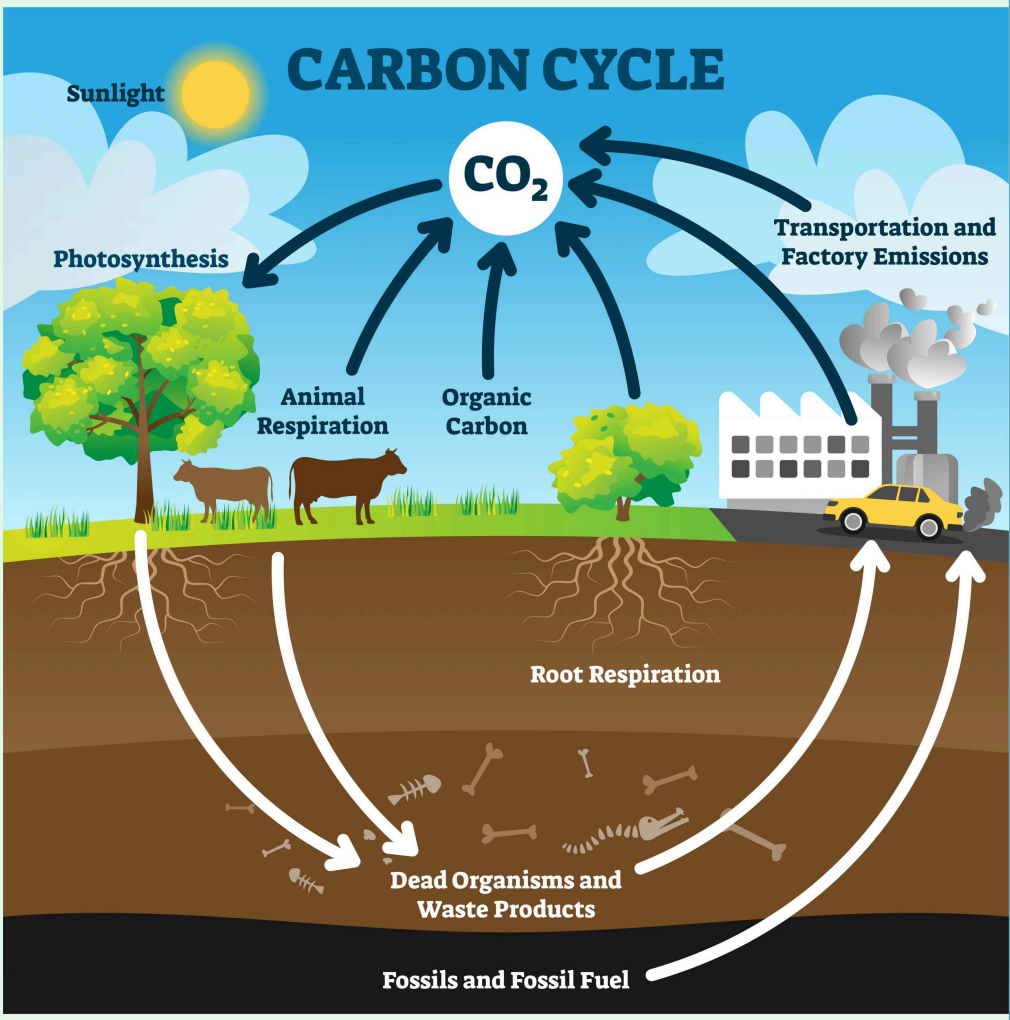
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-47

THE CARBON CYCLE

According to the ***Law of Conservation of Mass,*** matter can be neither created nor destroyed. Therefore, when nutrients (i.e., matter) are melted, burned, etc., they aren't destroyed. Also, when more nutrients appear in one part of the earth, it was not created. Rather, nutrients cycle through different parts of the earth. ***Nutrient cycling is a system with fluxes and reservoirs.***

Example

Here is an example of a typical carbon cycle. Apply the concepts learned in the previous section to the carbon cycle using the following diagram.



A standard carbon cycle diagram.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-48

The diagram in the example box above is similar to how carbon cycles are drawn in biology textbooks. It is technically a system, but does not explicitly illustrate how carbon moves through Earth's four spheres, depicted below.

The four spheres of Earth include the atmosphere, biosphere, lithosphere, and hydrosphere. All images taken in Michigan's Upper Peninsula by Andrea Bierema.

The following activity will end with a carbon cycle that focuses on these four spheres.

Exercise

The following is a list of processes describing how carbon moves (i.e., the ***fluxes*** of the carbon cycle). Refer to the definitions of each of these processes while performing the activity below.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-49

Using the definitions of each carbon flux above, develop a carbon cycle model. In the model below, each corner is one of the spheres (e.g., atmosphere), and each arrow represents a flux, which is the movement of carbon from one sphere to another sphere. Notice that one of the arrows (between the atmosphere and hydrosphere) is a double arrow; one of the fluxes represents carbon moving back and forth between the atmosphere and hydrosphere.

To complete the model below, drag each carbon flux (on the right side of the activity) to its appropriate arrow. The two red, dotted-line arrows are human activities, and the black solid-line arrows are natural processes.

Alternatively, feel free to complete the activity below the carbon cycle model, which addresses the same information, but in sentence form.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-50

This activity meets the same objectives as above, but just in a different format. Feel free to do this one instead or do it before creating the visual model above.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-51

POTENTIAL CARBON MOLECULE PATHS

As seen in the above activity, there are many ways in which carbon moves through the earth's spheres. To combine the ideas of the first carbon diagram shown earlier and the created carbon model, consider what are the more specific reservoirs of carbon in each sphere. For instance, the first model shows trees and cows, which are in the biosphere, and fossil fuels used by factories and cars, in which fossil fuels are part of the lithosphere.

Exercises

Here's one example of how a carbon molecule may travel through the cycle:

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=66#h5p-52

Here's another example; this time moving through all four spheres:

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https://openbooks.lib.msu.edu/isb202/?p=66#h5p-53

RESIDENCE TIME

Residence time is the average amount of time that matter remains in a reservoir. For carbon, this varies rather dramatically from sphere to sphere.

How to calculate residence time, assuming equilibrium in fluxes adding to, and fluxes removing, carbon from a given sphere:

Residence Time = [Amount of substance in sphere] / [total flux in OR out]

For example, if the total amount of carbon in a sphere is 8 billion tons and total flux in or out of the sphere is 4 billion tons per year:

[8 billion tons of carbon] / [4 billion tons per year] = 2 years

The conclusion to be made from this residence time example is that one atom of carbon will be in the given sphere for an average of 2 years before moving naturally to another sphere in the carbon system. Remember that this is an average; some atoms will spend much less time, and some will spend much more, in the sphere.

Exercise

Here is the total amount of carbon in each sphere:

- Biosphere: 605 billion tons
- Atmosphere: 760 billion tons
- Hydrosphere: 39,000 billion tons
- Lithosphere: 40,005,600 billion tons

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=66#h5p-54

REFERENCE

Aronson, D. (1996). Overview of systems thinking. Retrieved from http://www.thinking.net/Systems_Thinking/OverviewSTarticle.pdf

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

"Development and Evaluation of an Inquiry-Based Unit for Teaching about Paleoclimate and Climate Change" by Barone, S., Master's Theses, 113, 2019, Used with permission.

"Introductory system slides." by Gilbert, L. *In* Systems Thinking, InTeGrate, CC BY-NC-SA 3.0.

"Unit 2 pre-class homework tutorial." by Low, R. *In* The Wicket Problem of Global Food Security, InTeGrate, CC BY-NC-SA

CHAPTER 9

Climate Change

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Distinguish between climate and weather.
- Explain past, present, and future climate.
- Describe examples that illustrate that life on earth depends on, is shaped by, and affects climate.
- Describe the Intergovernmental Panel on Climate Change.
- Describe examples of how humans influence the climate system.
- Describe how system climate models are developed and analyzed.

How is climate change portrayed in television comedies? Watch the following video to find out!

A YouTube element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=70

WEATHER VS. CLIMATE

Although these words are often used interchangeably, they have very different meanings. View the following video to learn how they differ.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=70#h5p-56

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Exercise

What are your local weather and climate like? Check out *Weather Underground's* Historical Weather Data to find out! Once on the website, type in your location and then click "view." The data charts represent the current day's temperature, precipitation, and wind speed. Scroll down to the charts, which also show the day's patterns as well as the average. Change the setting toward the top of the page to "month" and scroll further down to see the daily observations. If viewing this at the beginning of the month, then change the month to the previous one.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=70#h5p-57

THE ATMOSPHERIC BLANKET AND ITS WARMING EFFECT

The gasses in the atmosphere act like a blanket, warming the earth and resulting in the natural greenhouse gas effect.

THE ATMOSPHERE

The Earth's atmosphere is an extremely thin shell compared with the size of our planet. The primary gases in the atmosphere by volume are nitrogen (78.1%), oxygen (20.9%), and argon (0.9%). These figures don't include water vapor, which varies significantly with location and altitude but averages about 0.4% of the atmosphere globally. Other naturally occurring gases include carbon dioxide (designated by chemists as CO_2), ozone, and methane, which all occur in trace amounts. Although CO_2, methane, and ozone occur naturally, human activities are increasing their concentrations. This blanket of atmosphere sustains life in many fundamental ways, as shown in the figure below.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=70#h5p-58

THE NATURAL GREENHOUSE GAS EFFECT

On the image below, click on the "question mark" hotspots to learn about solar radiation.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=70#h5p-59

Not all of the emitted heat energy can escape to space. The greenhouse gases in the intervening atmosphere absorb (or trap) some of this heat energy. As a result, the heat energy leaving the planet is reduced by the intervening atmosphere. It is this trapping of heat energy that otherwise would have escaped to space through the atmosphere that is referred to as the ***greenhouse effect***.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=70#h5p-60

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

PAST CLIMATE

Because scientists cannot go back in time to directly measure climatic variables, such as average temperature and precipitation, they must instead indirectly measure temperature. To do this, scientists rely on historical evidence of Earth's past climate.

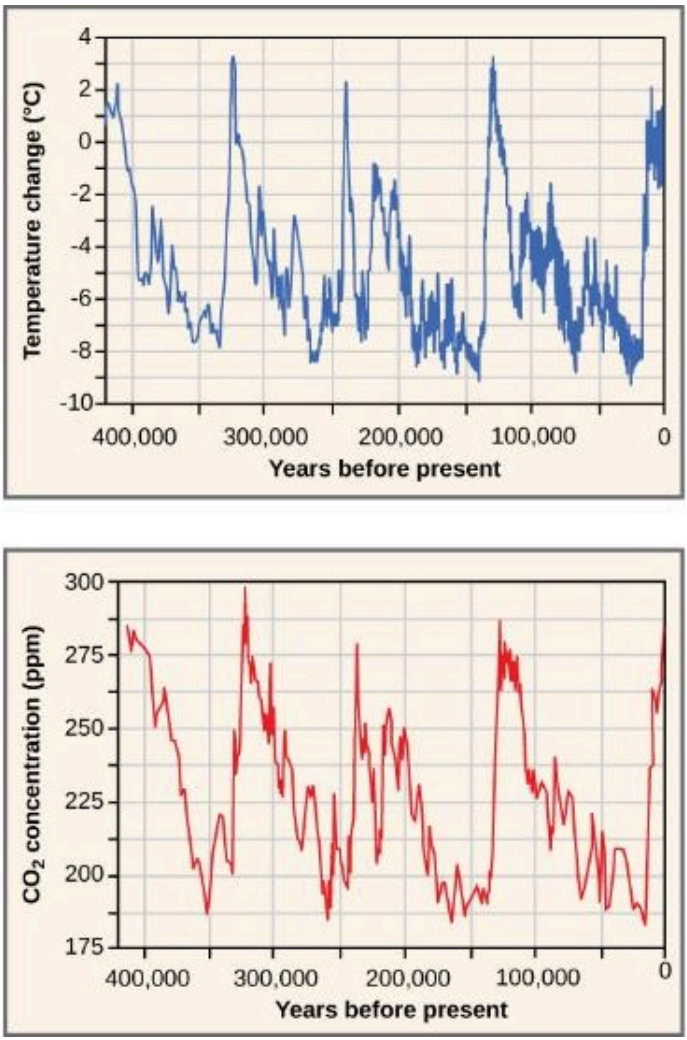
Scientists obtaining an ice core.

Antarctic ice cores are a key example of such evidence for climate change. These ice cores are samples of polar ice obtained by means of drills that reach thousands of meters into ice sheets or high mountain glaciers. Viewing the ice cores is like traveling backward through

time; the deeper the sample, the earlier the time period. Trapped within the ice are air bubbles and other biological evidence that can reveal temperature and carbon dioxide data. Antarctic ice cores have been collected and analyzed to indirectly estimate the temperature of the Earth over the past 400,000 years.

The 0°C on the graph below represents the long-term average. Temperatures that are greater than 0°C exceed Earth's long-term average temperature. Conversely, temperatures that are less than 0°C are less than Earth's average temperature. This figure shows that there have been periodic cycles of increasing and decreasing temperature.

Before the late 1800s, the Earth has been as much as 9°C cooler and about 3°C warmer. Note that the second graph below shows that the atmospheric concentration of carbon dioxide has also risen and fallen in periodic cycles. Also, note the relationship between carbon dioxide concentration and temperature. The graph shows that carbon dioxide levels in the atmosphere have historically cycled between 180 and 300 parts per million (ppm) by volume.



Ice at the Russian Vostok station in East Antarctica was laid down over the course of 420,000 years and reached a depth of over 3,000 m. By measuring the amount of CO2 trapped in the ice, scientists have determined past atmospheric CO2 concentrations. Temperatures relative to modern-day were determined from the amount of deuterium (an isotope of hydrogen) present.

The figure above does not show the last 2,000 years with enough detail to compare the changes in Earth's temperature during the last 400,000 years with the temperature change that has occurred in the more recent past. Two significant temperature anomalies, or irregularities, have occurred in the last 2,000 years. These are the Medieval Climate Anomaly (or the Medieval Warm Period) and the Little Ice Age. A third temperature anomaly aligns with the Industrial Era. The Medieval Climate Anomaly occurred between 900 and 1300 AD. During this time period, many climate scientists think that slightly warmer weather conditions prevailed in many parts of the world; the higher-than-average temperature changes varied between 0.10°C and 0.20°C above the norm. Although 0.10°C does not seem large enough to produce any noticeable change, it did free seas of ice. Because of this warming, the Vikings were able to colonize Greenland.

The Little Ice Age was a cold period that occurred between 1550 AD and 1850 AD. During this time, a slight cooling of a little less than 1°C was observed in North America, Europe, and possibly other areas of the Earth. This 1°C change in global temperature is a seemingly small deviation in temperature (as was observed during the Medieval Climate Anomaly); however, it also resulted in noticeable climatic changes. Historical accounts reveal a time of exceptionally harsh winters with much snow and frost.

The Industrial Revolution, which began around 1750, was characterized by changes in much of human society. Advances in agriculture increased the food supply, which improved the standard of living for people in Europe and the United States. New technologies were invented that provided jobs and cheaper goods. These new technologies were powered using fossil fuels; especially coal. The Industrial Revolution starting in the early nineteenth century ushered in the beginning of the Industrial Era. When

Activity

What proportion of Earth's history have humans been on Earth? Check

out Learn.Genetic's Geologic Time Scale to find out! Note: Once on the website, don't give up scrolling down.

fossil fuel is burned, carbon dioxide is released. With the beginning of the Industrial Era, atmospheric carbon dioxide began to rise.

CLIMATE MODELS

HOW WE USE MODELS

Models help us to work through complicated problems and understand complex systems. They also allow us to test theories and solutions. From models as simple as toy cars and kitchens to complex representations such as flight simulators and virtual globes, we use models throughout our lives to explore and understand how things work.

CLIMATE MODELS, AND HOW THEY WORK

Climate models are based on well-documented physical processes to simulate the transfer of energy and materials through the climate system. Climate models, also known as general circulation models or GCMs, use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, and land. Building and running a climate model is a complex process of identifying and quantifying Earth system processes, representing them with mathematical equations, setting variables to represent initial conditions and subsequent changes in climate forcing, and repeatedly solving the equations using powerful supercomputers.

CLIMATE MODEL RESOLUTION

Climate models separate Earth's surface into a three-dimensional

grid of cells. The results of processes modeled in each cell are passed to neighboring cells to model the exchange of matter and energy over time. Grid cell size defines the resolution of the model: the smaller the size of the grid cells, the higher the level of detail in the model. More detailed models have more grid cells, so they need more computing power.

See an animation showing different grid sizes »

Explore information about supercomputer systems used to run global climate models »

Climate models also include the element of time, called a time step. Time steps can be in minutes, hours, days, or years. Like grid cell size, the smaller the time step, the more detailed the results will be. However, this higher temporal resolution requires additional computing power.

HOW ARE CLIMATE MODELS TESTED?

Once a climate model is set up, it can be tested via a process known as "hind-casting." This process runs the model from the present time back into the past. The model results are then compared with observed climate and weather conditions to see how well they match. This testing allows scientists to check the accuracy of the models and, if needed, revise their equations. Science teams around the world test and compare their model outputs to observations and results from other models.

Using Scenarios to Predict Future Climate

Once a climate model can perform well in hind-casting tests, its results for simulating future climate are also assumed to be valid. To project climate into the future, the climate forcing is set to change according to a possible future scenario. Scenarios are possible stories about how quickly the human population will grow, how land will be used, how economies will evolve, and the

atmospheric conditions (and therefore, climate forcing) that would result in each storyline.

In 2000, the Intergovernmental Panel on Climate Change (IPCC) issued its Special Report on Emissions Scenarios (SRES), describing four scenario families to describe a range of possible future conditions. Referred to by letter-number combinations such as A1, A2, B1, and B2, each scenario was based on a complex relationship between the socioeconomic forces driving greenhouse gas and aerosol emissions and the levels to which those emissions would climb during the 21st century. The SRES scenarios have been in use for more than a decade, so many climate model results describe their inputs using the letter-number combinations.

In 2013, climate scientists agreed upon a new set of scenarios that focused on the level of greenhouse gases in the atmosphere in 2100. Collectively, these scenarios are known as Representative Concentration Pathways or RCPs. Each RCP indicates the amount of climate forcing, expressed in Watts per square meter, that would result from greenhouse gases in the atmosphere in 2100. The rate and trajectory of the forcing is the pathway. Like their predecessors, these values are used in setting up climate models.

Learn more about RCPs »

Results of Current Climate Models

Around the world, different teams of scientists have built and run models to project future climate conditions under various scenarios for the next century. The model results project that global temperature will continue to increase, but show that human decisions and behavior we choose today will determine how dramatically climate will change in the future.

How are Climate Models Different From Weather Prediction Models?

Unlike weather forecasts, which describe a detailed picture of the expected daily sequence of conditions starting from the present, climate models are probabilistic, indicating areas with higher chances to be warmer or cooler and wetter or drier than usual. Climate models are based on global patterns in the ocean and atmosphere, and records of the types of weather that occurred under similar patterns in the past.

View maps showing short-term climate forecasts »

IPCC (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE)

The Intergovernmental Panel on Climate Change (IPCC) is the most prominent international scientific body for assessing climate change. It was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). There are currently 195 member-countries in the IPCC, and membership is open to all countries in the WMO and UN. The IPCC is responsible for reviewing and evaluating scientific, technical, and socioeconomic information related to climate change. While the IPCC neither conducts research nor monitors any climate change data directly, it provides policymakers with the most comprehensive picture of the scientific consensus.

Who are the people in this panel?

A YouTube element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=70

To learn more about some of the scientists involved, check out the IPCC's playlist "25 Years of the IPCC- Individual Videos."

IPCC'S CLIMATE ASSESSMENT REPORT

The IPCC is currently working on its 6th assessment report, which is scheduled to be released in 2022. The following video is a summary of the 5th assessment report.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=70#h5p-62

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

If you would like to learn more about these reports, then view the videos for each working group:

- Working Group 1: Physical Science Basis
  - View in English, or
  - Choose another language from this playlist
- Working Group 2: Impacts, Adaptation, and Vulnerability
  - View in English, or
  - Choose another language from this playlist
- Working Group 3: Mitigation of Climate Change
  - View in English, or
  - Choose another language from this playlist

View the synthesis report.

So what do the models look like? The following are links to the IPCC 5th Assessment Report, "Summary for Policymakers" figures per working group.

Working Group 1: Physical Science Basis

Working Group 1 investigates past, present, and future climate.

- Figure SPM.1 Temperature: a) The observed annual and decadal average temperature from 1850 to 2012,

compared to the average for 1961 to 1990. Negative values indicate average temperatures were below the 1961-1990 average and positive values indicate above that average. b) World map of the observed change in surface temperature from 1901 to 2012.

- Figure SPM.2 Precipitation: World maps illustrating the change in precipitation from 1901 to 2010 and 1951 to 2010.
- Figure SPM.3 Cryosphere (snow and ice): For the 20th century, a) the amount of spring snow cover in the Northern Hemisphere, b) the extent of Arctic summer sea ice, c) change in global average upper ocean heat content relative to 1970, and d) change in global average sea level relative to 1900-1905.
- Figure SPM.4 Carbon Dioxide: a) Atmospheric concentration of carbon dioxide and b) surface ocean carbon dioxide and pH (the lower the number, the more acidic).
- Figure SPM.5 Drivers of Climate Change: Anthropogenic and natural climate change drivers and their impacts in 2011 compared to 1750.
- Figure SPM.6 Natural and Anthropogenic Impact: Global and regional graphs illustrating the impact of natural forcings and combined natural and anthropogenic forcings.
- Figure SPM.7 Predicted Temperature: Predicted temperature changes relative to 1986-2005 using four models (each model represents a different scenario (from cutting all carbon emissions today to not changing carbon emissions at all).
- Figure SPM.8 Predicted Climate: World maps showing predicted changes in climate for 2081-2100 relative to

1986-2005 for two different scenarios for a) temperature, b) precipitation, c) Northern Hemisphere September sea ice extent, and d) ocean surface pH (lower values mean more acidic).

- Figure SMP.9 Predicted Sea Level Rise: Graph depicting predicted sea-level rise using four models (each model represents a different scenario (from cutting all carbon emissions today to not changing carbon emissions at all).
- Figure SMP.10 Carbon Dioxide and Temperature: Global surface temperature correlated with temperature change relative to 1861-1880.
- See the WG1 SMP figures in context with full captions.

Working Group 2: Impacts, Adaptation, and Vulnerability

Working Group 2 investigates how changes in climate impact the environment and society.

- Figure SPM.2 Widespread Impacts: A world map illustrating how different regions are impacted by climate change.
- Figure SPM.5 Species Migration: The maximum speeds that species can move across landscapes compared to how quickly temperatures are expected to change.
- Figure SPM.6 Fisheries: Predicted climate change impact on a) catch potential and b) change in pH and which taxa are most impacted.
- Figure SPM.7 Crop Yield: Predicted climate change impact on future crop yields.
- Figure SPM.8 Solution Model: A model illustrating risks and mitigations.

- See the WG2 SMP figures in context with full captions.

Working Group 3: Mitigation of Climate Change

Working Group 3 investigates how we may reduce future climate change and the impact of its effects.

- Figure SPM.1 Greenhouse Gases: Total annual greenhouse gases by type: fossil fuel and industrial processes, forestry and other land use (FOLU), nitrous oxide (N_2O), and fluorinated gases covered under the Kyoto Protocol (F-gases).
- Figure SPM.2 Economic Sectors: Direct and indirect carbon dioxide emissions by economic sector.
- Figure SPM.4 Baseline and Mitigation Scenarios: Global greenhouse gas emissions for four scenarios: baseline (not changing our emissions path), two scenarios with varying emission levels, and one scenario for if we stopped carbon emissions.
- Figure SPM.9 Investment: Changes in annual investment flows projected for 2010-2029 based on keeping carbon dioxide emissions in a range of about 430 to 530 parts per million.
- See the WG3 SMP figures in context with full captions.

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

"Climate and The Effects of Global Climate Change" by OpenStax College, *Biology 2e*, CC BY 4.0. Download the original article for free at https://openstax.org/books/biology-2e/pages/1-introduction

"Climate Models" by Climate.gov, NOAA, Public domain.

"Climate Change" by Ramanathan, V., *Bending the Curve: Climate Change Solutions Digital Textbook,* 2019, CC-BY-NC-SA.

CHAPTER 10

Species Interactions

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Define niche.
- Describe types of species interactions.
- Define competitive exclusion and resource partitioning principles.
- Use food webs to infer examples of species interaction within a community.
- Use ecological models to appropriately predict how an abundance of species may impact other species within a community.

COMMUNITY ECOLOGY

Ecology is studied at different scales and species interactions are part of the “community ecology” scale.

An interactive H5P element has been excluded from this version of the text. You can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=76#h5p-63

TWO-SPECIES INTERACTIONS

Community ecology includes the ways in which species interact. Research sometimes focuses on two species of a complex community and the general ways those species interact with one another can be classified by whether the species are positively, negatively, or neutrally impacted. The following video describes the main types of species interactions, with examples. The table below summarizes these types.

An interactive H5P element has been excluded from this version of the text. You

can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=76#h5p-64

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Interaction	Definition	Species A	Species B	Possible Symbiosis (i.e., lives in close proximity to each other)
Mutualism*	A long-term, close association between two species in which both partners benefit	+	+	Yes
Commensalism*	Species A benefits from the relationship and species B is not affected.	+	N	Yes
Consumption: Parasitism	Species A consumes part- but typically does not kill- species B.	+	-	Yes
Consumption: Parasitoidism*	A new generation of species A consumes species B.	+	-	Yes
Consumption: Predation	Species A consumes species B.	+	-	No
Consumption: Herbivory	Species A consumes part- but does not kill- Species B.	+	-	No
Competition	Two species "fight" over a resource. Although one species may "win," it is still negatively impacted by taking part in the competition	-	-	No

Exercise

Test your understanding of species interactions!

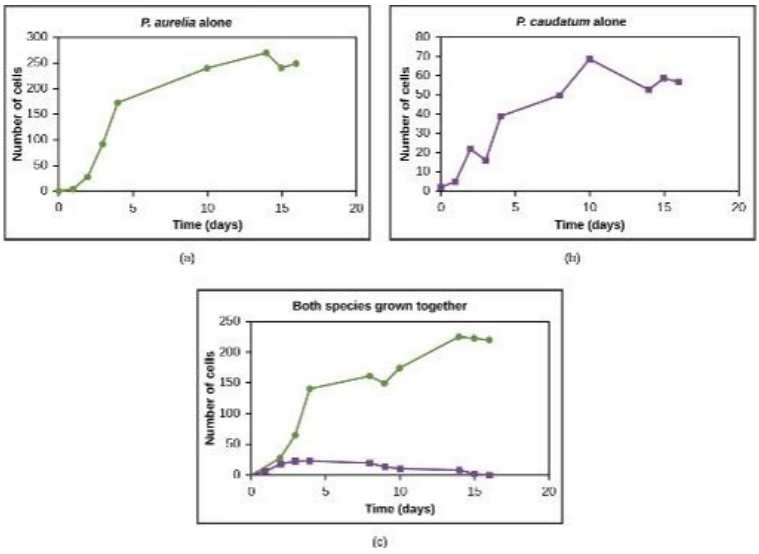
An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=76#h5p-65

Learn more about “aquatic cleaning stations“!

NICHES AND HOW THEY INFLUENCE COMPETITION

Resources are often limited within a habitat and multiple species may compete to obtain them. All species have an ***ecological niche*** in the ecosystem, which describes how they acquire the resources they need and how they interact with other species in the community. The ***competitive exclusion principle*** states that two species cannot occupy the same niche in a habitat. In other words, different species cannot coexist in a community if they are competing for all the same resources.

An example of this principle is shown below with two protozoan species: *Paramecium aurelia* and *Paramecium caudatum*. When grown individually in the laboratory, they both thrive. When they are placed together in the same test tube (habitat), *P. aurelia* outcompetes *P. caudatum* for food, leading to the latter’s eventual extinction.



Paramecium aurelia (graph a) and Paramecium caudatum (graph b) grow well individually, but when they compete for the same resources, the P. aurelia outcompetes the P. caudatum. In graph c, the top growth curve is P. aurelia and the bottom growth curve is P. caudatum.

Exercise

Does competition between two species that share a similar niche always result in one dying off? Try out the Virtual Biology Lab's simulation of barnacle competition. Once on the website, read through the background information and the tutorial. Then run the experiment- feel free to keep the variables consistent or see what happens when you change them.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=76#h5p-66

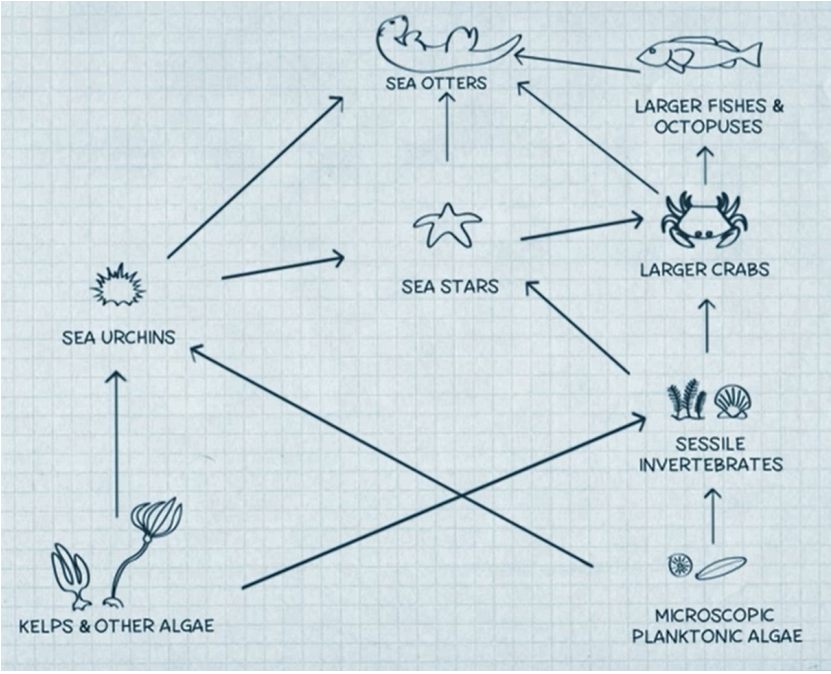
MULTI-SPECIES SPECIES INTERACTIONS

This section refers to food webs. Please see Khan Academy's Food Chains and Food Webs for a review.

In community ecology, we can examine the interaction of two species or we can think at a larger, more complex scale and examine how many species interact. One way to do so is to start with a food web to identify some of the interactions that are occurring within a community. The following video describes this in more detail using the example of a coastal food web.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=76#h5p-67

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.



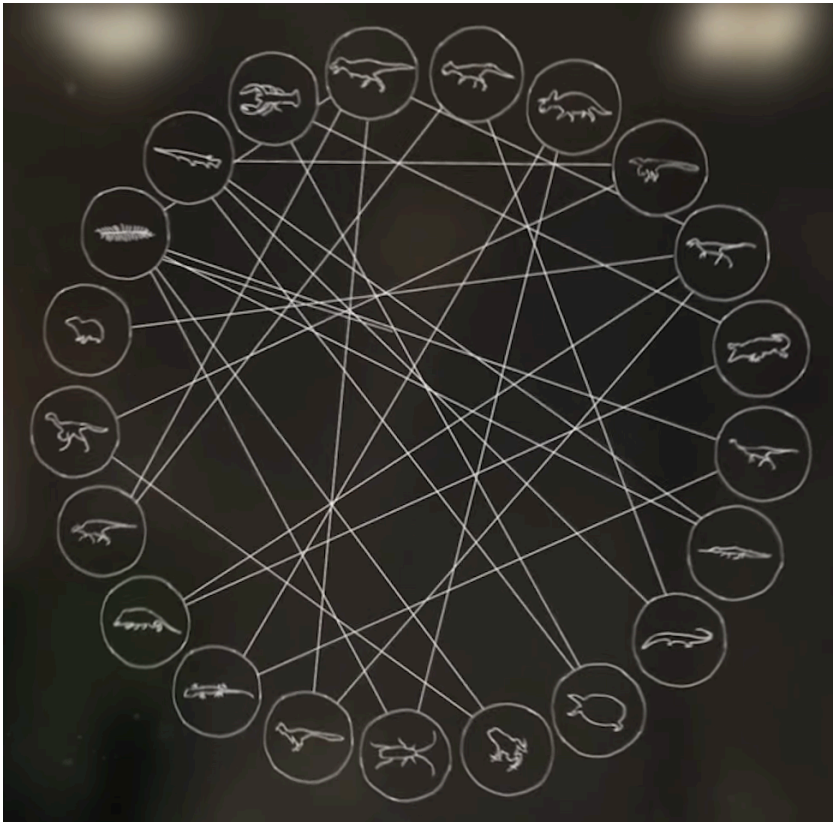
This is the coastal community food web shown in the video above by Khan Academy.

An interactive H5P element has been excluded from this version of the text. You can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=76#h5p-68

SPECIES INTERACTION MODEL

The food web is a model that illustrates how energy moves. Models can also be created to show how species interact with one another (beyond predator/prey and competition for food). The following model was introduced in the video. Rather than having each line represent energy movement, they can be labeled with different species interactions such as mutualism. This is a visual way to explain the complexity of species interactions within a community.

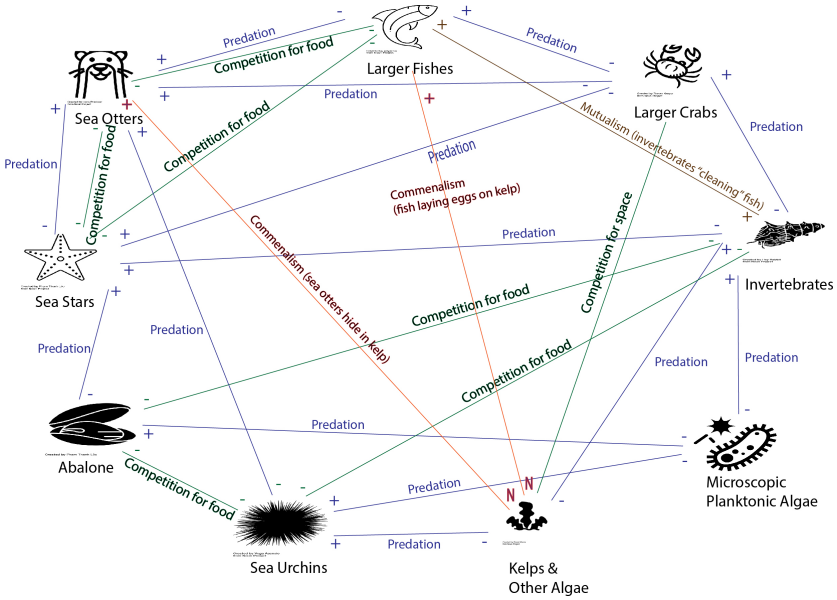


A model showing the connections between species within a community.

For instance, the following model is a complete species interaction

model using the species from the video's Pacific coast food web. Notice how species are now connected with lines rather than arrows. Interactions influence both species involved, while an arrow in a food web indicates the direction that energy moves. Each end of a line is also labeled with a positive (+), negative (-), and neutral (N), indicating how the species is impacted by the interaction. These symbols align with the symbols used in the interactions table shown toward the beginning of the chapter. For instance, in looking at the lines/interactions labeled as "competition for food," both species are labeled as being negatively impacted by placing a negative on each side of the line.

The "predation" and "competition for food" interactions align with the food web. Food webs allude to predation interactions and if species are eating the same species, then they are likely competing for the food source. The rest of the interactions labeled are from outside research, rather than from studying the food web.



A species interaction model, connecting species with lines that are labeled with the interaction taking place (e.g., predation).

The interactions in the above species interaction model are (in no particular order):

- Predation of sea otters (+) on sea stars, sea urchins, larger crabs, and larger fishes (-)
- Sea otters (-) compete for food with sea stars and larger fishes (-)
- Sea otters (+) hide in kelp & other algae (neutral), which is a commensalism
- Larger fishes (+) have a mutualism with invertebrates (+) because some invertebrates “clean” the fishes and consume what they clean.
- Larger crabs (+) are predators of invertebrates (-)

- Larger crabs (-) and kelps & other algae (-) compete for space
- Invertebrates (+) are predators of kelps and other algae (-) and microscopic planktonic algae (-)
- Invertebrates (-) compete for food with abalones and sea urchins
- Larger fishes (-) and sea stars (-) compete for food
- Larger fishes (+) lay eggs on kelp (neutral), which is a commensalism
- Sea stars (+) are predators of abalone (-), invertebrates (-), and larger crabs (-)
- Abalones (+) are predators of microscopic planktonic algae (-)
- Sea urchins (-) complete for food with abalone (-) and invertebrates (-)
- Sea urchins (+) are predators of microscopic planktonic algae (-) and kelps & other algae (-)
- Larger fishes (+) are predators of larger crabs

ATTRIBUTION

This chapter is a modified derivative of the following articles:

"Community Ecology" by OpenStax College, Biology 2e, CC BY 4.0. Access for free at https://openstax.org/books/biology-2e/pages/1-introduction

"Interactions in Communities" by Khan Academy, CC BY-NC-SA 4.0.

CHAPTER 11

Population Growth

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Define population.
- Describe common population growth models.
- Define carrying capacity.
- Provide accurate explanations of population growth graphs, including carrying capacity.
- Define and identify examples of density-independent and density-dependent factors.
- Explain how population growth data plays a role in conservation.
- Draw connections between human population growth and social/political and economic conditions.

POPULATION ECOLOGY

Ecology is studied at different scales, and population growth is part of the "population ecology" scale.

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https://openbooks.lib.msu.edu/isb202/?p=84#h5p-69

GRAPH INTERPRETATION

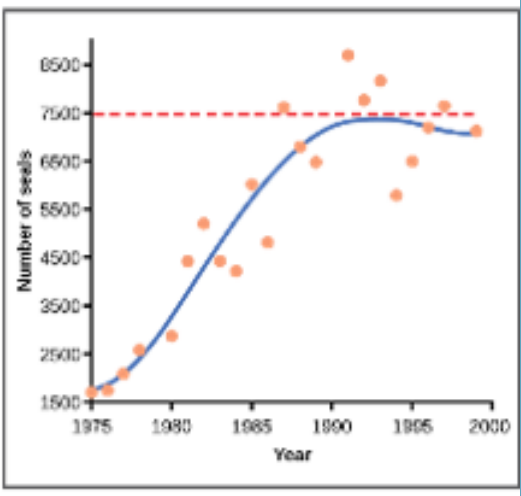
Exercise: Graph Interpretation

Population growth, a common topic in population ecology, plots population size over time on a graph. Before learning about population growth, let's test your graph reading skills.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-70

Exercise: Population Growth Graph

Now, let's read a population growth graph:



Population growth of seals. The x-axis (independent variable) is the years and the y-axis (dependent variable) is the number of seals.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-71

POPULATION GROWTH

Exercise

Learn more about population growth modeling through this simulation!

There are two main models used to describe how population size changes over time: exponential growth and logistic growth. Click on the information hotspots (labeled as "i") in the figure below to learn more.

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Although several populations in nature follow logistic and exponential growth patterns, population growth can be much more complicated. For instance, many insects undergo brief exponential growth, followed by periods of mass death (or drop in population).

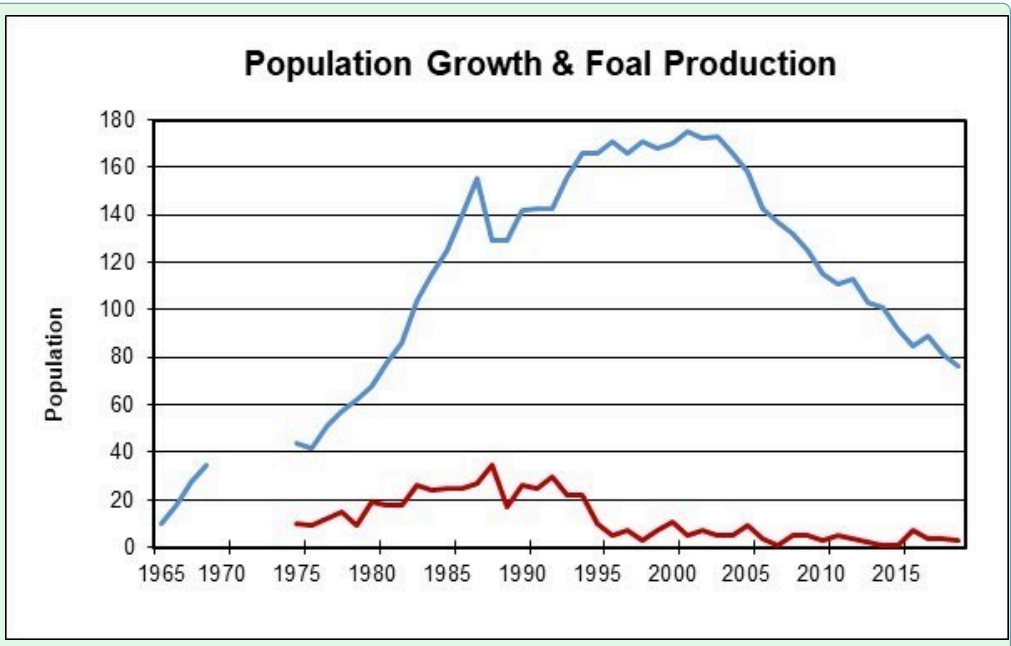
Example

Population growth may not look like either exponential or logistic growth models. For instance, the horse population on Assateague Island in Maryland (pictured below) experienced increase and stabilization—similar to logistic growth—but then underwent a stable decline.

To complicate the interpretation of this graph further, the stabilization and decline were due to human management of the population. Studies showed that the environment would not sustain such a large population over time, and many of the plant-species' population growth would drop dramatically—eventually causing a crash in the horse's

population size. Managers injected female horses with a vaccine that caused immune cells to attack sperm cells.

Mare and foal grazing on Assateague Island.



Horse population growth and foal production on Assateague Island National Seashore, 1965-2015. Blue line – horse population, red line – foal births, blank space – unavailable data.

Check out the following article to learn more!

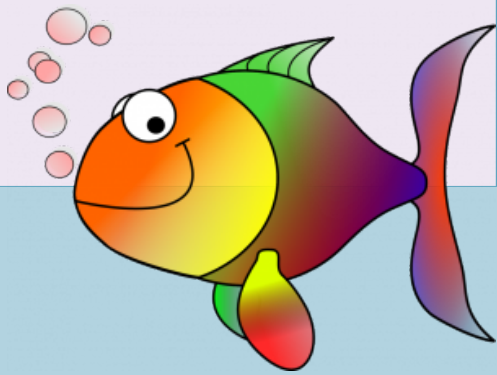
National Park Service. (n.d.). Resource management brief – horses. Retrieved June 24, 2020 from https://www.nps.gov/asis/learn/nature/resource-management-brief-horses.htm

Practice

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-73

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-74

Can you identify the carrying capacity in these populations of the fictitious smiling rainbow fish?



Smiling rainbow fish.

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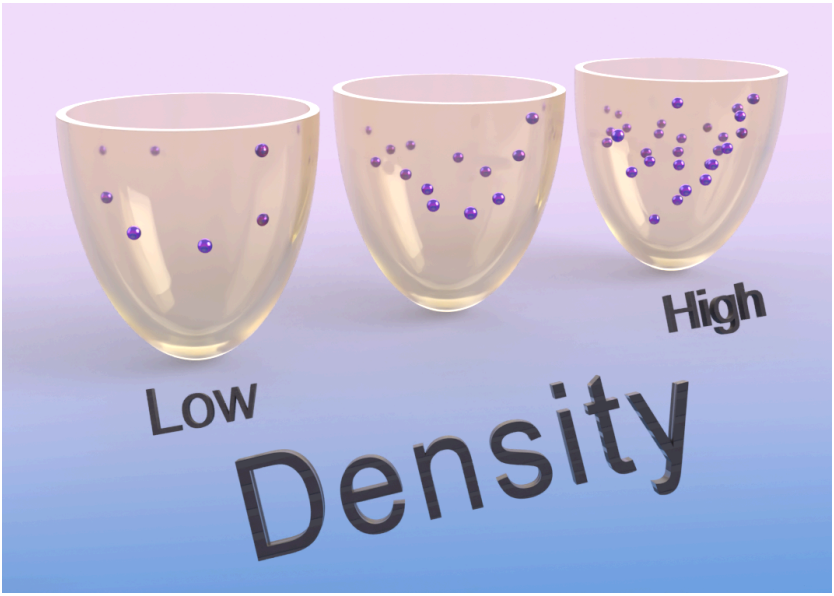
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-75

POPULATION DENSITY

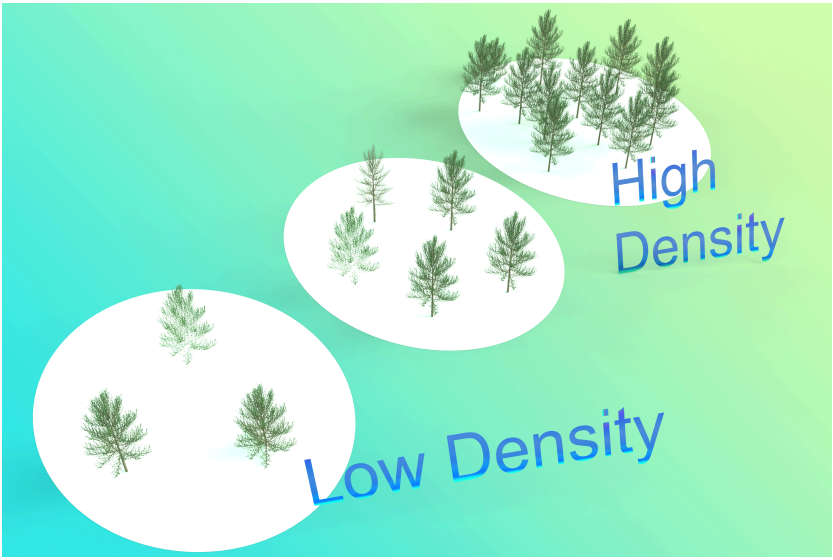
Although examining how the size of the population changes over time is informative, it neglects to take into account how much space the population is occupying. How dense a population is can impact survival and be influenced by a number of factors.

DENSITY

You may have heard of density in a chemistry or physics class before. In those cases, density typically refers to how dense an object is (as seen in the figure below). This is the amount of matter in a given volume (calculated by mass/volume).



The diagram illustrates that higher density means that the particles are closer together.



Density is also used to explain populations. In this image, the density of pine trees in each "environment" varies from low density to high density.

Population density is similar to object density, except it refers to the number of individuals (or organisms) instead of the number of particles.

POPULATION GROWTH FACTORS

Factors that influence population size, such as a drought or drop in prey, are categorized into one of two types:

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https://openbooks.lib.msu.edu/isb202/?p=84#h5p-76

Based on those definitions, identify each factor as density-dependent or independent.

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https://openbooks.lib.msu.edu/isb202/?p=84#h5p-77

POPULATION GROWTH AND CONSERVATION

Population growth is used to inform conservation—whether it be to determine if conservation efforts are needed (i.e., a population is dropping in size) or testing to see if a conservation strategy is working.

Exercises

View the following interactive video to learn about lion conservation in Gorogonsa National Park and practice some of the population growth concepts!

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-78

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Need more practice and information? Go through the *Connecting Concepts* interactive lesson on population dynamics, which describes population growth trends of zebra mussels and elephants!

HUMAN POPULATION

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=84#h5p-79

For closed captioning or to view the full transcript, click on the

"YouTube" link in the video (or click here) and view the video on YouTube.

The previous video explored why our population is increasing in size, but when did our population start increasing and what does it look like now? The following video does an excellent job of showing how our rate of increase has changed over time. Note: It's going to seem like not a lot is going for a while, but keep watching!

A YouTube element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=84

More Information

How do your personal habitats and way of life impact the planet? How many Earths would we need if everyone lived a similar way as you? Find out by taking this ecological footprint quiz!

Next, find out your water footprint. You'll be surprised by how many things that we do use water!

REFERENCE

National Park Service. (n.d.). Resource management brief – horses. Retrieved June 24, 2020 from https://www.nps.gov/asis/learn/nature/resource-management-brief-horses.htm

CHAPTER 12

Evolution

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Define evolution.
- Describe different mechanisms of evolution, including natural selection, genetic drift, gene flow, and mutation.
- Recognize that new heritable traits result from random mutations.
- Describe sexual selection.
- Identify examples of intrasexual and intersexual selection.
- Use data and physical traits to predict which evolutionary mechanisms and potential selective agents influence a population.
- Distinguish between microevolution and macroevolution.
- Describe possible mechanisms of speciation.

DEFINITION OF EVOLUTION

Biological evolution, simply put, is ***descent with modification***.

Biological evolution is not simply a matter of change over time. Lots of things change over time: trees lose their leaves and mountain ranges rise and erode, but they aren't examples of biological evolution because they don't involve descent through genetic inheritance.

The central idea of biological evolution is that ***all life on Earth shares a common ancestor***, just as you and your cousins share a common grandmother.

Through the process of descent with modification, the common ancestor of life on Earth gave rise to the fantastic diversity that we see documented in the fossil record and around us today. Evolution means that we're all distant cousins: humans and oak trees; hummingbirds and whales.

Evolution occurs at different scales:

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-80

MECHANISMS OF EVOLUTION

Although the term "evolution" is often used synonymously with "natural selection," they are actually referring to different concepts. Evolution is an observable phenomenon in which gene frequencies

change over time, but it does not explain *why* a population is undergoing evolution. This is where natural selection—and other mechanisms—come into play. They explain "the why."

There are four main mechanisms of evolution:

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-81

Exercise

Let's look at some examples of evolution and see if we can identify which evolutionary mechanism is at play.

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-82

Once you complete that, here is another game. This is a matching game using the images from the above quiz. As you match two images, recall which type of mechanism it is and why!

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-83

All of these mechanisms can cause changes in the frequencies of genes in populations, so all of them are mechanisms of evolutionary change. However, natural selection and genetic drift cannot operate unless there is genetic variation—that is, unless some individuals are genetically different from others. If the population of beetles was 100% green, selection and drift would not have any effect because their genetic make-up could not change.

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-84

Important Notes Regarding Mutations

Mutations are random

Mutations can be beneficial, neutral, or harmful for the organism, but mutations do not "try" to supply what the organism "needs." In this respect, mutations are random—whether a particular mutation happens or not is unrelated to how useful that mutation would be.

Not all mutations matter to evolution

Because all cells in our body contain DNA, there are lots of places for mutations to occur; however, not all mutations matter for evolution. Mutations that occur in non-reproductive cells won't be passed onto offspring.

For instance, if a skin cell has a mutation that causes uncontrollable cell division (i.e., cancer), that mutation is not passed to the next generation.

See the "Protein Structure and Function" chapter in this textbook for more information.

SEXUAL SELECTION

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-137

Darwin noticed that there were many traits and behaviors of organisms that could not just be explained by the ability to survive. For example, the brilliant plumage of peacocks should actually lower their rates of survival. That is, the peacocks' feathers act like a neon sign to predators, advertising "Easy, delicious dinner here!" But if these bright feathers only lower peacocks' chances at survival, why do they have them? The same can be asked of similar characteristics of other animals, such as the large antlers of male

stags or the wattles of roosters, which also seem to be unfavorable to survival. Again, if these traits only make the animals less likely to survive, why did they develop in the first place? And how have these animals continued to survive with these traits over thousands and thousands of years? Darwin's answer to this conundrum was the theory of sexual selection: the evolution of characteristics, not because of survival advantage, but because of mating advantage.

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-138

Exercise

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https://openbooks.lib.msu.edu/isb202/?p=88#h5p-139

EVOLUTION EXAMPLES

Learn more about the mechanisms of evolution via the following examples.

Exercises

Learn more about evolution through this example:

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=88#h5p-85

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

To continue learning how predation impacts the natural selection of traits, check out *Connected Bio's* simulation on the evolution of fur color in deer mice and *PhET*'s simulation (below) on the natural selection of rabbits!

An interactive or media element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=88

Exercise

Check out Virtual Biology Lab's Fish Pond simulation. In this simulation, change the migration rate (to test genetic flow), mutation rate, or genotype relative fitness (to test natural selection). You can also change the initial population size.

How does having a small population size affect genotype frequency, by chance (i.e., genetic drift)?

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=88#h5p-86

MACROEVOLUTION

As explained toward the beginning of this chapter, "macroevolution" refers to the evolution of one or more species. Before examining speciation, let's first learn about what it means to be a species.

SPECIES CONCEPT

A species is often defined as a group of individuals that actually or potentially interbreed in nature. In this sense, a species is the biggest gene pool possible under natural conditions.

That definition of a species might seem cut and dried, but it is not—in nature, there are lots of places where it is difficult to

apply this definition. For example, many bacteria reproduce mainly asexually through binary fission. The definition of a species as a group of interbreeding individuals cannot be easily applied to organisms that reproduce only or mainly asexually.

Also, many plants and some animals form hybrids in nature. Hooded crows and carrion crows look different, and largely mate within their own groups, but in some areas they hybridize. Should they be considered the same species or separate species?

Carrion crow

Hooded crow

There are lots of other places where the boundary of a species is blurred. It's not so surprising that these blurry places exist—after all, the idea of a species is something that we humans invented for our own convenience!

SPECIATION

Speciation is a lineage-splitting event that produces two or more separate species. Let's learn about speciation in the birds of paradise in the following interactive video.

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can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=88#h5p-87

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Exercise

Go through additional case studies on evolution, including speciation in *Connecting Concepts*' Natural Selection interactive lesson and Speciation interactive lesson.

ATTRIBUTIONS

This chapter is a modified derivative of:

Buss, D. M. 2021. Evolutionary theories in psychology. In R. Biswas-Diener & E. Diener (Eds), *Noba textbook series: Psychology.* Champaign, IL: DEF publishers. <http://noba.to/ymcbwrx4>.

Understanding Evolution. 2020. University of California Museum of Paleontology. 8 August 2020 <http://evolution.berkeley.edu/>.

CHAPTER 13

Phylogenetic Trees: Modeling Evolution

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Provide accurate explanations of a phylogenetic tree, which is a scientific model that explains how species are evolutionarily related to each other.
- Convert relevant information into a phylogenetic tree.
- Identify common ancestors on a phylogenetic tree.
- Label shared derived characteristics on a phylogenetic tree.

THE HISTORY OF LIFE: LOOKING AT THE PATTERNS

The central ideas of evolution are that life has a history—it has changed over time—and that different species share common ancestors.

Here, you can explore how evolutionary change and evolutionary relationships are represented in "family trees," how these trees are constructed, and how this knowledge affects biological classification. You will also find a timeline of evolutionary history and information on some specific events in the history of life: human evolution and the origin of life.

THE FAMILY TREE

The process of evolution produces a pattern of relationships between species. As lineages evolve and split and modifications are inherited, their evolutionary paths diverge. This produces a branching pattern of evolutionary relationships.

By studying inherited species' characteristics and other historical evidence, we can reconstruct evolutionary relationships and represent them on a "family tree," called a phylogeny. The phylogeny you see below represents the basic relationships that tie all life on Earth together.

An interactive H5P element has been excluded from this version of the text. You

can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=90#h5p-88

THE THREE DOMAINS

This tree, like all phylogenetic trees, is a hypothesis about the relationships among organisms. It illustrates the idea that all of life is related and can be divided into three major clades, often referred to as the three domains: Archaea, Bacteria, and Eukaryota. We can zoom in on particular branches of the tree to explore the phylogeny of particular lineages, such as Animalia (outlined in red). Then we can zoom in even further to examine some of the major lineages within Vertebrata. Just click the button in the center of the image below.

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https://openbooks.lib.msu.edu/isb202/?p=90#h5p-89

The tree is supported by many lines of evidence, but it is probably not flawless. Scientists constantly reevaluate hypotheses and compare them to new evidence. As scientists gather even more

data, they may revise these particular hypotheses, rearranging some of the branches on the tree. For example, evidence discovered in the last 50 years suggests that birds are dinosaurs, which required adjustment to several "vertebrate twigs."

UNDERSTANDING PHYLOGENIES

The following diagram describes the different components of phylogenetic trees. Click on the Information tab in each box to learn more!

An interactive H5P element has been excluded from this version of the text. You can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=90#h5p-90

For additional help on understanding phylogenies, see Learn.Genetic's "Tree Diagrams" video and "Tree Diagrams" interactive.

Exercise

Let's see what you learned!

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=90#h5p-91

You can also go back to the HHMI Biointeractive's Lizard Evolution lab. Once you launch the interactive, click on the module tab to the left, and select "Module 2: Phylogeny."

Want even more practice? Try Nova Lab's The Evolution Lab!

ATTRIBUTION

This chapter is a modified derivative of Understanding Evolution. 2020. University of California Museum of Paleontology. 22 August 2008 <http://evolution.berkeley.edu/>.

CHAPTER 14

Reproduction

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Define and identify examples of sexual and asexual reproduction.
- Explain how cell division is a part of reproduction.
- Describe and identify from real photos what happens to chromosomes during mitosis and meiosis.
- Define and identify sex cells.
- Define fertilization.
- Distinguish between chromatid replicates and chromosome pairs.

Note on Sex and Gender

This chapter highlights topics regarding reproduction and sex and does not refer to gender, which is a different concept.

Sex refers to a set of biological attributes in humans and animals. It is primarily associated with physical and physiological features including chromosomes, gene expression, hormone levels and function, and reproductive/sexual anatomy. Sex is usually categorized as female or male but there is variation in the biological attributes that comprise sex and how those attributes are expressed.

Gender refers to the socially constructed roles, behaviors, expressions, and identities of girls, women, boys, men, and gender-diverse people. It influences how people perceive themselves and each other, how they act and interact, and the distribution of power and resources in society. Gender identity is not confined to a binary (girl/woman, boy/man) nor is it static; it exists along a continuum and can change over time. There is considerable diversity in how individuals and groups understand, experience, and express gender through their roles, the expectations placed on them, relations with others, and the complex ways that gender is institutionalized in society.

SEXUAL AND ASEXUAL REPRODUCTION

Reproduction is the production of offspring. This can happen in a variety of ways and is usually separated into sexual and asexual reproduction.

Sexual reproduction: Reproduction giving rise to offspring that have genetically unique combinations of genes (involves meiosis, a cell division process that creates sex cells).

Asexual reproduction: Reproduction that results in offspring that is genetically identical to the reproducing individual. Note that this is a different term than human asexual identity.

Exercise

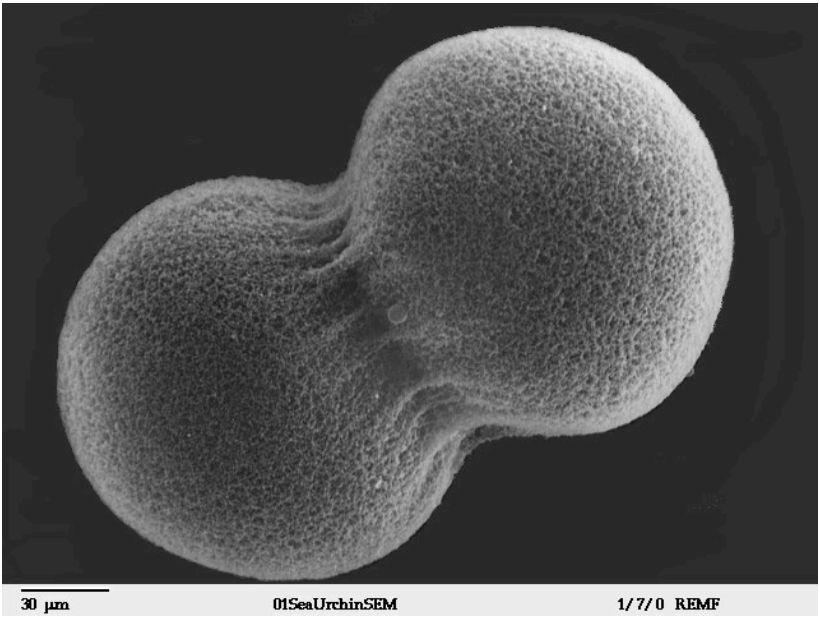
Consider the definitions of sexual and asexual reproduction above as you complete the following exercise.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=335#h5p-148

The rest of this section goes into more detail of the differences between sexual and asexual reproduction at the cellular level.

CELL DIVISION

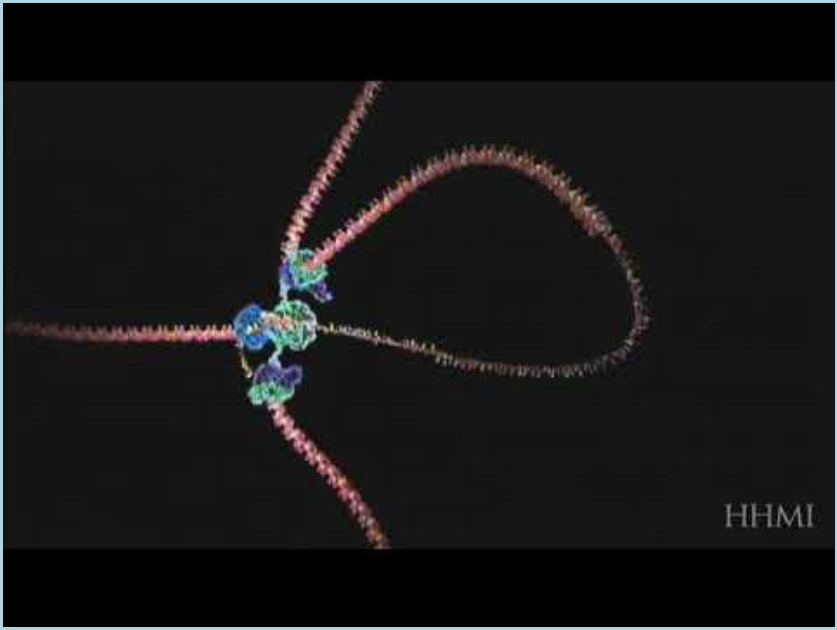
Reproduction requires cell division- either for creating sex cells (for sexual reproduction) or the reproduction itself (asexual reproduction). Cell division is when one cell divides into two- as the image below is illustrating. But, what happens in the cell during cell division?



Scanning electron microscope image of Lytechinus pictus [sea urchin] embryo entering the 2-cell stage.

DNA REPLICATION

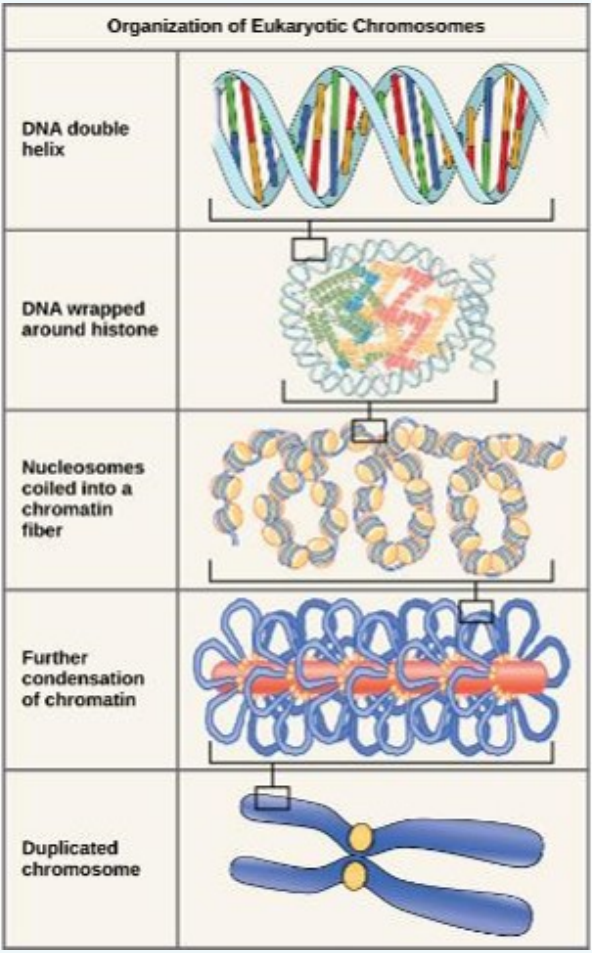
As a cell prepares for division, some of the organelles duplicate-often by dividing. One of the key processes that need to happen is for the DNA to duplicate, or as it is often referred to as, replicate. What would happen if the DNA did not duplicate before cell division? Recall from an earlier chapter that every DNA molecule contains genes. If all of these genes were not replicated, then only some of them would go to one cell and others to another cell and the cell would not have the complete map to create the proteins it needs to survive and function.



A YouTube element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=335

CHROMOSOMES

See the chapter Gene Expression Overview to review content on eukaryotic DNA and chromosomes. Below is a graphic that shows how DNA is packaged into a chromosome.



*Organization of a **eukaryotic** chromosome: Double-stranded DNA wraps around*

histone proteins to form nucleosomes that create the appearance of "beads on a string." The nucleosomes are coiled into a 30-nm chromatin fiber. When a cell prepares for division, the chromosomes condense even further.

After DNA replicates, it condenses into visible (under a microscope, that is) chromosomes. The original molecule and its replicate bind together forming one chromosome that is composed of two chromatids.

Exercise

Complete the exercise below based on this fact: After DNA replicates, the chromatids of the original and new DNA molecules bind together.

Note: The term "***chromosome***" is used to describe two chromatids (i.e., two DNA molecules) bound together or a single chromatid (i.e., one DNA molecule).

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https://openbooks.lib.msu.edu/isb202/?p=335#h5p-143

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TYPES OF CELL DIVISION

After the DNA is replicated, the cell finishes preparing for division (e.g., proteins needed for division are synthesized). Cell division results in new cells. During binary fission and mitosis, it results in two identical cells that are also identical to the parent cells. Meiosis, on the other hand, results in four unique cells.

Binary Fission and Mitosis

Binary fission is a form of reproduction that produces two unicellular offspring that are identical to each other and the parent cell. When the parent cell has a nucleus (and therefore, cell division includes the division of a nucleus), it is called ***mitosis***.

Note: The term "binary fission" can be confusing. Often, it is used to

explain asexual reproduction in bacteria and other organisms that do not have a nucleus. However, the term is sometimes used to explain reproduction in unicellular organisms that do have a nucleus (e.g., unicellular algae) and even some multicellular plants. In these cases, the full phrase is "binary fission by mitosis." Additionally, some organisms reproduce via "multiple fission by mitosis," such as amoeba. Confusing, right? For our purposes, we will use "binary fission" to describe asexual reproduction without mitosis, which occurs in bacteria and other organisms that do not contain a nucleus.

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The rest of this section will focus on eukaryotic cells (i.e., cells with a nucleus and more than one chromosome), which divide via mitosis. Mitosis occurs for three main reasons:

- Asexual reproduction: creates two identical, unicellular offspring
- Growth: a multicellular organism produces more cells as it grows

- Repair: old cells are replaced via the division of live cells

The main processes that occur in mitosis are that the chromosomes (those with two identical chromatids- the original and replicate DNA molecules) line up in the middle of the cell and the chromatids are pulled apart from one another by spindles and move to opposite sides of the cell. Once this happens, the same DNA exists in both halves of the cell and the cell can divide into two.

The video below illustrates what this separation of paired chromatids looks like.

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The next video (Inoue, Bajer, and Mole-Bajer, 2011) illustrates what happens to the chromatids; the spindle fibers are not visible. The video begins right after the DNA condenses into chromatids after DNA replication. It illustrates the chromatids continuing to condense and gradually travel to the center of the cell. Once in the center (halfway through the video), it almost looks like the chromosomes duplicate, but it is actually just the chromatids separating from one another. Once they separate, a cell membrane begins to form in the middle and the chromatids become less condensed and, therefore, more difficult to see. A nuclear envelope/membrane forms around the genetic material on each side.

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Exercise

Complete the following activity after viewing the videos above.

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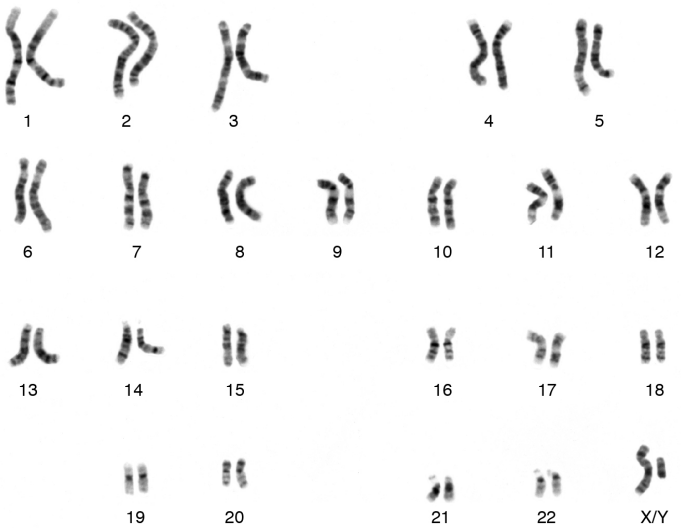
Meiosis

Unlike binary fission and mitosis, meiosis includes two rounds of cell division and produces four, unique cells. This ***process creates sex cells*** (or in the case of plants, the precursors of sex cells).

There are two main events that occur during meiosis:

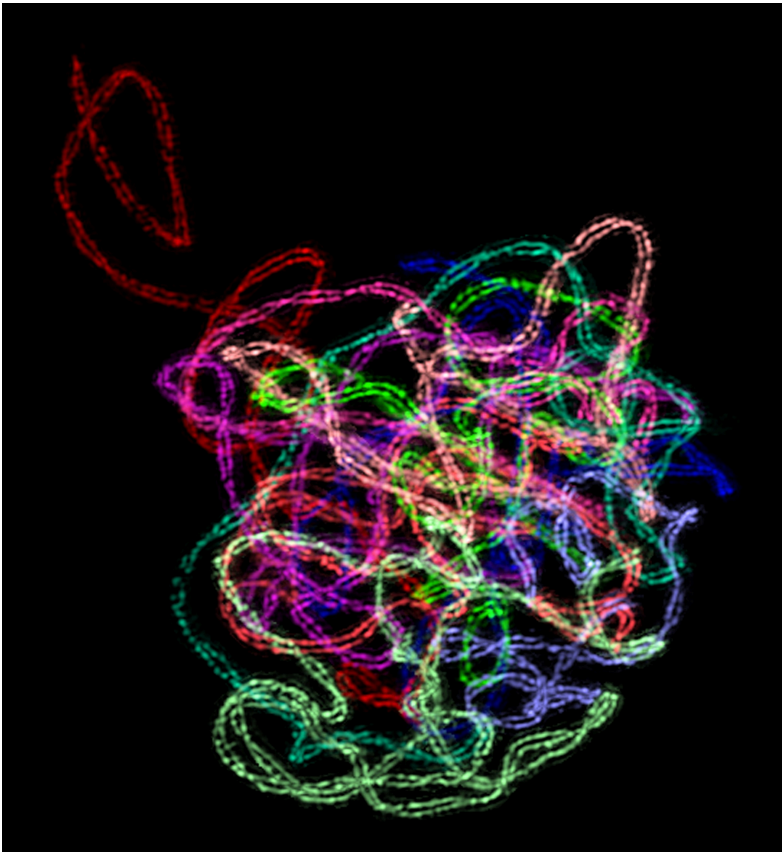
1. The ***separation of chromosomes*** that have ***similar*** genetic information.
2. The ***separation of identical chromatids*** (similar to mitosis).

Most organisms that reproduce sexually have two sets of every gene- albeit, different variations of these genes. This is because they receive genetic material from two parents. Because genes are located on chromosomes, the chromosomes of these offspring can be paired according to the genes located on them.



An organized representation of human chromosomes. The number of chromosome pairs varies species-to-species; humans have 23 pairs. For each chromosome pair, one chromosome came from the female parent and the other from the male parent. Each pair of chromosomes contain different variations of the same genes. The exception is the X/Y, which are the sex chromosomes.

Before meiosis begins, the chromosomes with the same genes pair up. These chromosome pairs will be separated into different cells during the first cell division of meiosis.



3D image of pairing chromosomes in preparation of meiosis. Proteins that aid in pairing are illuminated in this image, which line along every chromosome.

Under the microscope, the separation of the chromosome pairs looks similar to separating identical chromatids. During this first division of meiosis, rather than ***chromosomes*** forming a single line that then divides into separate chromatids, the ***chromosome pairs*** line up and the pairs are separated from each other.

The video (Oldenbourg and LaFountain , 2010) below begins with the chromosome pairs lined up in the middle of the cell and then

they are separated by spindle fibers. These cells are from an insect spermatocyte.

A video element has been excluded from this version of the text. You can watch it online here: https://openbooks.lib.msu.edu/isb202/?p=335

Exercise

Complete the following activity after reading the above information and watching the video.

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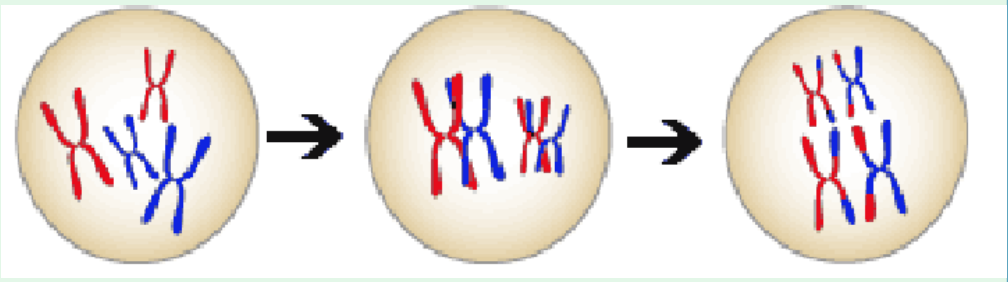
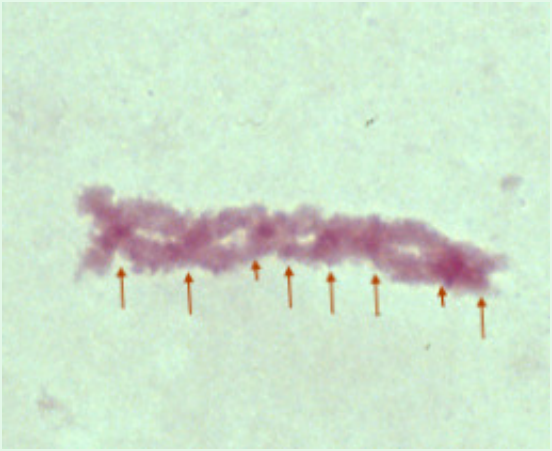
Chromosome Recombination Increases Genetic Diversity

Before meiosis officially begins, not only does the DNA replicate, creating chromatid replicates that bind together, recombination occurs. Recombination introduces new gene combinations into populations by “crossing” over chromosomes of the same pair. That

is, once the chromosomes find their matched pairs, they exchange some DNA with each other. The exchange is variants of the same genes- so offspring still receive the full instructions to produce it. Because of this shuffling, genes from the parent's female parent and genes from the parent's male parent can wind up next to one another on the same stretch of DNA. ***This is why meiosis produces four unique cells- not two sets of two unique cells.***



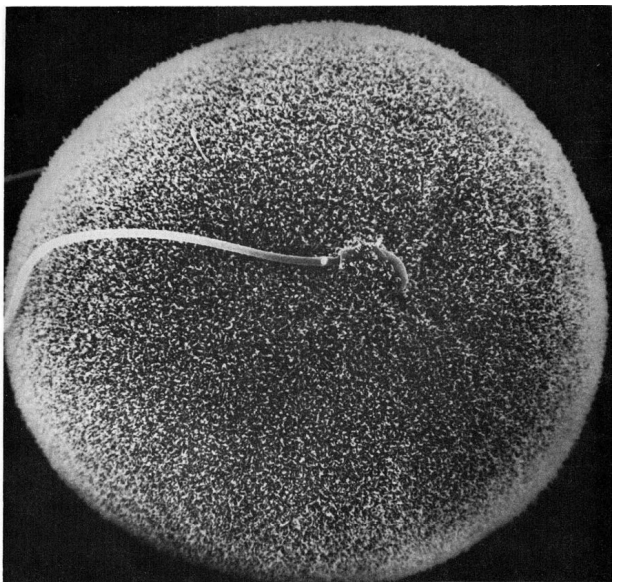
This graphic illustrates chromosome recombination (also called "crossing over." The red chromosomes are from one parent and the blue chromosomes are from the other parent. As the cell prepares for meiosis, the chromosome pairs come together and parts of the chromatids from one parent exchange with the other parent. Note that in this situation, "parent" refers to the parents of the individual that is producing the sex cells- it is not fertilization.



Photograph of one chromosome pair from the cell depicted in the above meiosis interactive. There are several recombination (i.e., crossing-over) events occurring for this one chromosome pair- the arrows in the image are pointing to those events.

SEX CELLS

Most sexually reproducing species have two sex cell types that differ in size: egg and sperm. Egg and sperm for each species are identified by the size of the sex cell rather than the characteristics of the individual possessing the sex cells: egg cells are larger than sperm cells. The difference in size is due to how the cytoplasm- the material in the cell- in a cell divides. For sperm cells, during meiosis, the cytoplasm divides evenly across the four cells. For egg cells, most of the cytoplasm goes into one cell; the other three that are produced via meiosis cannot be fertilized.



Sperm fertilizing an egg. The large sphere is the egg and the thin fiber with a head going across it horizontally is the sperm. Notice the difference in size between these two sex cells.

Some individuals only produce one type of sex cell (identified as males or females) while others may produce both sperm and eggs. Those that produce both types are called hermaphrodites- either sequential (they can switch from producing one sex to producing another sex cell) or simultaneous they can produce both sex cells at one time).

FERTILIZATION AND EARLY EMBRYONIC DEVELOPMENT

In sexually reproducing species, two sex cells- that are two different types, such as sperm and egg- combine to produce a single cell (called a zygote) with a nucleus.

Human fertilization: an egg cell surrounded by a few sperm cells.

In most animals and other multicellular organisms, fertilization is followed by mitosis for growth. The following video (Inoue, Sardet, and Speksnijder, 2011) illustrates fertilization and early embryonic development.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=335#h5p-149

ATTRIBUTIONS

This chapter is a modified derivative of the following sources:

Canadian Institutes of Health Research. (2020). What is gender? What is sex? This text is a modified derivative of the version available on the *CIHR website*.

Understanding Evolution. University of California Museum of Paleontology. "Sex and genetic shuffling: The details." 10 August 2021 http://evolution.berkeley.edu/evolibrary/news/060101_batsars

Webster, A., Zemenick, A., & Jones, S. (n.d.). Inclusive and accurate approaches for teaching sex and gender in biology. From *Biodiversify* https://projectbiodiversify.org/definitions/

VIDEOS

Rudolf Oldenbourg, James R. LaFountain (2010) CIL:9064, *Nephrotoma suturalis*, spermatocyte. CIL. Dataset. https://doi.org/doi:10.7295/W9CIL9064 Public domain.

Shinya Inoue, A.S. Bajer, J. Mole-Bajer (2011) CIL:11952, *Haemanthus katharinae*, endosperm. CIL. Dataset. https://doi.org/doi:10.7295/W9CIL11952 CC BY-NC-SA.

Shinya Inoue, Lionel Jaffe, Christian Sardet, Johanna Speksnijder (2011) CIL:11962, Phallusia mammilata, egg. CIL. Dataset. https://doi.org/doi:10.7295/W9CIL11962 CC BY-NC-SA.

Thomas Maresca, Edward Salmon (2011) CIL:26271, Drosophila melanogaster. CIL. Dataset. https://doi.org/doi:10.7295/W9CIL26271 Public domain

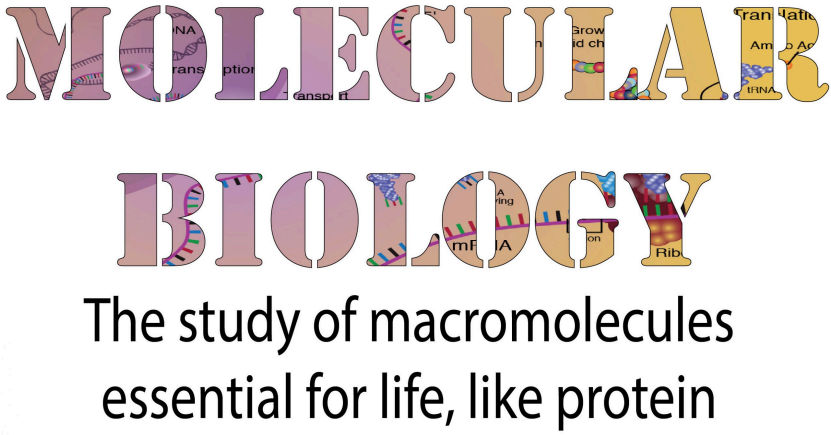
UNIT III

MOLECULAR BIOLOGY

CHAPTER 15

Introduction to Molecular Biology

ANDREA BIEREMA

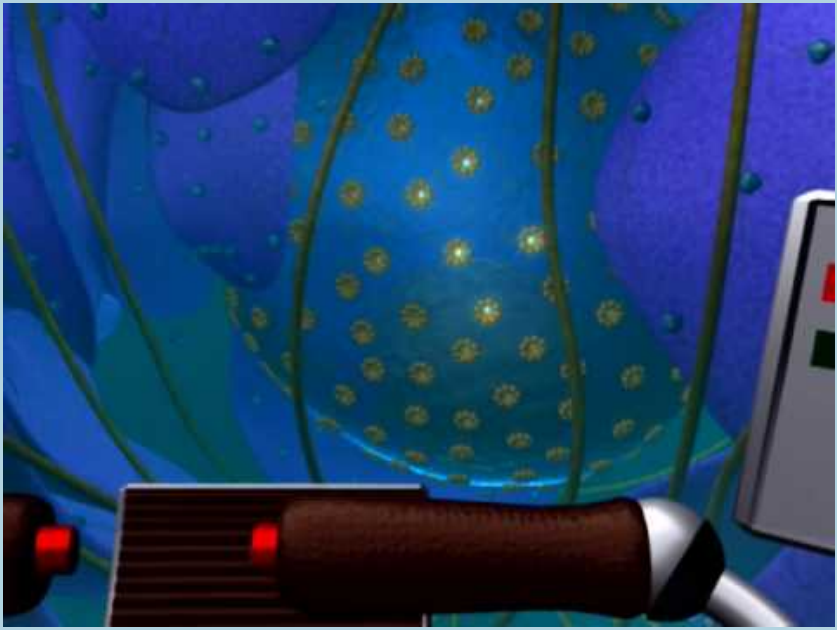


This unit addresses how DNA is read to create protein and that proteins determine an organism's characteristics. The first chapter

introduces proteins. Then the next several chapters describe in detail how proteins are synthesized. They are followed by a chapter that illustrates an example in which proteins are used: cell signaling. The unit ends with a discussion on how we as humans can sequence, modify and edit DNA—which then affects protein synthesis—via genetic engineering.

THE CELL

Review the main structures of a cell before continuing on to the next chapters. The following video gives a tour of the cell:



A YouTube element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=95

Additional Information

To take a closer look into the organelles of a cell, check out Genome Unlocking Life's Code animations!

MOLECULAR BIOLOGY

We cover a span of topics in this unit. To find out some of the basics of molecular biology and how they relate to one's life, watch the following video (the transcript is located below the video). It's an excellent animation!

A video element has been excluded from this version of the text. You can watch it online here: https://openbooks.lib.msu.edu/isb202/?p=95

Video transcript

- Inside each cell is a code of instructions for life… this is your genome. Unfolded, it is 6 feet long yet… 30,000 times thinner than a strand of hair… trimming it is not a good idea. All your cells have the same genome but different parts are active in different cells.
- Your genome is made of deoxyribonucleic acid (DNA). It is the parts list and instruction manual for life and can make a complete you from scratch. English uses 26 letters. Morse code uses 2. Computers use 2. Your genome uses 4 chemicals

(Adenine, Thymine, Guanine, and Cytosine) and forms words that are 3 letters long. Each word codes for a building block of a protein. The word TGA means stop and finishes a sentence. Each sentence in your genome is called a gene and codes for a protein.

- Genome codes for proteins. Proteins make us alive so that you can watch this film. You breathe, you move, you think because many proteins are working very hard. Your genome has billions of letters with 20,000 sentences coding for 20,000+ proteins. 2% of the genome codes for building proteins. 30% regulates when to build these proteins. A great part is unknown.
- Genome is a fancy word for all your DNA. Your genome makes you who you are. For example, the normal hemoglobin gene contains the word GAG. With a single letter, error hemoglobin folds differently causing sickle cell anemia.
- The way you live can influence how the genome works. Some genes increase the risk of adult diabetes. However, with diet and exercise, you can overcome the genome and prevent diabetes. Being a couch potato does not help your genome.
- DNA has two complementary strands: A always matches T and G always matches C. It's like an object and its mold pressed together... you can create one from the other. When the cell divides the strands replicate creating two double strands.
- If there is a matching error, a protein repairs it keeping the genome intact. With a faulty repair protein, errors accumulate...

this is the cause of many cancers. It's like having a horrible repairman wreck your home.

- During cell division, the genome gets condense into groupings called chromosomes. You get 23 from your father and 23 from your mother to make 23 pairs. If you get a faulty gene from one the good copy compensates... this is why you don't marry your sister. Many errors in DNA are harmless... they don't lead to disease and are passed on. Analyzing these errors you can trace a piece of DNA back to an individual. Useful to get suspects in and out of jail and also to trace ancestors.
- Your DNA is pretty durable... can last for 100,000 years if you don't get cremated.
- 99.9% of your genome is identical to the genome of the person next to you. Every living thing on Earth has DNA. Humans and mice are 85% similar. Humans and flies are 49% similar. Humans and bananas are 41% similar.
- You have a genome; therefore, you are alive.
- TGA = the end.
- Genome: unlocking life's code.

CHAPTER 16

Protein Structure and Function

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Explain how proteins result in an organism's traits.
- Explain the relationship between amino acids and proteins.
- Identify examples of proteins.
- Recognize that molecular structure determines molecular interactions and relates to the cellular functions of proteins.
- Describe how protein structure influences its function.
- Describe the relationship between mutation and evolution.

OVERVIEW

This chapter is titled "protein structure and function" because

protein structure heavily influences its function. The structure of a protein is caused by the chemical properties of its amino acids, which is coded by a DNA sequence (a gene).

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https://openbooks.lib.msu.edu/isb202/?p=104#h5p-142

This figure illustrates the insulin protein: part of its DNA sequence, part of its amino acid sequence, a representation of the protein, what the protein does, and the trait it causes. Hover over each image to learn more.

TRAITS

A trait is a specific characteristic of an organism, such as eye color or blood type. Traits can be determined by genes or the environment, or more commonly by interactions between them. The genetic contribution (i.e., the DNA) to a trait is called the genotype. The outward expression of the genotype, including visible and physiological traits, is called the phenotype.

PROTEINS

Proteins are coded and regulated by genes. These proteins, along with the environment, cause an organism's traits.

Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. Proteins may be structural, regulatory, contractile, or protective. They may serve in transport, storage, or membranes; or they may be toxins or enzymes. Each cell in a living system may contain thousands of proteins, each with a unique function. Their structures, like their functions, vary greatly. They are all, however, amino acid polymers arranged in a linear sequence (also referred to as a "peptide").

Protein types and functions:

Genetic Diseases

Learn more about protein function by checking out Learn.Genetic's "Examples of Single Gene Disorders", which describes how proteins are involved in various gene disorders.

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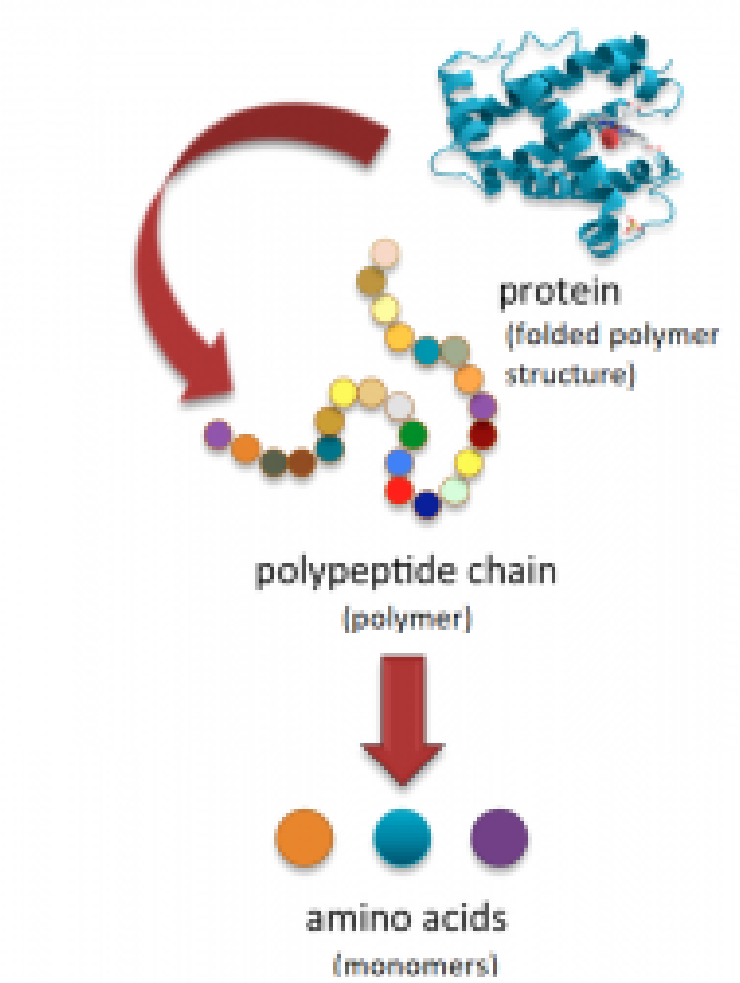
MONOMERS AND POLYMERS

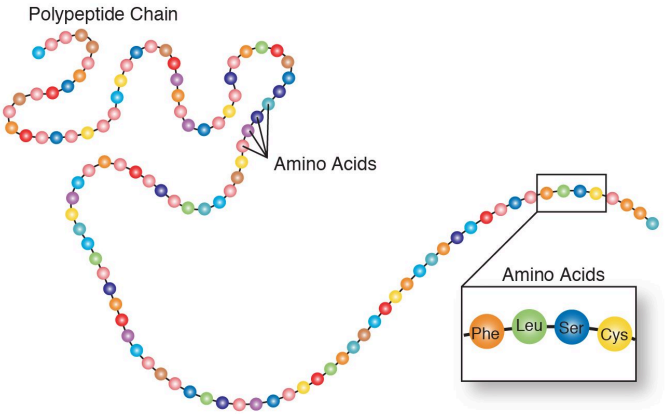
Monomers are molecules that can bind into long chains—these

long chains are called “polymers.” In other words, a polymer (“poly” = many) are made of monomers (“mono” meaning “one”).

Amino acids are the monomers that comprise polypeptides (polypeptides being the polymers). A polypeptide folds into a 3D structure called a protein. Scientists use the name “amino acid” because these acids contain both amino group and carboxyl-acid-group in their basic structure. As we mentioned, there are 20 common amino acids present in proteins. Nine of these are essential amino acids in humans because the human body cannot produce them and we obtain them from our diet. Below are two illustrations depicting the relationship between amino acids and polypeptides.



A protein is a folded polymer structure, which contains a polypeptide chain (polymer), which contains amino acids (monomers).



A polypeptide chain is chain composed of amino acids. There are 20 amino acids commonly found in organisms.

PROTEIN STRUCTURE

Example

For an interactive illustration of the protein structure levels, check out the protein folding simulation by

As mentioned above, a protein's shape is critical to its function. For example, an enzyme can bind to a specific substrate at an active site. If this active site is altered because of local changes or changes in overall protein structure, the enzyme may be unable to bind to the substrate. To understand how the protein gets its final shape or conformation, we need to understand the four levels of protein structure: primary, secondary, tertiary, and quaternary. See the image below and click on the information hotspots (labeled with an "i") for explanations.

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LabXchange, which uses hemoglobin as an example and describes the molecular structure in more detail.

As seen in the image above, a strand of amino acids folds on itself, creating a unique shape in the tertiary structure of the protein. This is caused by the chemical properties of the amino acids. The chemical properties of the amino acids determine how this shape occurs. For instance, each amino acid is negatively (-), positively (+), or neutrally (N) charged. Negatively charged amino acids bind with positively charged amino acids (neutrally charged amino acids are not affected). Also, the amino acid called cysteine contains sulfur and sulfurs easily bind with each other, creating a "disulfide bond." Because of this, cysteines bind with other cysteines. See the table below for a list of all 20 amino acids and their charges. There are other properties that also influence a protein's shape, such as the amino acid's polarity. Note that these bonds are not as strong as what is created between amino acids when an amino acid chain is created, but these bonds are strong enough to hold the shape in the protein.

A list of the 20 amino acids common in all living things. The table includes the full name and abbreviations of each amino acid as well as their charge (positive, negative, or neutral). It is also noted which one can create a disulfide bond.

Amino Acid	3-Letter Abbrev.	1-Letter Abbrev.	Charge	Disulfide Bond Formation?
Alanine	Ala	A	Neutral	
Arginine	Arg	R	Positive (+)	
Asparagine	Asn	N	Neutral	
Aspartate (Aspartic acid)	Asp	D	Negative (-)	
Cysteine	Cys	C	Neutral	Yes
Glutamine	Gln	Q	Neutral	
Glutamate (Glutamic acid)	Glu	E	Negative (-)	
Glycine	Gly	G	Neutral	
Histidine	His	H	Positive (+)	
Isoleucine	Ile	I	Neutral	
Leucine	Leu	L	Neutral	
Lysine	Lys	K	Positive (+)	
Methionine	Met	M	Neutral	
Phenylalanine	Phe	F	Neutral	
Proline	Pro	P	Neutral	
Serine	Ser	S	Neutral	
Threonine	Thr	T	Neutral	
Tryptophan	Trp	W	Neutral	
Tyrosine	Tyr	Y	Neutral	
Valine	Val	V	Neutral	

Exercise

Use the chart above to determine which amino acids may bond together to form the tertiary structure.

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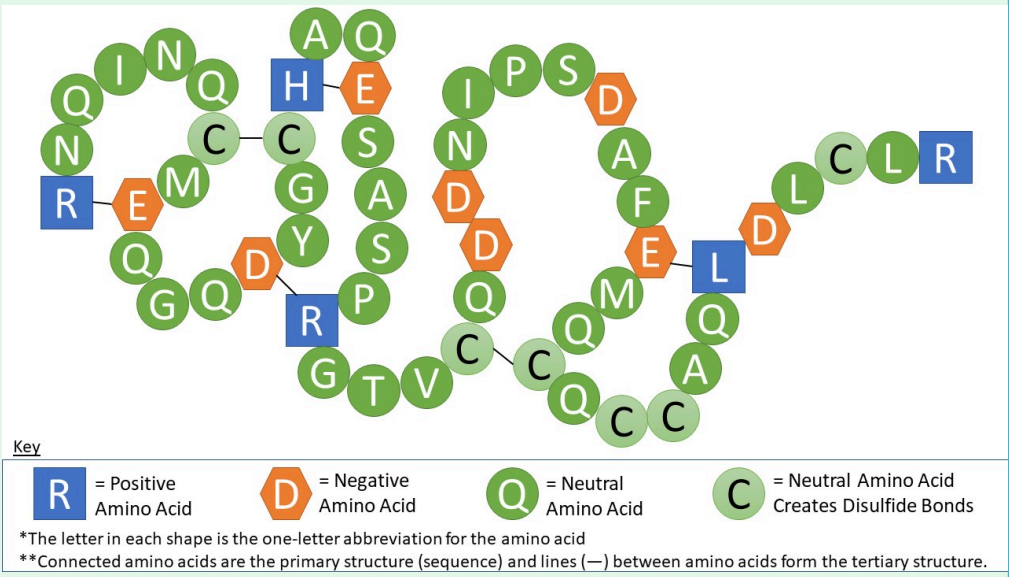
https://openbooks.lib.msu.edu/isb202/?p=104#h5p-94

Example

Here is an example of a polypeptide model depicting how charges influence the tertiary structure. The first and second images are the same, except the second image has hotspots with additional information marked with a question mark (?). The key at the bottom of the image is necessary for interpreting the image.



An example of a protein structure. Amino acids are represented by shapes. The sequence is the primary structure and the solid lines connecting amino acids illustrate how charges and disulfide bonds create the tertiary structure.

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MUTATIONS

Mutations can impact protein synthesis and amino acid sequence.

If these mutations are heritable, then they may influence the evolution of a species. Therefore, this chapter includes information on mutations and evolution.

WHAT ARE MUTATIONS?

Mutation is a change in DNA, the hereditary material of life. An organism's DNA codes for the production of proteins, which affects how it looks, how it behaves, and its physiology—all aspects of its life. So, a change in an organism's DNA can cause changes in all aspects of its life.

Mutation Examples

See Learn.Genetics' "The Outcome of Mutation" for descriptions of how specific traits are influenced by mutation.

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https://openbooks.lib.msu.edu/isb202/?p=104#h5p-140

The gene encoding the protein ultimately determines the unique sequence for every protein. A change in the nucleotide sequence of the gene's coding region may lead to adding a different amino acid to the growing polypeptide chain, causing a change in protein structure and function. In sickle cell anemia, the hemoglobin β chain has a single amino acid substitution, causing a change in protein structure and function. Specifically, valine in the β chain substitutes the amino acid glutamic. What is most remarkable to consider is that a hemoglobin molecule is comprised of two alpha and two beta chains that each consist of about 150 amino acids. The molecule, therefore, has

about 600 amino acids. The structural difference between a normal hemoglobin molecule and a sickle cell molecule—which dramatically decreases life expectancy—is a single amino acid out of the total 600. What is even more remarkable is that three nucleotides each encode those 600 amino acids and a single base change (point mutation)—1 in 1800 bases—causes the mutation.

This change to one amino acid in the chain causes hemoglobin molecules to form long fibers that distort the biconcave, or disc-shaped, red blood cells and causes them to assume a crescent, or "sickle," shape that clogs blood vessels. This can lead to a myriad of serious health problems such as breathlessness, dizziness, headaches, and abdominal pain for those affected by this disease.

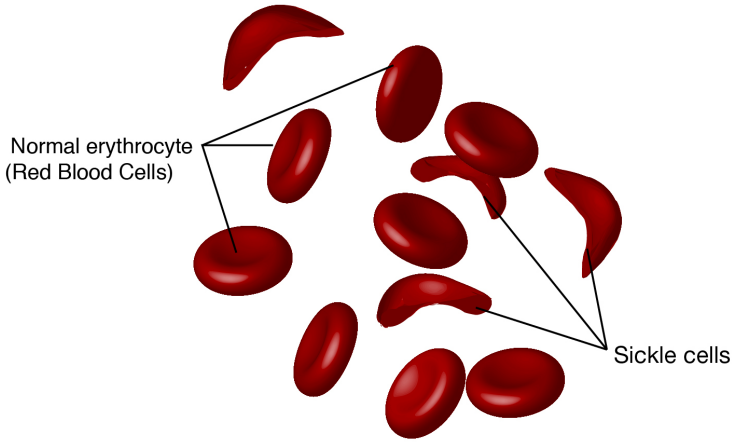


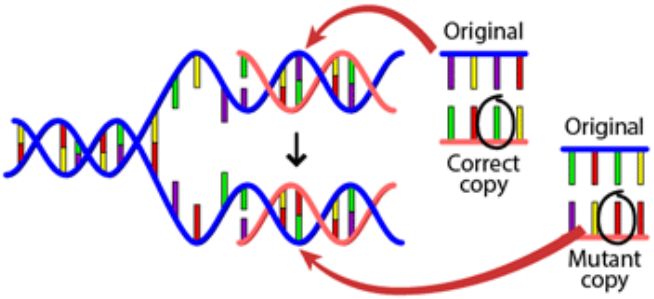
Illustration of normal and sickle cells.

THE CAUSES OF MUTATIONS

Mutations happen for several reasons:

- DNA fails to copy accurately: Most of the mutations that

we think matter to evolution are "naturally occurring." For example, when a cell divides, it makes a copy of its DNA and sometimes that copy is not quite perfect. That small difference from the original DNA sequence is a mutation.



Mutation can occur during DNA replication.

- External influences can create mutations: Mutations can also be caused by exposure to specific chemicals or radiation. These agents cause the DNA to break down. This is not necessarily unnatural—even in the most isolated and pristine environments, DNA breaks down. Nevertheless, when the cell repairs the DNA, it might not do a perfect job of the repair. So, the cell would end up with DNA slightly different than the original DNA and hence, a mutation.

EVOLUTION

Biological evolution, simply put, is descent with modification. This definition encompasses small-scale evolution (changes in gene—or, more precisely and technically, allele—frequency in a population from one generation to the next) and large-scale evolution (the descent of different species from a common ancestor over many generations). Evolution is responsible for both

the remarkable similarities we see across all life and the amazing diversity of that life, but how does it work?

For evolutionary mechanisms (such as natural selection) to act, there needs to be genetic variation and mutations, or changes, in the DNA. DNA codes for proteins, and when those proteins are produced, mutations create variation. Mutations can be beneficial, neutral, or harmful for the organism, but mutations do not "try" to supply what the organism "needs." In this respect, mutations are random—whether a particular mutation happens or not is unrelated to how useful that mutation would be.

Because all cells in our body contain DNA, there are lots of places for mutations to occur; however, not all mutations matter for evolution. Somatic mutations occur in non-reproductive cells and won't be passed onto offspring. Mutations can also be caused by exposure to specific chemicals or radiation. These agents cause the DNA to break down. This is not necessarily unnatural—even in the most isolated and pristine environments, DNA breaks down. Nevertheless, when the cell repairs the DNA, it might not do a perfect job of the repair. So the cell would end up with DNA slightly different than the original DNA and hence, a mutation.

A single germline mutation can have a range of effects:

- *No change occurs in phenotype*: Some mutations don't have any noticeable effect on the phenotype of an organism. This can happen in many situations: perhaps the mutation occurs in a stretch of DNA with no function, or perhaps the mutation occurs in a protein-coding region but ends up not affecting the amino acid sequence of the protein.

Cat with curled ears, which was caused by a mutation.

- *Small change occurs in phenotype*: A single mutation caused this cat's ears to curl backward slightly.
- *Big change occurs in phenotype*: Some really important phenotypic changes, like DDT resistance in insects, are sometimes caused by single mutations. A single mutation can also have strong negative effects for the organism. Mutations that cause the death of an organism are called lethals—and it doesn't get more negative than that.

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There are some sorts of changes that a single mutation, or even

a lot of mutations, could not cause. Neither mutations nor wishful thinking will make pigs have wings; only pop culture could have created the Teenage Mutant Ninja Turtles—mutations could not have done it.

See the "Evolution" chapter in this textbook for more information.

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

"Biological Molecules" by OpenStax College, Biology, CC BY 4.0. Download the original article for free at https://openstax.org/books/biology-2e/pages/3-4-proteins

"Trait" by National Human Genome Research Institute, National Institutes of Health, *Talking Glossary of Genetic Terms.*

Understanding Evolution. 2020. University of California Museum of Paleontology. 16 July 2020 <http://evolution.berkeley.edu/>. Published with permission.

CHAPTER 17

Gene Expression Overview

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Describe the structure and purpose of DNA and RNA.
- Describe the general process of protein synthesis.
- Describe the molecular anatomy of genes and genomes.
- Identify DNA and mRNA bases and binding patterns.
- Interpret a codon-amino acid chart.
- Given a DNA sequence, determine the corresponding mRNA sequence and amino acid sequence.

WHAT IS A GENE?

The gene is the basic physical unit of inheritance. Genes are passed from parents to offspring and contain the information needed to specify traits. Genes are arranged, one after another, on structures called chromosomes. A chromosome contains a single, long DNA molecule- only a portion of which corresponds to a single gene- as well as the structural proteins (called histones) that the DNA molecule wraps around. Humans have approximately 20,000 genes arranged on their chromosomes. Watch the following brief video for an animated view of the relationship between chromosomes and genes.

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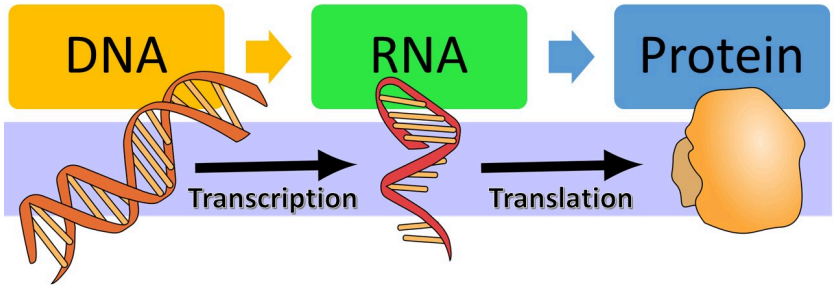
https://openbooks.lib.msu.edu/isb202/?p=108#h5p-141

CENTRAL DOGMA

The central dogma of molecular biology is that DNA codes for RNA and RNA codes for protein. In addition to DNA coding for RNA, much of the DNA regulates the synthesis of RNA- which ultimately means that it regulates the synthesis of protein. We will learn about gene regulation in later chapters.

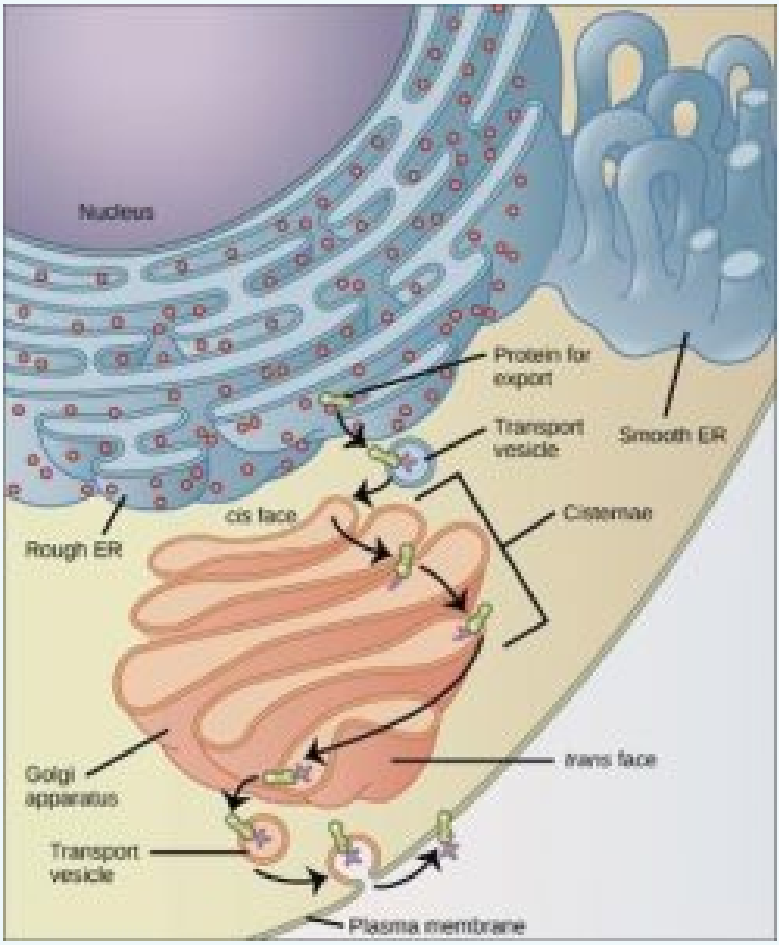


The central dogma states that DNA is used to make RNA via transcription, which is used to make protein via translation.

Because proteins are coded by genes, the term "***gene expression***" refers to protein synthesis (i.e., making proteins), including the ***regulation*** of that synthesis.

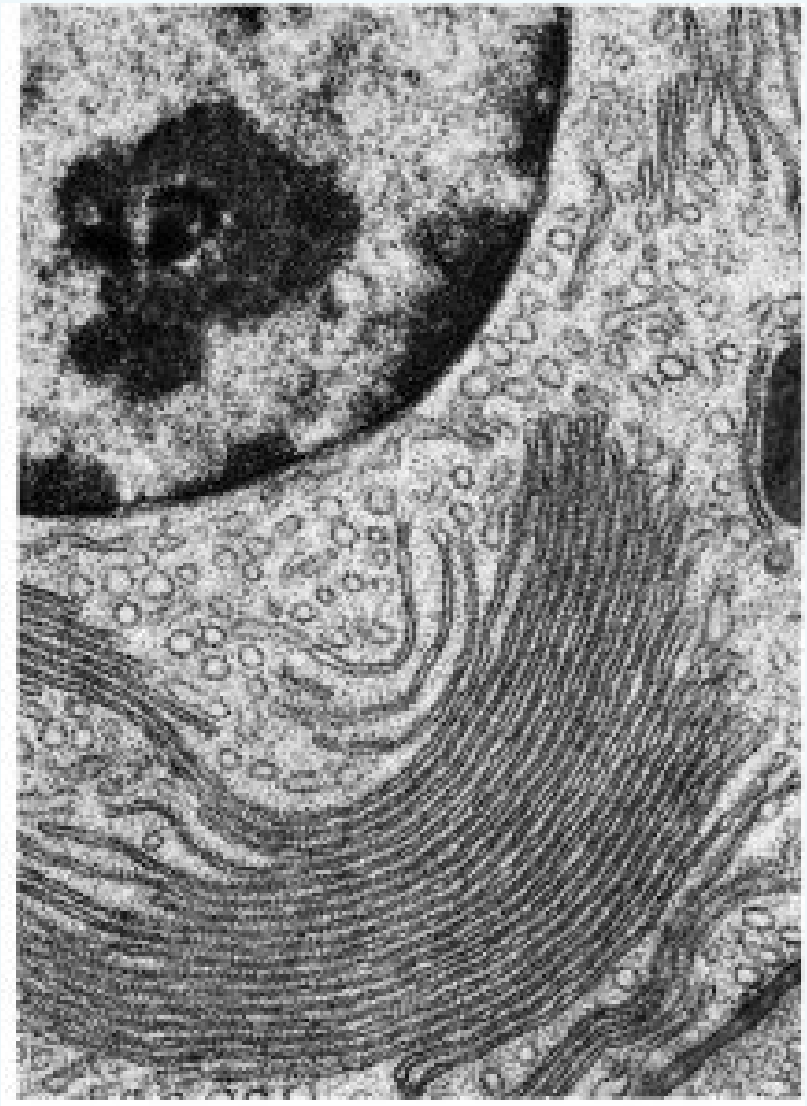
There are two main processes that must occur to synthesize proteins: transcription and translation. During the process of ***transcription***—which occurs in the nucleus—an mRNA molecule is created by reading the DNA. Note that DNA never "becomes" RNA; rather, the DNA is "read" to make an RNA molecule. The mRNA leaves the nucleus and then, through the process of ***translation***, the mRNA is read to create an amino acid sequence that folds into a protein.

Transcription occurs in the nucleus and translation occurs outside of the nucleus at the ribosomes (which are either in the cytoplasm or attached to the rough endoplasmic reticulum. Below is a micrograph image that was taken of this area and the other is a cartoon representation.



Cartoon image of the nucleus and rough ER (it is "rough" because ribosomes are attached it). This cartoon also shows what can happen to protein after it is

produced, which is leave the cell through vesicles.



Electron micrograph of part of the nucleus and the rough endoplasmic reticulum (RER) in an acinar cell from the pancreas of the small brown bat, Myotis lucifugus. The nucleus of the cell is in the upper left corner; the RER in the lower half of the micrograph is stacked and studded with ribosomes. Figure 168 from Chapter 5 (Endoplasmic Reticulum) of 'The Cell, 2nd Ed.' by Don W. Fawcett M.D.

Consider what the terms "transcribe" and "translate" mean in relation to language. To "transcribe" something means to rewrite text again in the same language while to "translate" something means to rewrite the text in a different language. Similar to these meanings, in biology, ***DNA is transcribed into RNA: both DNA and RNA are made of nucleic acid*** (i.e., the same "language"). With the assistance of proteins, DNA is "read" and transcribed into an mRNA sequence. To read RNA and create protein, though, we refer to it as being translated: ***RNA is made of nucleic acid, and protein is made of amino acids (i.e., different "languages")***. Therefore, DNA is transcribed to create an mRNA sequence, and then the mRNA sequence is translated to make a protein.

DNA AND RNA

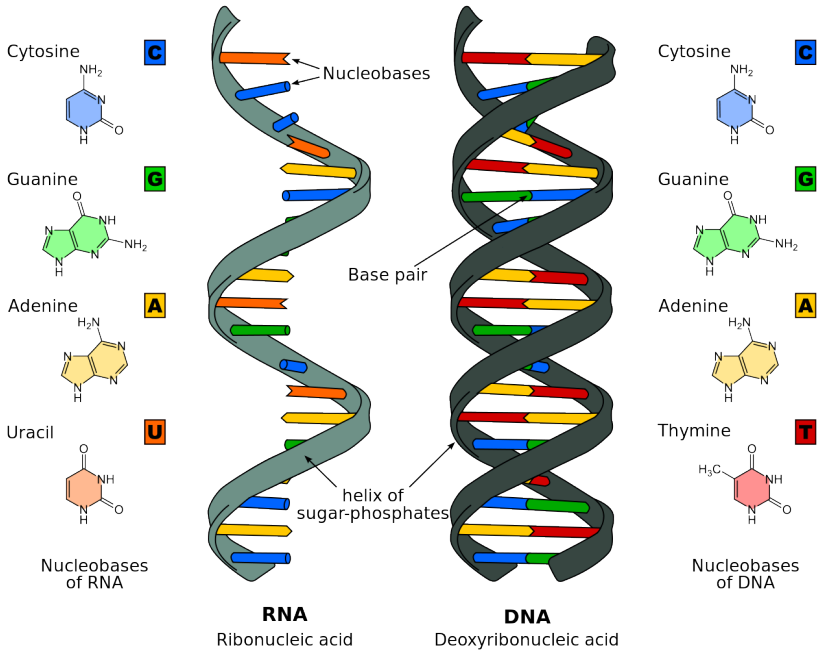
The two main types of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). As described earlier in this chapter, DNA is the genetic material in all living organisms, ranging from single-celled bacteria to multicellular mammals. It is in the nucleus of eukaryotes and in the organelles mitochondria and

chloroplasts. In prokaryotes, the DNA is not enclosed in a membranous envelope.

The ***cell's entire genetic content is its genome***, and the study of genomes is genomics. In eukaryotic cells but not in prokaryotes, a DNA molecule may contain tens of thousands of genes. Many genes contain information to make protein products (e.g., mRNA). Other genes code for RNA products. DNA controls all of the cellular activities by turning the genes "on" or "off."

The other type of nucleic acid, RNA, is mostly involved in protein synthesis. ***The DNA molecules never leave the nucleus*** but instead use an intermediary molecule to communicate with the rest of the cell. This ***intermediary is the messenger RNA (mRNA)***. Other types of RNA—like rRNA, tRNA, and microRNA—are involved in protein synthesis and its regulation.

DNA and RNA are comprised of ***monomers*** that scientists call ***nucleotides***. The nucleotides combine with each other to form a ***polynucleotide***, DNA or RNA. Three components comprise each nucleotide: a nitrogenous base, a pentose (five-carbon) sugar, and a phosphate group. Each nitrogenous base in a nucleotide is attached to a sugar molecule, which is attached to one or more phosphate groups. Therefore, although the terms "base" and "nucleotide" are sometimes used interchangeably, a nucleotide contains a base as well as part of the sugar-phosphate backbone.



Comparison of the molecular structure of RNA and DNA.

Comparison of RNA (left molecule) and DNA (right molecule). The color of the bases in RNA and DNA aligns with the colored boxes next to each base molecule.

Exercises

Examine the image above and then answer the following questions:

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PROTEIN SYNTHESIS OVERVIEW

The two main processes in protein synthesis are transcription and translation. The following is an overview of each of these processes.

Each process will be described in more detail in future chapters. Note that the rest of this textbook will focus on what happens in eukaryotic cells. Please see this page by Lumen for details on prokaryotic gene expression.

TRANSCRIPTION

A gene is complex: it contains not only the code for the resulting protein but also several regulatory factors that determine if and when the region that codes for a protein are read to create protein. What follows is a diagram of the components of a gene that are used in transcription.

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This textbook focuses on the DNA and the ending product of transcription: mRNA.

Exercise

Given a specific DNA strand, what is the sequence of the resulting mRNA molecule? We will learn about how mRNA is created in a later chapter.

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TRANSLATION

Translation involves different types of RNA, and we will explain them in more detail in later chapters: rRNA, tRNA, mRNA, and microRNA.

After an mRNA is created, it leaves the nucleus and is attracted

to or attracts a ribosome, which is a molecule made of rRNA and polypeptides. Then, in the ribosome, and with the assistance of tRNAs, the mRNA is read and an amino acid sequence is created.

DNA and mRNA create sequences with just four types of bases; yet, these bases code for 20 unique amino acids (the makeup of protein). How is this possible? Watch the following video to find out!

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For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

The mRNA is read in sets of three bases known as codons. Each codon codes for a single amino acid. In this way, the mRNA is read and the protein product is made.

Below is a chart showing which codons code for which bases. There are two representations; move to the next slide for the second representation.

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can view it online here:

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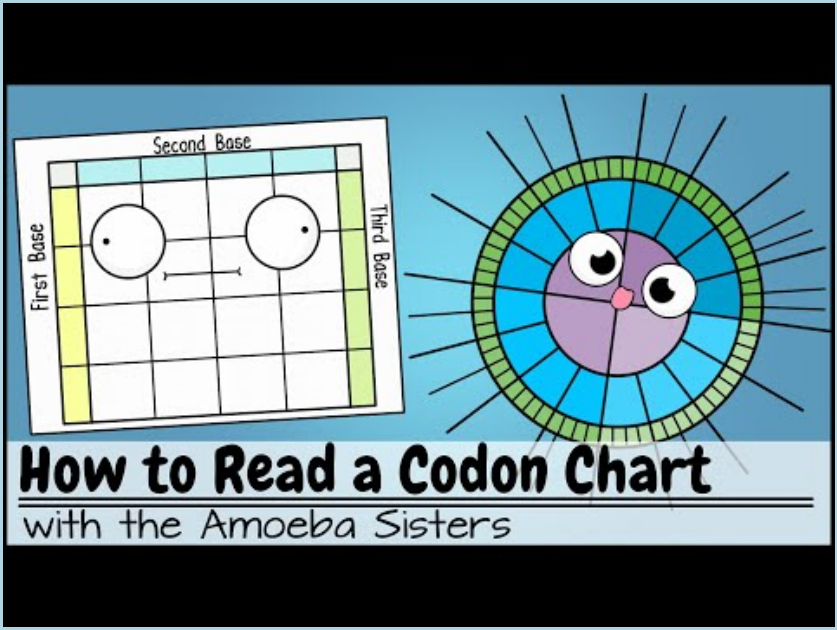
These charts can be a little confusing at first. Watch the following video to learn how to interpret both chart formats.



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Exercise

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CONCLUSION

This chapter focused on DNA, mRNA, and protein sequences. The next several chapters describe gene expression processes- both protein synthesis and regulation of that synthesis. Master how sequences are read during protein synthesis (the focus of the current chapter) before moving on to the next chapter. Below are some sources to help further your understanding!

Example

Check out Learn.Genetics' "How a Firefly's Tail Makes Light" video for an overview of protein synthesis!

Exercises

Need a little more practice?

Try out Learn.Genetics' "Transcribe and Translate a Gene" and The Concord Consortium's "DNA to Protein" interactives for further practice!

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

"Gene" by National Human Genome Research Institute, National Institutes of Health, *Talking Glossary of Genetic Terms.*

"Nucleic Acids" by OpenStax College, Biology 2e, CC BY 4.0. Download the original article at https://openstax.org/books/biology-2e/pages/3-5-nucleic-acids

CHAPTER 18

Protein Synthesis I: Transcription

ANDREA BIEREMA

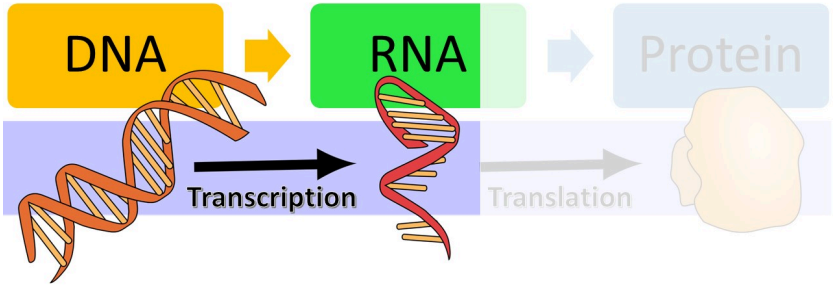
Learning Objectives

Students will be able to:

- Explain the processes necessary for transcription to begin.
- Explain how DNA is transcribed to create an mRNA sequence.
- Describe the role of polymerase in transcription.
- Recognize that protein synthesis regulation (i.e., changes in gene expression) allow cells to respond to changes in the environment.
- Explain which gene-expression regulatory factors are at play for transcription.

OVERVIEW

This chapter focuses on how transcription works; that is, how information coded in the DNA molecule is read to create an mRNA sequence. Please see the previous chapter for a general overview of transcription and DNA and RNA bases before continuing to read this chapter.



Transcription is the process of creating an mRNA sequence by "reading" the DNA sequence.

THE PROCESS OF TRANSCRIPTION: A FIRST LOOK

Let's first look at a basic overview of what the process of transcription looks like. At the beginning of the following video, you will see that transcription is regulated by a variety of proteins. By "regulation", we mean that certain proteins are needed for transcription to start and some proteins can even prevent transcription from happening. Transcription is happening throughout your body all of the time, but not every gene is constantly being transcribed in every cell; it is regulated by different proteins and depends on which proteins your body needs in which cells.

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For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Exercise

Now that you have watched a basic overview of transcription, test your knowledge with the following activity in which you will place the following transcription steps in the correct order.

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https://openbooks.lib.msu.edu/isb202/?p=117#h5p-107

ROLE OF THE POLYMERASE

The polymerase is an enzyme—and a protein—that aids in the transcription process. The polymerase was depicted in the previous video. Now let's look more closely at what is happening within the polymerase in relation to the steps described previously.

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TRANSCRIPTION REGULATION

The overview above depicted components of transcription regulation. Basically, there are proteins that have to bind to the DNA, and each other, before the polymerase can begin transcription.

There are many steps along the way of protein synthesis and gene expression is regulated. Gene expression is when a gene in DNA is "turned on," that is, used to make the protein it specifies. Not all the genes in your body are turned on at the same time or in the same cells or parts of the body.

For many genes, transcription is the key on/off control point: if a gene is not transcribed in a cell, it can't be used to make a protein in that cell.

If a gene does get transcribed, it is likely going to be used to make

a protein (i.e. expressed). In general (but not always) the more often a gene is transcribed, the more protein that will be made.

Various factors control how much a gene is transcribed. For instance, how tightly the DNA of the gene is wound around its supporting proteins to form chromatin can affect a gene's availability for transcription.

Proteins called transcription factors, however, play a particularly central role in regulating transcription. These important proteins help determine which genes are active in each cell of your body.

TRANSCRIPTION FACTORS

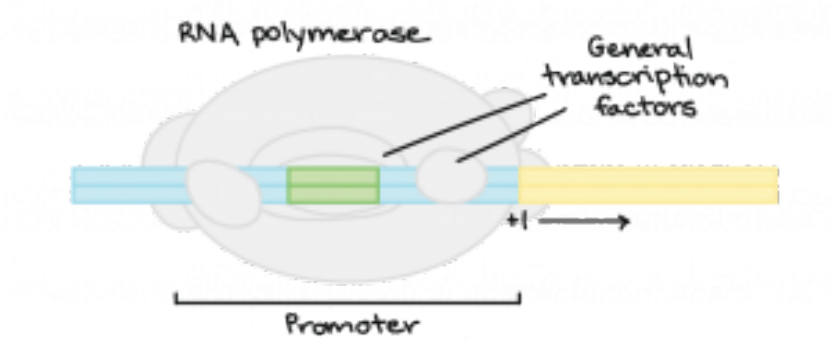
More information

In bacteria, RNA polymerase attaches right to the DNA of the promoter. You can see how this process works, and how it can be regulated by transcription factors, in the *lac* operon an

What has to happen for a gene to be transcribed? The enzyme **RNA polymerase**, which makes a new RNA molecule from a DNA template, must attach to the DNA of the gene. It attaches to a spot called the **promoter**.

The RNA polymerase can attach to the **promoter** only with the help of proteins called **general transcription factors**. They are part of the cell's core transcription "toolkit," needed for the transcription of any gene.

d *trp* operon videos.



The RNA polymerase and general transcription factors create a "protein complex" at the promoter (a section of the DNA gene).

However, many transcription factors (including some of the coolest ones!) are not the general kind. Instead, there is a large class of transcription factors that control the expression of specific, individual genes. For instance, a transcription factor might activate only a set of genes needed in certain neurons.

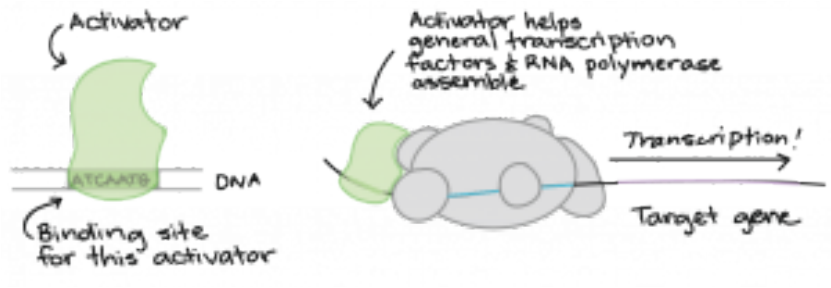
HOW DO TRANSCRIPTION FACTORS WORK?

A typical transcription factor binds to DNA at a certain target sequence. Once it's bound, the transcription factor makes it either harder or easier for RNA polymerase to bind to the promoter of the gene.

Activators

Some transcription factors **activate** transcription. For instance,

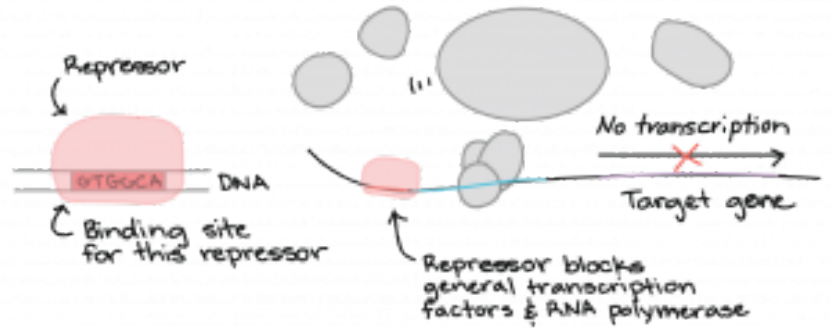
they may help the general transcription factors and/or RNA polymerase bind to the promoter, as shown in the diagram below.



Once the activator binds, transcription of the target gene occurs.

Repressors

Other transcription factors **repress** transcription. This repression can work in a variety of ways. As one example, a repressor may get in the way of the basal transcription factors or RNA polymerase, making it so they can't bind to the promoter or begin transcription.



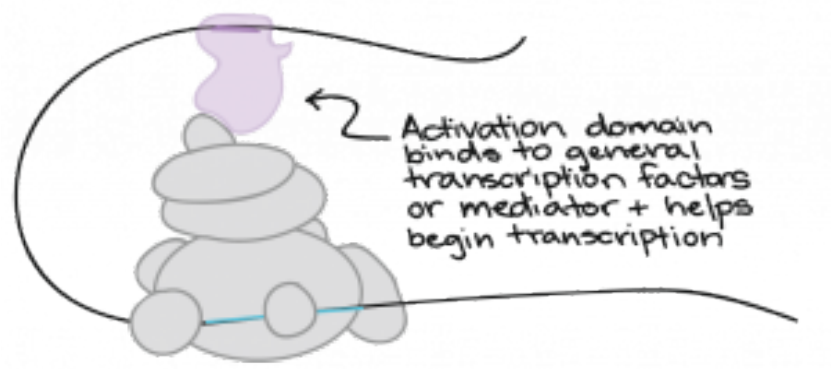
Once the repressor binds, transcription of the target gene does not occur.

TURNING GENES ON IN SPECIFIC BODY PARTS

Some genes need to be expressed in more than one body part or

type of cell. For instance, suppose a gene needed to be turned on in your spine, skull, and fingertips, but not in the rest of your body. How can transcription factors make this pattern happen?

A gene with this type of pattern may have several **enhancers** (far-away clusters of binding sites for activators) or **silencers** (the same thing, but for repressors). Each enhancer or silencer may activate or repress the gene in a certain cell type or body part, binding transcription factors that are made in that part of the body.[1,2]

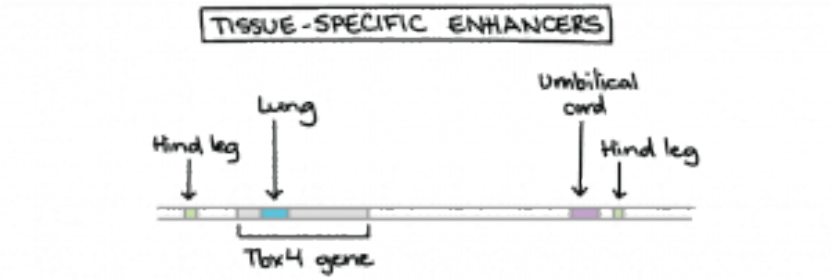


A DNA molecule with binding sites in blue and surrounded by proteins. The DNA molecule loops so that the switch, which is upstream from where the proteins initial bind, can also bind to the protein complex.

Example: Modular Mouse

As an example, let's consider a gene found in mice, called *Tbx4*. This gene is important for the development of many different parts of the mouse body, including the blood vessels and hind legs.[3]

During development, several well-defined enhancers drive *Tbx4* expression in different parts of the mouse embryo. The diagram below shows some of the *Tbx4* enhancers, each labeled with the body part where it produces expression.



Multiple enhancers for one gene; each enhancer is specific to a tissue type (e.g., hind leg).

Evolution of Development

Enhancers like those of the *Tbx4* gene are called tissue-specific enhancers: they control a gene's expression in a certain part of the body. Mutations of tissue-specific enhancers and silencers may play a key role in the evolution of body form.[4]

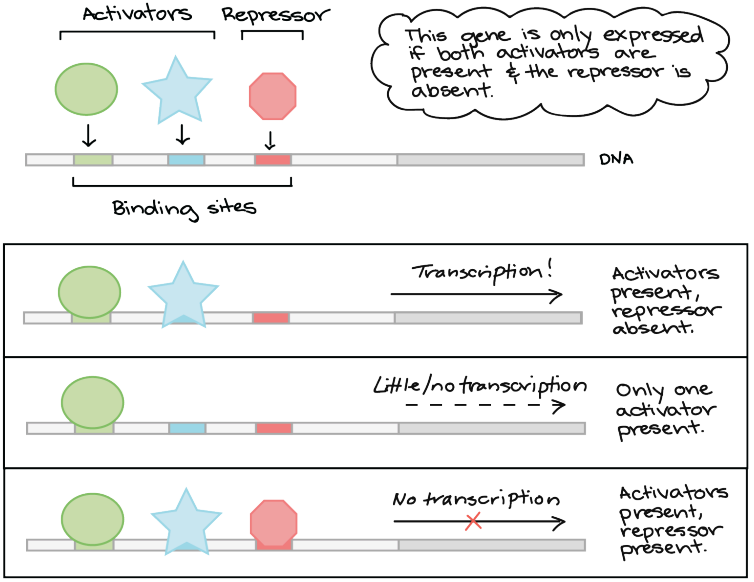
How could that work? Suppose that a mutation, or change in DNA, happened in the coding sequence of the *Tbx4* gene. The mutation would inactivate the gene everywhere in the body and a mouse without a normal copy would likely die. However, a mutation in an enhancer might just change the expression pattern a bit, leading to a new feature (e.g., a shorter leg) without killing the mouse.

TRANSCRIPTION FACTORS AND CELLULAR "LOGIC"

Can cells do logic? Not in the same way as your amazing brain. However, cells can detect information and combine it to determine the correct response—in much the same way that your calculator detects pushed buttons and outputs an answer.

We can see an example of this "molecular logic" when we consider how transcription factors regulate genes. Many genes are controlled by several different transcription factors, with a specific

combination needed to turn the gene on; this is particularly true in eukaryotes and is sometimes called combinatorial regulation.[5,6] For instance, a gene may be expressed only if activators A and B are present, and if repressor C is absent.



A gene is only expressed if both activators are present and the repressor is absent.

The use of multiple transcription factors to regulate a gene means that different sources of information can be integrated into a single outcome. For instance, imagine that:

- Activator A is present only in skin cells
- Activator B is active only in cells receiving "divide now!" signals (growth factors) from neighbors
- Repressor C is produced when a cell's DNA is damaged

In this case, the gene would be "turned on" only in skin cells that are receiving division signals and have undamaged, healthy DNA.

This pattern of regulation might make sense for a gene involved in cell division in skin cells. In fact, the loss of proteins similar to repressor C can lead to cancer.

Real-life combinatorial regulation can be a bit more complicated than this. For instance, many different transcription factors may be involved, or it may matter exactly how many molecules of a given transcription factor are bound to the DNA.

A CLOSER LOOK

After reading through this section, view the following video, which depicts many of the regulatory factors described above.

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https://openbooks.lib.msu.edu/isb202/?p=117#h5p-109

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

EXAMPLES

Now that you have learned some of the basics, check out this example that applies what you learned to a specific case study.

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https://openbooks.lib.msu.edu/isb202/?p=117#h5p-110

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

The video above briefly describes the laboratory part of this research. To learn more about what this research looks like, check out the "Stickleback Evolution Virtual Lab."

Lactose Example

If you are still a little unsure of how switches work, then check out this *HMMI Biointeractive* interactive. The ability to digest lactose as an adult is a rare phenomenon in mammals. It evolved twice in humans—in Africa and Europe.

Exercise

Now let's test your understanding of transcription regulation!

Take the quiz below the simulation as you work your way through it. Note that if you are using your mouse to scroll down, it may not work at this point—use the scrolling bar at the right edge of your web browser instead.

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THE PROCESS OF TRANSCRIPTION: A DETAILED LOOK

This chapter began with an overview of transcription and then focused more deeply on the role of the polymerase and regulatory proteins. Now watch the following video. It is an in-depth version of the first video of this chapter, incorporating aspects described throughout this chapter.

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https://openbooks.lib.msu.edu/isb202/?p=117#h5p-112

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

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ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

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"Transcription Factors" by Khan Academy, CC BY-NC-SA 4.0. All Khan Academy content is available for free at (www.khanacademy.org).

CHAPTER 19

Protein Synthesis II: RNA Processing

ANDREA BIEREMA

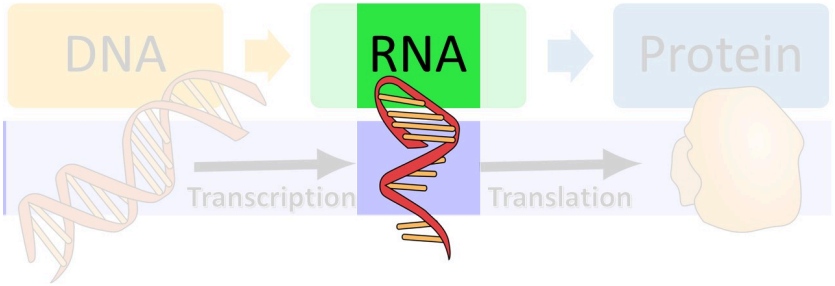
Learning Objectives

Students will be able to:

- Describe the molecular anatomy of genes and genomes.
- Describe exons and introns.
- Explain how splicing occurs during mRNA processing.
- Explain the process of alternative splicing.
- Describe how alternative splicing contributes to cells having different functions.
- Identify additional steps that take place during mRNA processing.

OVERVIEW

At the end of transcription, once the polymerase releases the RNA molecule, the RNA is not quite ready for translation and is not technically an "mRNA" yet. It still needs to be "processed," which means that certain nucleotides are removed and others are added—at the end of this, it is an mRNA molecule, but before that, it is a pre-mRNA molecule. This occurs as the RNA molecule is leaving the nucleus. After it is processed, it is then ready for translation, which is covered in a future chapter. This chapter focuses on the different steps that take place during mRNA processing and how some of these steps allow for cells within a single organism to have different functions. Please see the previous chapter for a review of transcription.



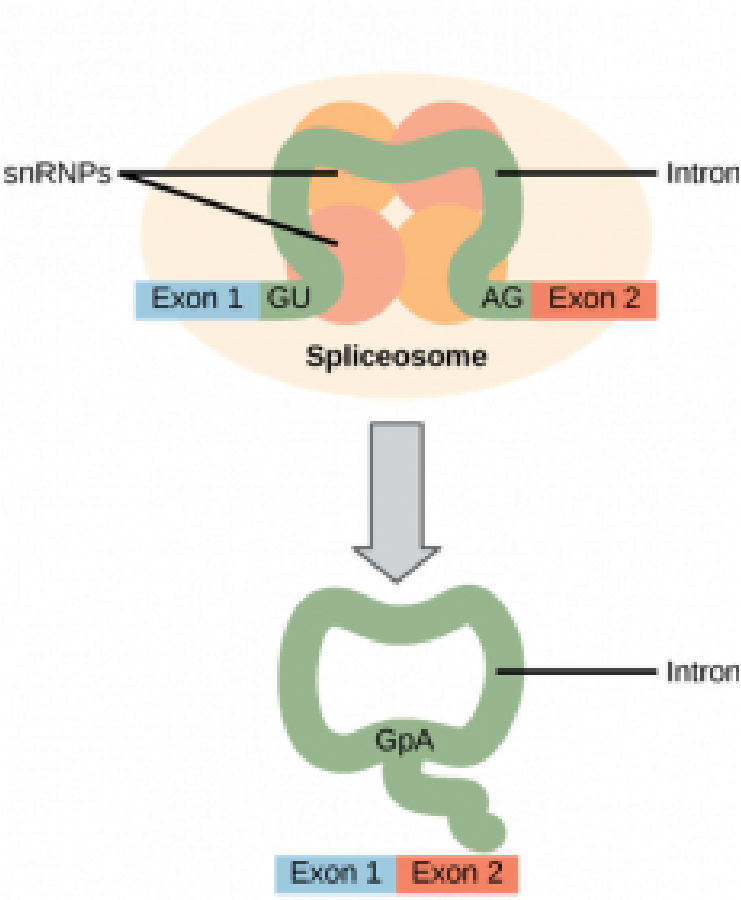
The focus of this chapter is what happens to the RNA produced from transcription, before it can be translated.

Splicing

After an mRNA molecule is produced, specific sequences throughout the mRNA molecule are removed. These sequences are called introns. The sequences that remain are called exons. To recall these terms, consider the following: exons correspond to protein-coding sequences ("EX–on" signifies that they are *ex*pressed), and *int*ervening sequences called introns ("IN-tron" denotes their *int*ervening role), which may be involved in gene

regulation but are removed from the pre-mRNA during processing. Intron sequences in mRNA do not encode functional proteins.

All of a pre-mRNA's introns must be completely and precisely removed before protein synthesis. If the process errs by even a single nucleotide, the reading frame of the rejoined exons would shift, and the resulting protein would be dysfunctional. The process of removing introns and reconnecting exons is called ***splicing***.



Pre-mRNA splicing involves the precise removal of introns from the primary RNA transcript. The splicing process is catalyzed by protein complexes called spliceosomes that are composed of proteins and RNA molecules called small nuclear RNAs (snRNAs).

If we consider that a base sequence is similar to letters on a page, then splicing is removing particular lines of text. View the following video, which follows this analogy, for a brief overview of what

splicing does (open the summary dialog at the end of the video to reflect on what you learned).

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=125#h5p-113

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

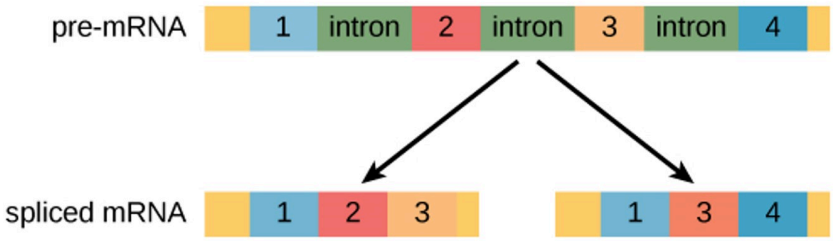
Exercise

Let's test your knowledge! Complete the following image by dragging the parts of the pre-RNA that will be the mature mRNA after mRNA processing. The untranslated regions are already in place.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=125#h5p-114

ALTERNATIVE SPLICING

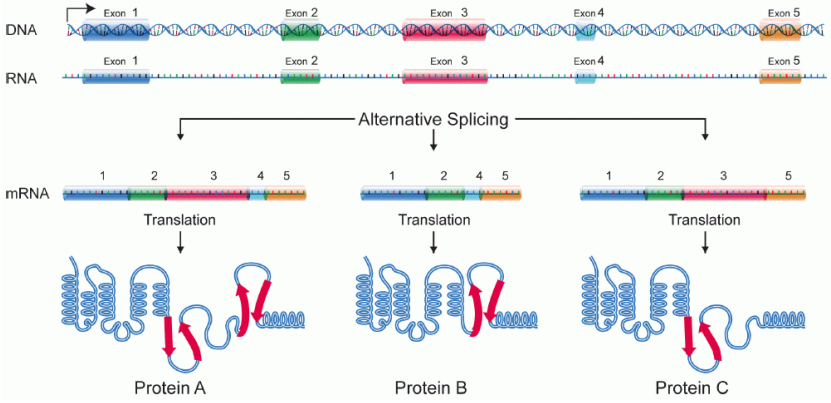
Genes that exhibited alternative RNA splicing were first observed in the 1970s. Alternative RNA splicing is a mechanism that allows different protein products to be produced from one gene when different combinations of exons are combined to form the mRNA. This alternative splicing can be haphazard, but more often it is controlled and acts as a mechanism of *gene regulation*, with the frequency of different splicing alternatives controlled by the cell as a way to control the production of different protein products in different cells or at different stages of development. Alternative splicing is now understood to be a common mechanism of gene regulation in eukaryotes; according to one estimate, 70% of genes in humans are expressed as multiple proteins through alternative splicing. Although there are multiple ways to alternatively splice RNA transcripts, the original 5'-3' order of the exons is *always conserved*. That is, a transcript with exons 1 2 3 4 5 6 7 might be spliced 1 2 4 5 6 7 or 1 2 3 6 7, but never 1 2 5 4 3 6 7.



An example of alternative splicing. Each number is a different exon, and not on exons are expressed. For example, a pre-mRNA with exons 1, 2, 3, 4 may express exons 1, 2, and 3 in one cell type and exons 1, 3, and 4 in another cell type.

Here is another representation of alternative splicing—this one

does not label the introns (assume the molecule segment between the exons are introns), like the previous but it shows how alternative splicing impacts the protein.

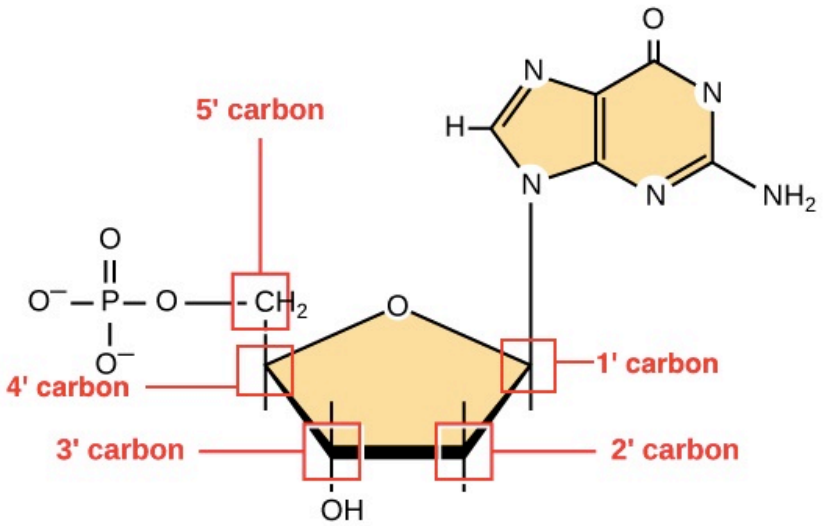


Pre-mRNA molecule alternatively spliced creates different proteins.

How could alternative splicing evolve? Introns have a beginning—and ending—recognition sequence; it is easy to imagine the failure of the splicing mechanism to identify the end of an intron and instead find the end of the next intron, thus removing two introns and the intervening exon. In fact, there are mechanisms in place to prevent such intron-skipping, but mutations are likely to lead to their failure. Such "mistakes" would more than likely produce a nonfunctional protein. Indeed, the cause of many genetic diseases is abnormal splicing rather than mutations in a coding sequence. However, alternative splicing could possibly create a protein variant without the loss of the original protein, opening up possibilities for adaptation of the new variant to new functions. Gene duplication has played an important role in the evolution of new functions in a similar way by providing genes that may evolve without eliminating the original, functional protein.

ADDITIONAL PROCESSING

Before the mRNA leaves the nucleus, it is given two protective "caps" that prevent the ends of the strand from degrading during its journey. The two ends of a DNA strand are referred to as 3' and 5', which references the position of sugar molecules in the DNA. The 5' cap is placed on the 5' end of the mRNA. The poly-A tail, which is attached to the 3' end, is usually composed of a long chain of adenine (A) nucleotides. These changes protect the two ends of the RNA from being broken down by other enzymes in the cell.



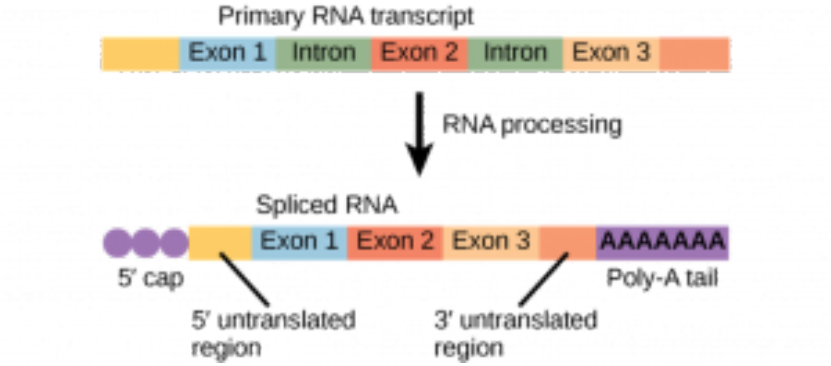
A nucleotide sugar is composed of 5 carbons; each one is numbered (the " ' " is called "prime"). Phosphates bind to the 3' carbon and the 5' carbon of each sugar. One end of a DNA or RNA molecule ends with the 3' carbon exposed and the other side ends with a phosphate attached to the last sugar's 5' end. This is why one end is referred to as 3' and the other end is referred to as 5'.

5' CAPPING

While the pre-mRNA is still being synthesized, a 7-methylguanosine cap is added to the 5' end of the growing transcript by a phosphate linkage. This functional group protects the nascent mRNA from degradation. In addition, factors involved in protein synthesis recognize the cap to help initiate translation by ribosomes.

3' POLY-A TAIL

Once elongation is complete, the pre-mRNA is cleaved by an endonuclease between an AAUAAA consensus sequence and a GU-rich sequence, leaving the AAUAAA sequence on the pre-mRNA. An enzyme called poly-A polymerase then adds a string of approximately 200 A residues, called the poly-A tail. This modification further protects the pre-mRNA from degradation and is also the binding site for a protein necessary for exporting the processed mRNA to the cytoplasm. Below is a more complete diagram of mRNA processing.



This image is more complete than the original one introduced earlier in this chapter. In addition to the removal of the introns, the mature mRNA has a cap on one end and poly-A tail on the other end.

TEST YOUR UNDERSTANDING

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https://openbooks.lib.msu.edu/isb202/?p=125#h5p-115

ATTRIBUTION

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CHAPTER 20

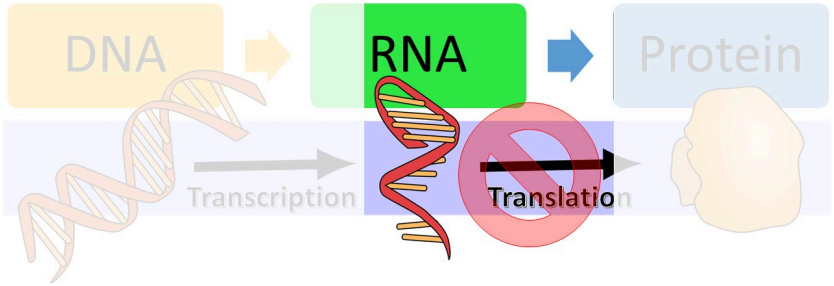
Protein Synthesis III: RNA Interference

ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Describe the process of RNA interference.
- Compare the two types of RNA interference: microRNA and siRNA.
- Explain how RNA interference affects gene expression.



RNAi affects protein synthesis after the mRNA is created but before translation begins. It prevents translation from occurring.

RECENT DISCOVERY

Not all RNA molecules code for protein. Some RNA control genes in a way that was only discovered recently: a process called RNA interference, or RNAi. Although scientists identified RNAi relatively recently, they now know that organisms have been using this trick for millions of years.

RNAi is a mechanism that organisms use to silence genes when the proteins that they code for are no longer needed. This silencing happens when short RNA molecules bind to stretches of mRNA, preventing translation of the mRNA.

Click on the "plus" hotspots on the figure below to learn more!

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can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=129#h5p-116

(credit: modification of work by Robinson, R)

Researchers believe that RNAi arose as a way to reduce the production of a gene's encoded protein for purposes of fine-tuning growth or self-defense. When viruses infect cells, for example, they command their host to produce specialized RNAs that allow the virus to survive and make copies of itself. Researchers believe that RNAi eliminates unwanted viral RNA and some speculate that it may even play a role in human immunity.

Oddly enough, scientists discovered RNAi from a failed experiment! Researchers investigating genes involved in plant growth noticed something strange: when they tried to turn petunia flowers purple by adding an extra "purple" gene, the flowers bloomed white instead.

This result fascinated researchers, who could not understand how adding genetic material could somehow get rid of an inherited trait. The mystery remained unsolved until, a few years later, two geneticists studying development saw a similar thing happening in lab animals.

The researchers, Andrew Z. Fire (then of the Carnegie Institutions of Washington in Baltimore and now at Stanford University) and Craig Mello (of the University of Massachusetts Medical School in Worcester) were trying to block the expression of genes that affect cell growth and tissue formation in roundworms, using a molecular tool called antisense RNA.

To their surprise, Mello and Fire found that their antisense RNA

tool wasn't doing much at all. Rather, they determined, a double-stranded contaminant produced during the synthesis of the single-stranded antisense RNA interfered with gene expression. Mello and Fire named the process RNAi (RNA *interference*) and in 2006 were awarded the Nobel Prize in physiology or medicine for their discovery.

Further experiments revealed that the double-stranded RNA gets chopped up inside the cell into much smaller pieces that stick to mRNA and block its action. That is, the mRNA cannot bind to a ribosome and translation cannot occur.

Today, scientists are taking a cue from nature and using RNAi to explore biology. They have learned, for example, that the process is not limited to worms and plants, but operates in humans too.

Medical researchers are currently testing new types of RNAi-based drugs for treating conditions such as macular degeneration (the leading cause of blindness) and various infections (including those caused by HIV and the herpes virus).

RNA TYPES

There are two main types of RNA that can interfere with mRNA and translation: microRNA and siRNA. This section describes microRNA in more detail. Watch the video in the next section to learn how microRNA and siRNA compare.

Molecules called microRNAs have been found in organisms as diverse as plants, worms, and people. The molecules are truly "micro," consisting of only a few dozen nucleotides, compared to typical human mRNAs that are a few thousand nucleotides long.

What's particularly interesting about microRNAs is that many of them evolved from DNA that used to be considered merely filler material. (14)

How do these small, but important, RNA molecules do their work? They start out much bigger, but get trimmed by cellular

enzymes including one aptly named Dicer. Like tiny pieces of Velcro®, microRNAs stick to certain mRNA molecules and stop them from passing on their protein-making instructions.

First discovered in a roundworm model system, some microRNAs help determine the organism's body plan. In their absence, very bad things can happen. For example, worms engineered to lack a microRNA called let-7 develop so abnormally that they often rupture and practically break in half as the worm grows.

Perhaps it is not surprising that because microRNA helps specify the timing of an organism's developmental plan, the appearance of the microRNAs themselves is carefully timed inside a developing organism. Biologists (including Amy Pasquinelli of the University of California, San Diego) are currently figuring out how microRNAs are made and cut to size, as well as how they are produced at the proper time during development.

MicroRNA molecules also have been linked to cancer. For example, Gregory Hannon of the Cold Spring Harbor Laboratory on Long Island in New York, found that certain microRNAs are associated with the severity of the blood cancer B-cell lymphoma in mice.

Since the discovery of microRNAs in the first years of the 21st century, scientists have identified hundreds of them that likely exist as part of a large family with similar nucleotide sequences. New roles for these molecules are still being found.

MECHANISMS

Watch the following video to learn about how the two main types of molecules used in RNAi (microRNA and siRNA) differ from one another and how they work to prevent (or interfere with) gene expression.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=129#h5p-117

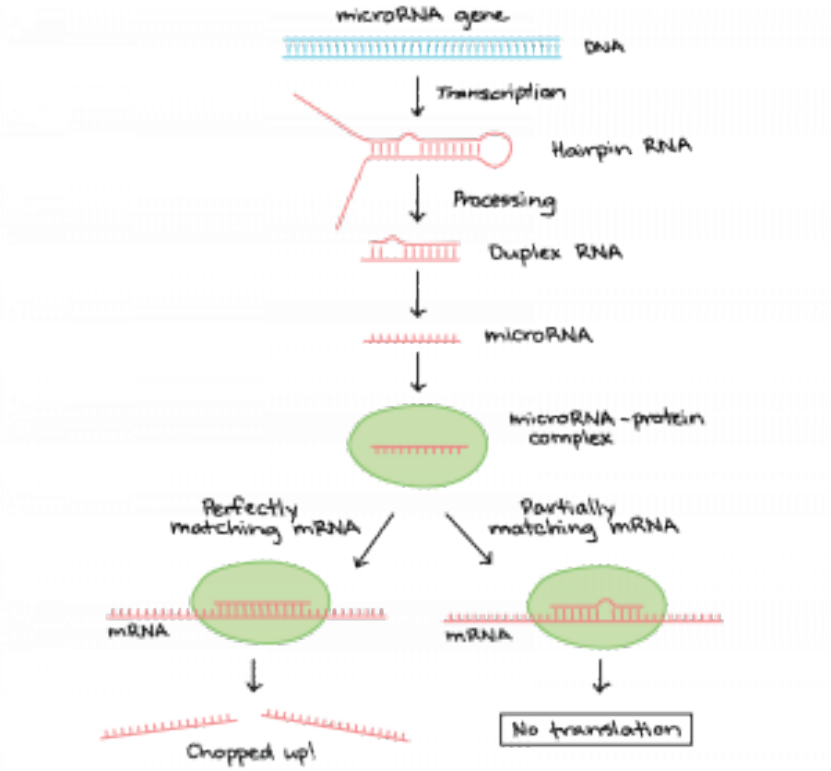
For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Exercise

After watching the video, answer the following question:

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=129#h5p-118

What happens after the microRNA binds to the mRNA?



A microRNA gene on DNA is transcribed and processed into a microRNA. It might perfectly or partially match the mRNA.

The miRNA directs the protein complex to "matching" mRNA molecules (ones that form base pairs with the miRNA). When the RNA-protein complex binds.[2]

- If the miRNA and its target match perfectly, an enzyme in the RNA-protein complex will typically chop the mRNA in half, leading to its breakdown.
- If the miRNA and its target have some mismatches, the RNA-protein complex may instead bind to the mRNA and keep it from being translated.

These are not the only ways that miRNAs inhibit expression of their targets and scientists are still investigating their many modes of action.[3]

Overview Interactive

For a review of what you learned in this chapter, see HHMI Biointeractive's RNA Interference interactive!

REFERENCES

1. Carthew, R. W. and Sontheimer, E. J. (2009). Origins and mechanisms of miRNAs and siRNAs. *Cell*, *136*(4), 648. http://dx.doi.org/10.1016/j.cell.2009.01.035.
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4. Sayed, Danish and Abdellatif, Maha. (2011). MicroRNAs in development and disease. *Physiological Reviews* 91(3), 831, 837-839. http://physrev.physiology.org/content/physrev/91/3/827.full.pdf.

ATTRIBUTIONS

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"Cells 101: Business Basics" by U.S. Department of Health and

Human Services, National Institutes of Health and National Institute of General Medical Sciences, Inside the Cell, Public Domain.

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CHAPTER 21

Protein Synthesis IV: Translation

ANDREA BIEREMA

Learning Objectives

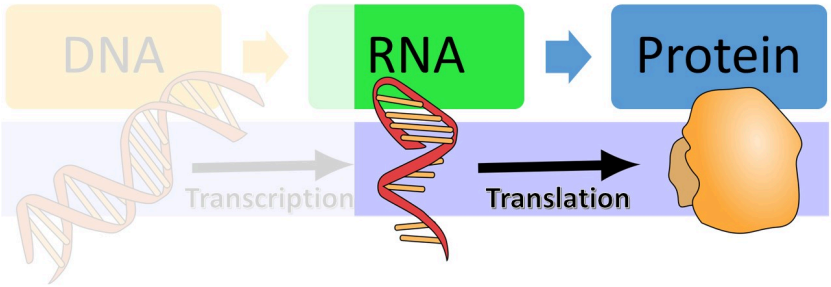
Students will be able to:

- Explain how mRNA is translated to synthesize protein.
- Describe the role of the ribosome, the tRNAs, and the mRNA in translation.
- Identify at which point on the mRNA molecule translation begins.
- Explain what happens when a stop codon on the mRNA is reached during translation.

OVERVIEW

So far in this book, we have learned how RNA is made, processed, and regulated. This chapter focuses on how translation works; that

is, how information coded in the mRNA molecule is read to create an amino acid sequence (i.e., polypeptide), which then folds into a protein. Please see an earlier chapter for a general overview of translation and which codons (i.e., base sequences) code for which amino acids.



Translation is the process of creating a polypeptide (i.e., an amino acid sequence) by "reading" the mRNA sequence and using tRNAs.

THE PROCESS OF TRANSLATION: A FIRST LOOK

Let's first look at a basic overview of what the process of translation looks like. The video below begins with the mRNA leaving the nucleus and binding with a ribosome. TransferRNAs (tRNAs) move in and out of the ribosome, carrying an amino acid into the ribosome and then leaving without it. An amino acid sequence (i.e., a polypeptide) is produced.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=132#h5p-119

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

Exercise

Now that you have watched a basic overview of translation, test your knowledge with the following activity in which you place the following translation steps in the correct order.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://openbooks.lib.msu.edu/isb202/?p=132#h5p-120

MOLECULES

The following video lists the different molecules at play in

translation. While watching it, consider how each of these molecules played a role in the first video of this chapter. Watch this before moving on to the mechanism.

An interactive H5P element has been excluded from this version of the text. You can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=132#h5p-121

MECHANISM

The first video in this chapter quickly showed what translation looks like. The following video slows down the process and explains in more detail what is happening in the ribosome.

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https://openbooks.lib.msu.edu/isb202/?p=132#h5p-122

THE PROCESS OF TRANSLATION: A DETAILED LOOK

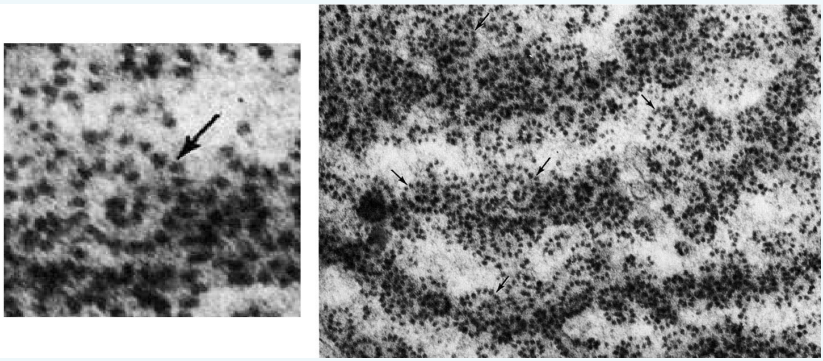
This chapter began with an overview of translation and then described in more detail what is happing in the ribosome and how the amino acid chain builds. Now watch the following video, which is an in-depth version of the first video of this chapter, now incorporating aspects described throughout this chapter.

An interactive H5P element has been excluded from this version of the text. You can view it online here:

https://openbooks.lib.msu.edu/isb202/?p=132#h5p-123

For closed captioning or to view the full transcript, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

The animations above focused on what happens at a single ribosome. In reality, though, an mRNA molecule may have several ribosomes attached to it at once, making multiple copies of the protein. They all begin at the first codon, but as one starts moving down the mRNA, another can attach; therefore, they all make the same protein.



The image on the left is a close-up of part of the image of the right, which is an electron micrograph *revealing the arrangement of ribosomes from a section of a glandular, adrenocortical cell of a human fetus at 27 weeks. This view reveals long loops and spirals of multiple ribosomes aligned along a single molecule of messenger RNA. A few of the spirals are identified with an arrow (the image on the left is a close-up of one of the identified spirals). Image by Eichi Yamada and is from Figure 174 from Chapter 5 (Endoplasmic Reticulum) of 'The Cell, 2nd Ed.' by Don W. Fawcett M.D.*

CHAPTER 22

Protein Synthesis V: Additional Regulation

ANDREA BIEREMA

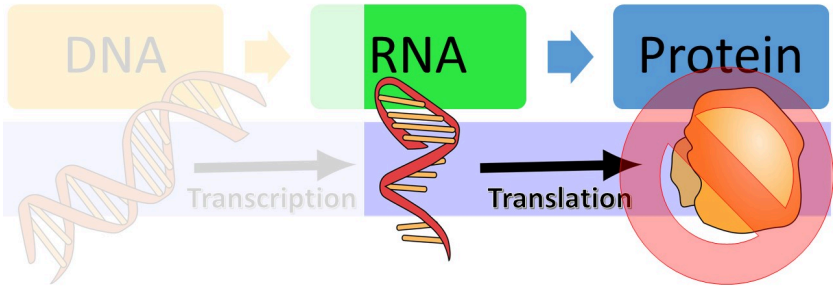
Learning Objective

Students will be able to:

- Identify ways in which gene expression is regulated during and after translation.

OVERVIEW

We have learned how we synthesize proteins and how gene expression is regulated before and after transcription, but the regulation can also happen during or after translation.



This chapter focuses on regulation that prevents the protein from being created after translation.

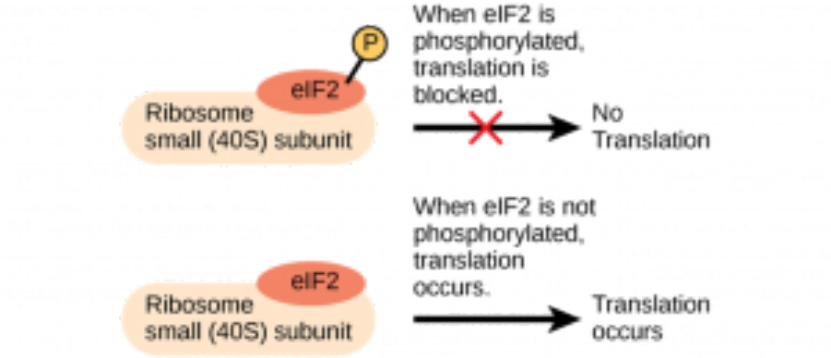
Regulation of Translation

We already saw how miRNAs can inhibit translation, but there are a number of other ways that translation of an mRNA can also be regulated in a cell. One key step for regulation is translation initiation.

In order for translation to begin, the ribosome, an RNA-and-protein complex that houses translation, must assemble on the mRNA. This process involves many "helper" proteins, which make sure the ribosome is correctly positioned. Translation can be regulated globally (for every mRNA in the cell) through changes in the availability or activity of the "helper" proteins.

For example, in order for translation to begin, a protein called eukaryotic initiation factor-2 (eIF-2) must bind to a part of the ribosome called the small subunit. Binding of eIF-2 is controlled by phosphorylation, or addition of a phosphate group to the protein.

When eIF-2 is phosphorylated, it's turned "off"—it undergoes a shape-change and can no longer play its role in initiation, so translation cannot begin. When eIF-2 is not phosphorylated, in contrast, it's "on" and can carry out its role in initiation, allowing translation to proceed.



Gene expression can be controlled by factors that bind the translation initiation complex.

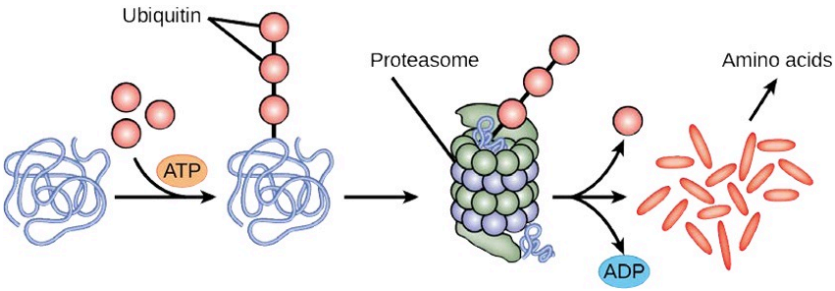
CHEMICAL MODIFICATIONS, PROTEIN ACTIVITY, AND LONGEVITY

Proteins can be chemically modified with the addition of groups including methyl, phosphate, acetyl, and ubiquitin groups. The addition or removal of these groups from proteins regulates their activity or the length of time they exist in the cell. Sometimes these modifications can regulate where a protein is found in the cell—for example, in the nucleus, in the cytoplasm, or attached to the plasma membrane.

Chemical modifications occur in response to external stimuli such as stress, the lack of nutrients, heat, or ultraviolet light exposure. These changes can alter epigenetic accessibility, transcription, mRNA stability, or translation—all resulting in changes in the expression of various genes. This is an efficient way for the cell to rapidly change the levels of specific proteins in response to the environment. Because proteins are involved in every stage of gene regulation, the phosphorylation of a protein (depending on the protein that is modified) can: alter accessibility to the chromosome; alter translation (by altering transcription

factor binding or function); change nuclear shuttling (by influencing modifications to the nuclear pore complex); alter RNA stability (by binding or not binding to the RNA to regulate its stability); modify translation (increase or decrease); or change post-translational modifications (add or remove phosphates or other chemical modifications).

The addition of a ubiquitin group to a protein marks that protein for degradation. Ubiquitin acts like a flag indicating that the protein lifespan is complete. These proteins are moved to the proteasome, an organelle that functions to remove proteins, to be degraded. One way to control gene expression, therefore, is to alter the longevity of the protein.



Proteins with ubiquitin tags are marked for degradation within the proteasome.

ATTRIBUTION

This chapter is a modified derivative of "Eukaryotic translational and post-translational gene regulation," by OpenStax College, Biology 2e, CC BY 4.0. Download the original article for free at https://openstax.org/books/biology-2e/pages/16-6-eukaryotic-translational-and-post-translational-gene-regulation

CHAPTER 23

Cell Signaling

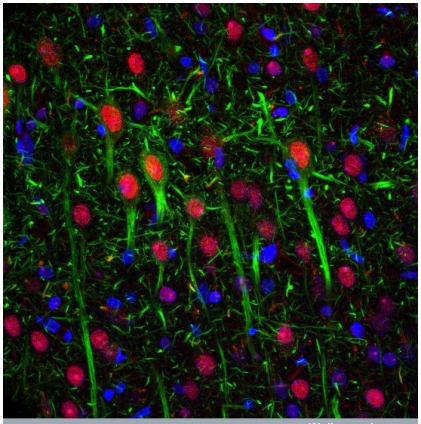
ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Describe how ligands and receptors are involved in cell signaling.
- Describe the different types of cell signaling.
- Explain how neurons (nerve cells) communicate with each other.
- Identify how drugs influence dopamine signaling.

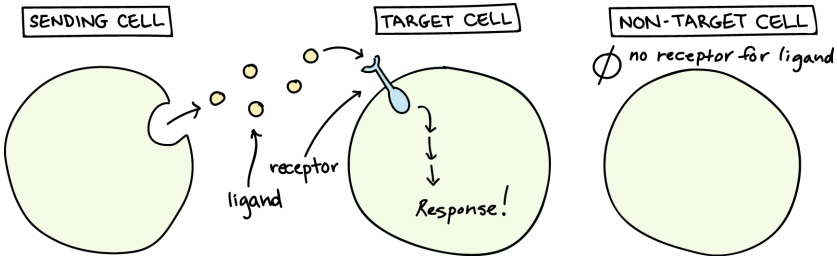
CELL SIGNALING OVERVIEW



An image of normal brain tissue from the thalamus. In red are the receptors for orexin. Orexins are peptide hormones that help keep us awake and alert, and may also stimulate the appetite. They are produced in the hypothalamus and act through their receptors located in the nuclei (shown in blue) of cells in many different parts of the brain. The green stain highlights the neurofilaments (filaments found in nerve cells). A drug called orexin-RA-1 that blocks the action of these receptors is currently under development as a sleeping pill. It may also have the effect of reducing the appetite.

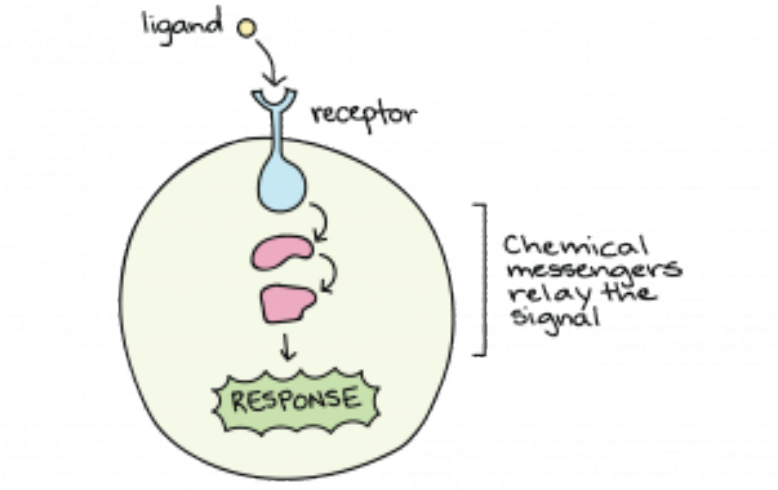
Cells "communicate" with each other via signaling. That is, one cell either directly connects or- more often- sends signaling molecules (which are often proteins) to another cell (or sometimes even back to itself), which triggers a response. Cell signaling influences a variety of cell functions, including the synthesis of specific proteins and cell division.

Not all cells can "catch" a particular signal. In order to detect the signal, the cell must have the right receptor for that signal. When a signaling molecule binds to its receptor, it alters the shape or activity of the receptor, triggering a change inside of the cell. Signaling molecules are often called ***ligands***, a general term for molecules that bind specifically to other molecules (such as receptors).



A sending cell produces ligand (signaling molecules) that bind to a receptor of the target cell, which elicits a response. Non-target cells do not have a receptor for that specific ligand and so do not respond.

The message carried by a ligand is often relayed through a chain of chemical messengers inside the cell. Ultimately, it leads to a change in the cell, such as protein synthesis.



Once a ligand (a signaling molecule) binds to a receptor, the receptor relays the signal to other molecules (such as proteins) in the cell. This chain of events causes a response in the cell.

Exercise

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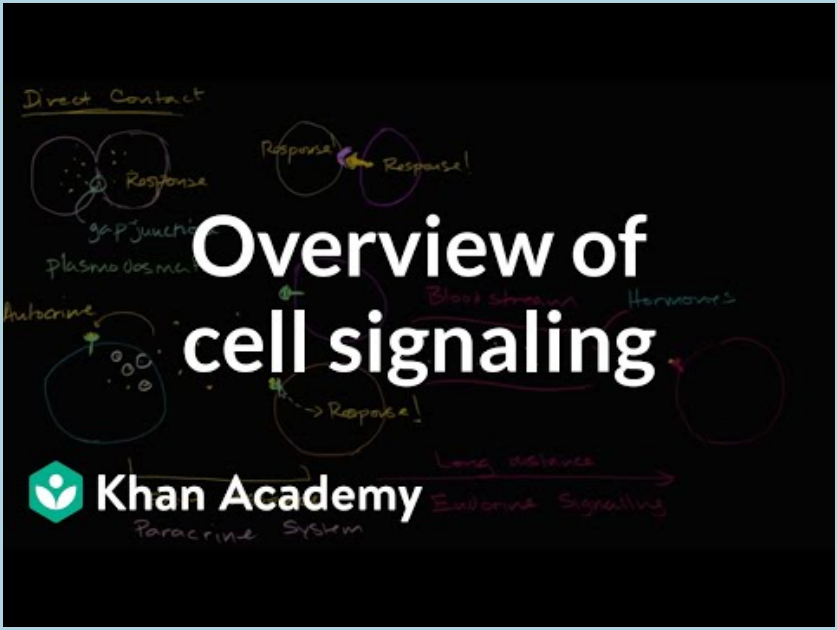
https://openbooks.lib.msu.edu/isb202/?p=465#h5p-151

Click here to see the entire image that this exercise was based on.

FORMS OF SIGNALING

There are different ways in which one cell sends another cell a signal. The video below summarizes these types of signals.



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Exercise

Complete this mini-quiz on the main types of cell signaling after watching the video above.

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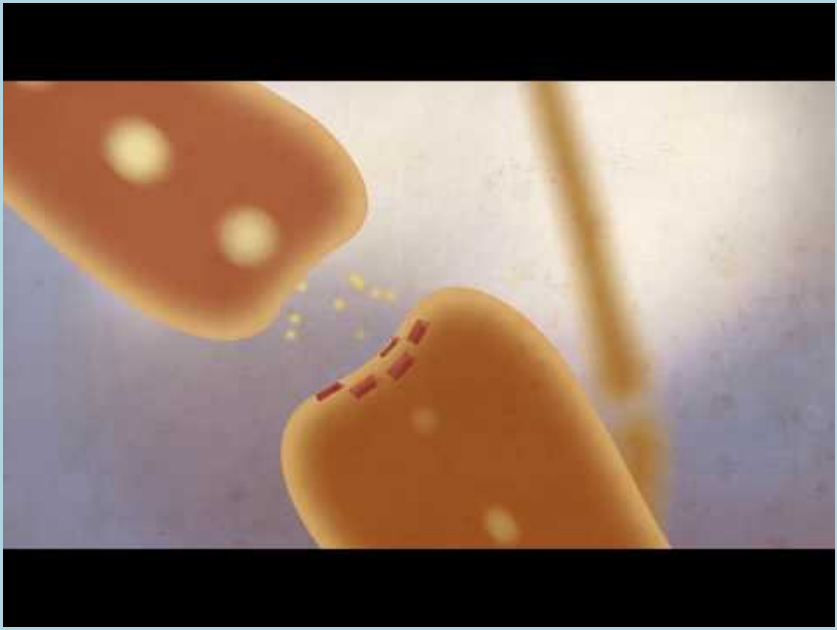
NEURON COMMUNICATION

One unique example of cell signaling is synaptic signaling, in which a nerve cell (called a "neuron") transmits a signal to another neuron. This process is named for the synapse, the junction between two nerve cells where signal transmission occurs.

When the sending neuron fires, an electrical impulse moves rapidly through the cell, traveling down a long, fiber-like extension called an axon. When the impulse reaches the synapse, it triggers the release of neurotransmitters, which quickly cross the small gap between the neurons. When the neurotransmitters arrive at the receiving cell, they bind to receptors and cause a chemical change inside of the cell (often, opening ion channels and changing the electrical potential across the membrane. The video below illustrates this process.



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Exercises

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The original image came from this Khan Academy article.

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https://openbooks.lib.msu.edu/isb202/?p=465#h5p-153

NEURONS AND DRUG USE

One neurotransmitter commonly discussed is dopamine. This molecule is naturally produced in the body and the release of it causes “feel good” sensations. Drugs can change the dopamine pathway, such as preventing it from releasing from the receptors.

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To learn how different drugs impact this pathway, see the animated infographic below (press play to see the animations).

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Press play on the above infographic to view animations of cell signaling. This animated infographic was produced by American Addiction Centers. Learn more about the project and find an accessible version on their page: https://drugabuse.com/featured/the-science-behind-addiction/

ATTRIBUTION

This chapter is a modified derivative of "Introduction to Cell Signaling." by Khan Academy, CC BY-NC-SA 4.0. Download the original article for free at https://www.khanacademy.org/science/biology/cell-signaling/mechanisms-of-cell-signaling/a/introduction-to-cell-signaling

CHAPTER 24

Genetic Engineering

ANDREA BIEREMA

Learning Objectives

Students will be able to

- Define DNA sequencing.
- Describe examples and mechanisms of genetic engineering.
- Define genetically modified organisms (i.e., GMO).
- Explain how CRISPR is used.
- Describe the role of Cas9 and the guide RNA in CRISPR.
- Identify key steps and their variations in CRISPR.

A variety of biotechnologies exist including cloning organisms, sequencing DNA, and modifying DNA. Although there is a wide range of molecular biotechnologies, this chapter first introduces DNA sequencing and then describes changes to the genome, which

results in changes in proteins or protein synthesis: **genetic engineering**.

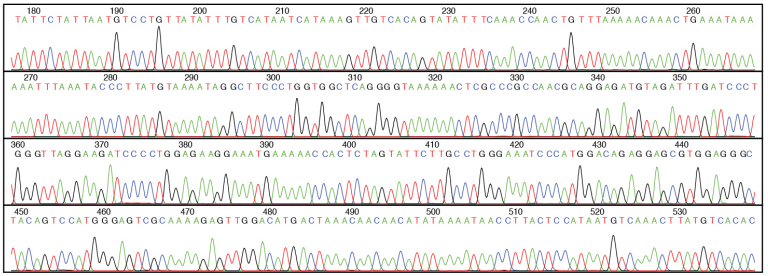
DNA SEQUENCING

The main theme of this chapter is genetic engineering, but before, we can change the DNA, we must first sequence it. Therefore, this chapter begins with an introduction to DNA sequencing.

DNA sequencing is the process of working out the exact order of the four bases, A, C, T, and G in a strand of DNA.

Human chromosomes range in size from about 50,000,000 to 300,000,000 base pairs and each human being has 46 (23 pairs) of these chromosomes. This means we have approximately 3.2 billion bases of DNA in total!

At present, we can't sequence a genome, or even a single chromosome, from start to finish. We have to break it up into smaller, more manageable chunks, or fragments. The order and number of bases in these fragments of DNA are then identified through techniques that label each base individually (in modern techniques the bases are labeled with different colors). From this information, scientists are able to work out the sequence of the DNA and find out lots of other interesting things about our genetic makeup.



Results of a computational DNA sequence analysis. Note that each color represents a different base (A, T, C, and G), the color of each peak designates the base in the sequence and that the DNA sequence is labeled on the X axis.

Early DNA sequencing was technically challenging and slow. Resources were expensive, and the reactions required complex conditions to work. It, therefore, took several years to sequence just one or two genes!

Over the last decade, DNA sequencing technologies have developed rapidly. We can now sequence an entire human genome, all 3.2 billion letters, in a matter of hours and for much less money.

INTRODUCTION TO GENETIC ENGINEERING

Genetic engineering refers to the direct manipulation of DNA to alter an organism's characteristics (phenotype) in a particular way. This may mean changing one base pair (A-T or C-G), deleting a whole region of DNA, or introducing an additional copy of a gene. It may also mean extracting DNA from another organism's genome and combining it with the DNA of that individual. It has been used by scientists to enhance or modify the characteristics of an individual organism from a virus to sheep, to possibly humans.

For example, genetic engineering can be used to produce plants that have a higher nutritional value or can tolerate exposure to herbicides.

We can change an organism's characteristics by introducing new pieces of DNA into their genomes. This could be:

- DNA from the same species.
- DNA from a different species.
- DNA made synthetically in the lab.

There are several techniques that can be used to modify a genome, including:

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GENETICALLY MODIFIED ORGANISMS (GMOS)

Genetically modified (GM) organisms are organisms that have had their genomes changed in a way that does not happen naturally. By changing an organism's genome, we change the resulting proteins, which change their characteristics. Any organism can be genetically modified, but laws restrict the creation of genetically modified humans, and the production and distribution of other GMOs are tightly regulated.

Exercise

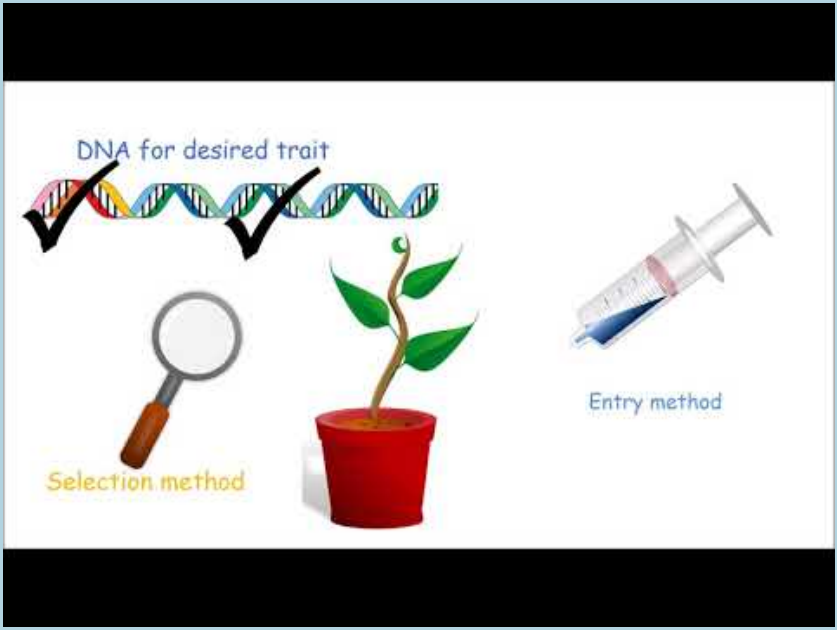
Learn more about the process of creating GMOs by going through *Connecting Concepts'* Interactive lesson on developing a genetically modified canola plant.

The first genetically modified organism was created in 1973 and was a bacterium. Then in 1974, the same techniques were applied to mice. The first genetically-modified foods were made available in 1994.

What is ***not*** a GMO? The genomes of organisms change naturally over time, and these natural changes are not classified as GMO (otherwise, everything would be classified as a GMO). Examples of natural changes include:

- when organisms mate, offspring get bits of DNA from both parents
- mutations arise as a result of mistakes when DNA is copied
- environmental factors like UV radiation can create changes in DNA.

The following video describes how genetically modified plants are made and which qualities may be desired.



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What does it look like when a needle is inserted into a cell?

If you are curious how a cell reacts to a needle, then watch the quick video below!

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https://openbooks.lib.msu.edu/isb202/?p=140

Time-lapse movie (sped up 10x) of a glass microneedle being inserted into an egg cell. The object in the cell being moved is a metaphase spindle. The spindle is made visible by the use of polarizing optics. Video created by Inoue, S. is licensed CC BY-NC-SA. doi:10.7295/W9CIL11958

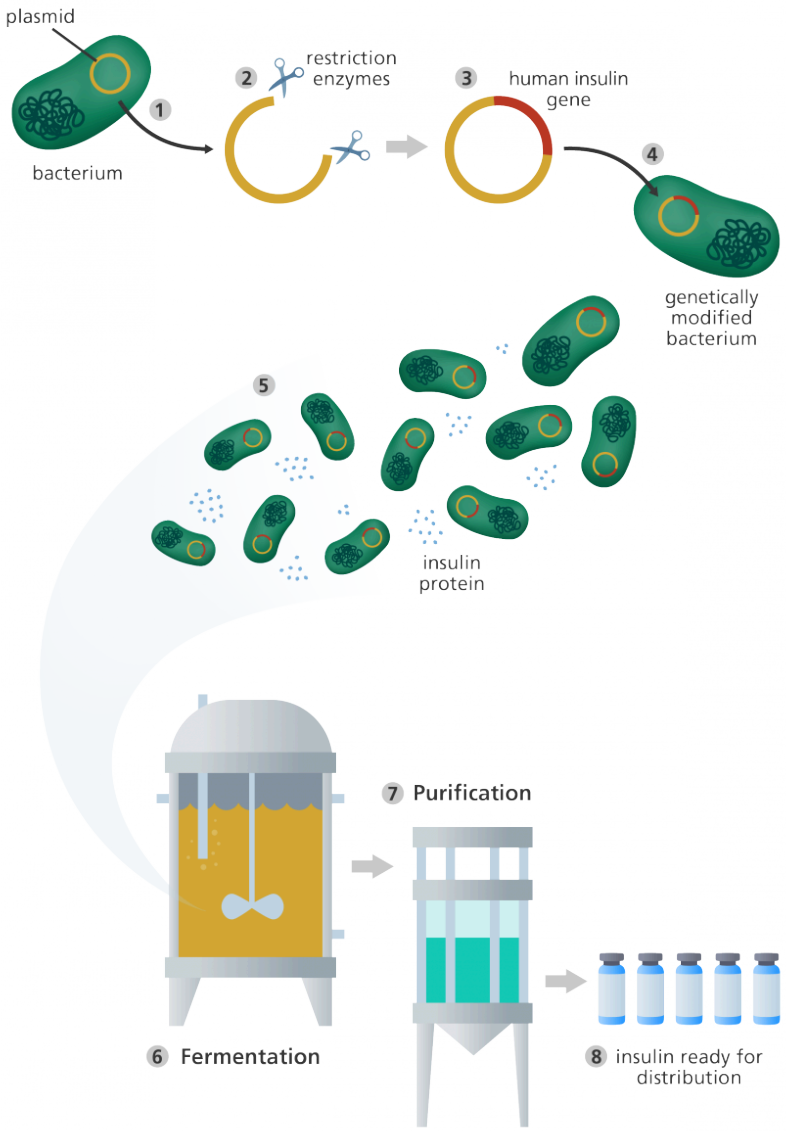
AN EXAMPLE OF GENETIC ENGINEERING: INSULIN PRODUCTION

Normally, insulin is produced in the pancreas, but in people with type 1 diabetes, there is a problem with insulin production. People with diabetes, therefore, have to inject insulin to control their blood sugar levels. Genetic engineering has been used to produce a type of insulin in yeast and in bacteria like *E. coli* that is very similar to our own. This genetically modified insulin, *Humulin* was licensed for human use in 1982.

To produce genetically-engineered insulin, a small, circular DNA called a plasmid is extracted from the bacteria or yeast cell. A small section is then cut out of the circular plasmid by restriction enzymes that act as “molecular scissors.” The gene for human insulin is inserted into the gap in the plasmid, creating a genetically modified plasmid.

This genetically modified plasmid is introduced into a new

bacteria or yeast cell. This cell divides rapidly and starts making insulin. To create large amounts of the cells, the genetically modified bacteria or yeast are grown in large fermentation vessels that contain all the nutrients they need. The more the cells divide, the more insulin is produced. When fermentation is complete, the mixture is filtered to release the insulin. The insulin is then purified and packaged into bottles and insulin pens for distribution to patients with diabetes.



An illustration showing how genetic modfication is used to produce insulin in bacteria.

Mosquitos and the Lethal Gene

For another example of genetic engineering, check out *HHMI Biointeractive*'s "Genetically Modified Mosquitos" video.

CRISPR

CRISPR-Cas9 is a genome-editing tool that is creating a buzz in the science world. It is faster, cheaper, and more accurate than previous techniques of editing DNA and has a wide range of potential applications. It can remove, add, and alter sections of the DNA sequence.

The CRISPR-Cas9 system consists of two key molecules that introduce a mutation into the DNA. These are:

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https://openbooks.lib.msu.edu/isb202/?p=140#h5p-125

Watch the following videos to learn about the CRISPR-Cas9 process.

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https://openbooks.lib.msu.edu/isb202/?p=140#h5p-126

For closed captioning or to view the full transcript of the above video, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

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https://openbooks.lib.msu.edu/isb202/?p=140#h5p-127

For closed captioning or to view the full transcript of the above video, click on the "YouTube" link in the video (or click here) and view the video on YouTube.

In addition to the videos above, *HHMI Biointeractive* CRISPR Cas-9 Mechanism and Applications interactive is a great illustration!

The following is an overview of the different ways in which DNA is edited:

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https://openbooks.lib.msu.edu/isb202/?p=140#h5p-128

Exercise

Check your understanding of the CRISPR process!

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https://openbooks.lib.msu.edu/isb202/?p=140#h5p-129

Exercise

Want to learn more about what this looks like in a laboratory? Check out this simulation and this scrolling interactive from LabXchange!

ATTRIBUTIONS

This chapter is a modified derivative of the following articles:

"What is CRISPR-Cas9?" by yourgenome, Genome Research Limited, 2021, CC-BY 4.0.

"What is DNA sequencing?" by yourgenome, Genome Research Limited, 2021, CC-BY 4.0.

"What is a GMO?" by yourgenome, Genome Research Limited, 2017, CC-BY 4.0.

"What is genetic engineering?" by yourgenome, Genome Research Limited, 2017, CC-BY 4.0.