Teacher Notes for "Introduction to Proteins and DNA"[1]

These Teacher Notes present a sequence of activities that will help students understand the basic structure and function of proteins and DNA. To understand how genes influence our characteristics, students learn that different versions of a protein can result in different characteristics, and a gene in the DNA determines which version of a protein is synthesized by a person's cells. This information is conveyed through a PowerPoint with a sequence of discussion questions and videos, a Student Handout, and an optional hands-on learning activity. This sequence can be used in an introductory unit on biological molecules or to introduce a unit on molecular biology.

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Learning Goals

Key Concepts

- Proteins are responsible for many important biological functions.
- Differences in the structure and function of proteins result in differences in the characteristics of biological organisms.
- DNA contains genes which provide the information necessary to make proteins.
- Different versions of the same gene result in different versions or amounts of a protein which can result in different characteristics.

In accord with the Next Generation Science Standards[2] (NGSS):

- This activity helps to prepare students for the Performance Expectations:
  - HS-LS1-1, "Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells."
  - HS-LS3-1, "Ask questions to clarify relationships about the role of DNA [and chromosomes] in coding the instructions for characteristic traits passed from parents to offspring."
- Students will gain understanding of two Disciplinary Core Ideas:
  - LS1.A: Structure and Function – "All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins."
  - LS3.A: Inheritance of Traits – "Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA."
- Students will engage in the Scientific Practice, "Constructing Explanations. Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources…"

[1] Dr. Ingrid Waldron, Biology Department, University of Pennsylvania, 2024. These Teacher Notes and the relevant PowerPoint and Student Handout are available at https://serendipstudio.org/exchange/bioactivities/proteins.
[2] Next Generation Science Standards (https://www.nextgenscience.org/)

- The proposed activities provide the opportunity to discuss the Crosscutting Concept, "Cause and Effect: Mechanism and Prediction: Cause and effect relationships can be suggested and predicted for complex natural [and human designed] systems by examining what is known about smaller scale mechanisms within the system."

Instructional Sequence and Suggestions

A. To introduce proteins, discuss these probe questions (slide 2 of the PowerPoint[3]):

- What are proteins?
- Why are proteins important?

The first two images on the slide provide two different representations of the molecular structure of proteins, and the third image shows foods that are high in protein. Students may mention that you need to eat protein if you want to build muscles when you work out. You may want to ask them how eating proteins contribute to increases in muscle size and strength. This can lead to the realizations that muscles are full of proteins that are needed for muscle contraction and the proteins we eat provide amino acids that our cells use to make our body's proteins.

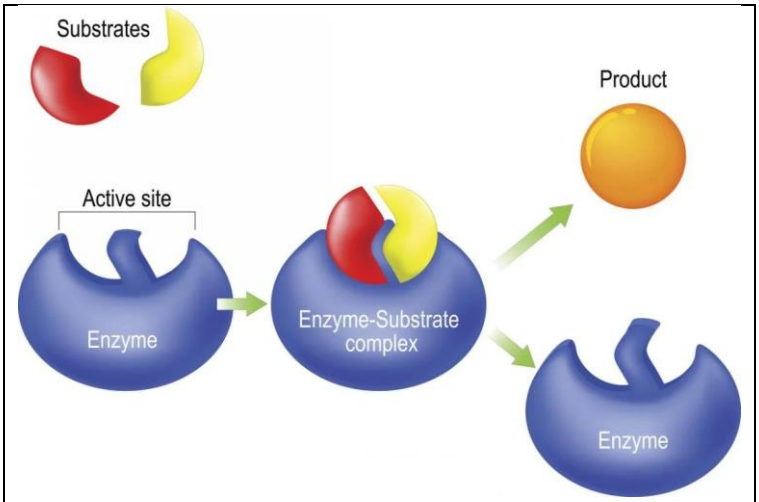
B. To introduce or review the structure and function of proteins, use the video recommended on slide 3, "What is a protein?" (https://www.youtube.com/watch?v=wvTv8TqWC48&feature=youtube) (~7 minutes; a Spanish language version of this video is available at https://www.youtube.com/watch?v=wZVWnH0VPuw). This video is probably the best overview. If the complete version of this video is too technical for your students, you can:

- show the first 50 seconds and then skip to 4 minutes and 15 seconds through 6 minutes and 30 seconds or
- substitute the 1-minute video, "What are proteins?" (https://learn.genetics.utah.edu/content/basics/proteins/), plus the non-video interactive, "Types of Proteins" (https://learn.genetics.utah.edu/content/evolution/proteintypes/).[4]

[3] The PowerPoint and the Student Handout are available at https://serendipstudio.org/exchange/bioactivities/proteins. A key for the Student Handout is available upon request to Ingrid Waldron (iwaldron@upenn.edu).

[4] The Learn Genetics video incorrectly states that proteins contain 20 different types of amino acids; the recommended video correctly states that human proteins contain 21 different types of amino acids, including selenocysteine. "Protein Functions in the Body" (http://www.youtube.com/watch?v=T500B5yTy58) offers amusing analogies to various protein functions. (If you use this video, show approximately the first 3 minutes and omit the hormone section at the end, since it has inaccuracies.) For detailed, clear explanations, you can use the "Structure and Function of Proteins" videos (https://www.youtube.com/watch?v=KH-LQSr7rHs + https://www.youtube.com/watch?v=MG8ziGyattk) (~12+6 minutes).

The recommended video only mentions the digestive enzyme, alpha amylase. To give your students a more complete picture of the importance of enzymes, you will probably want to mention that enzymes play a crucial role in molecular synthesis, as well as breakdown of molecules.



(https://www.medicalnewstoday.com/articles/319704)

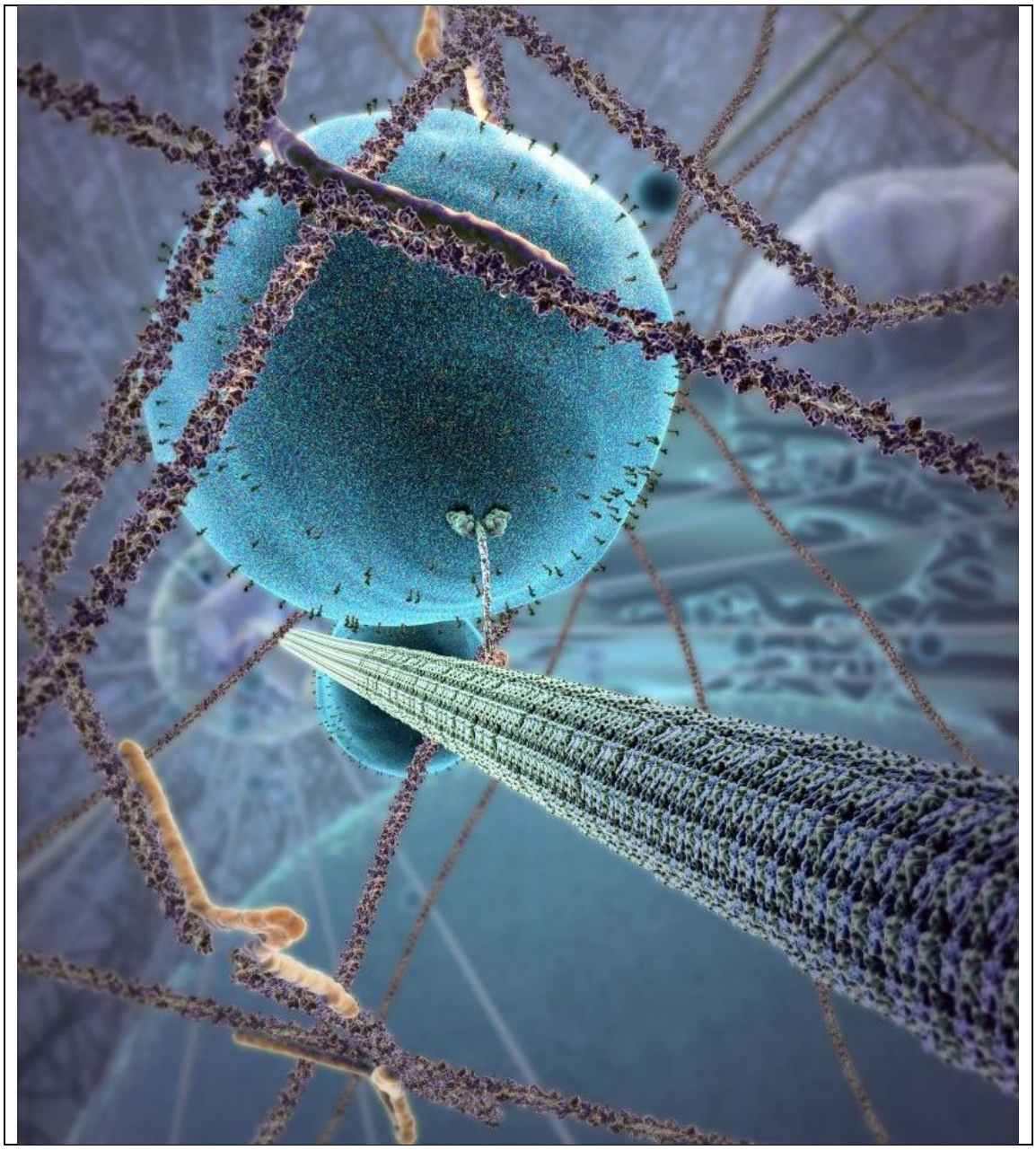
C. Use slide 4 of the PowerPoint to reinforce student understanding of the concept that structure matches function, using the example of the differences between the structure and functions of hands and feet. You may want to ask your students for additional examples of the relationship between structure and function. Familiar examples include:

- the broad flat shape of wings in insects, birds and bats
- the differences in structure and function between incisors and molars
- the similar streamlined shape of fish, penguins, and whales.

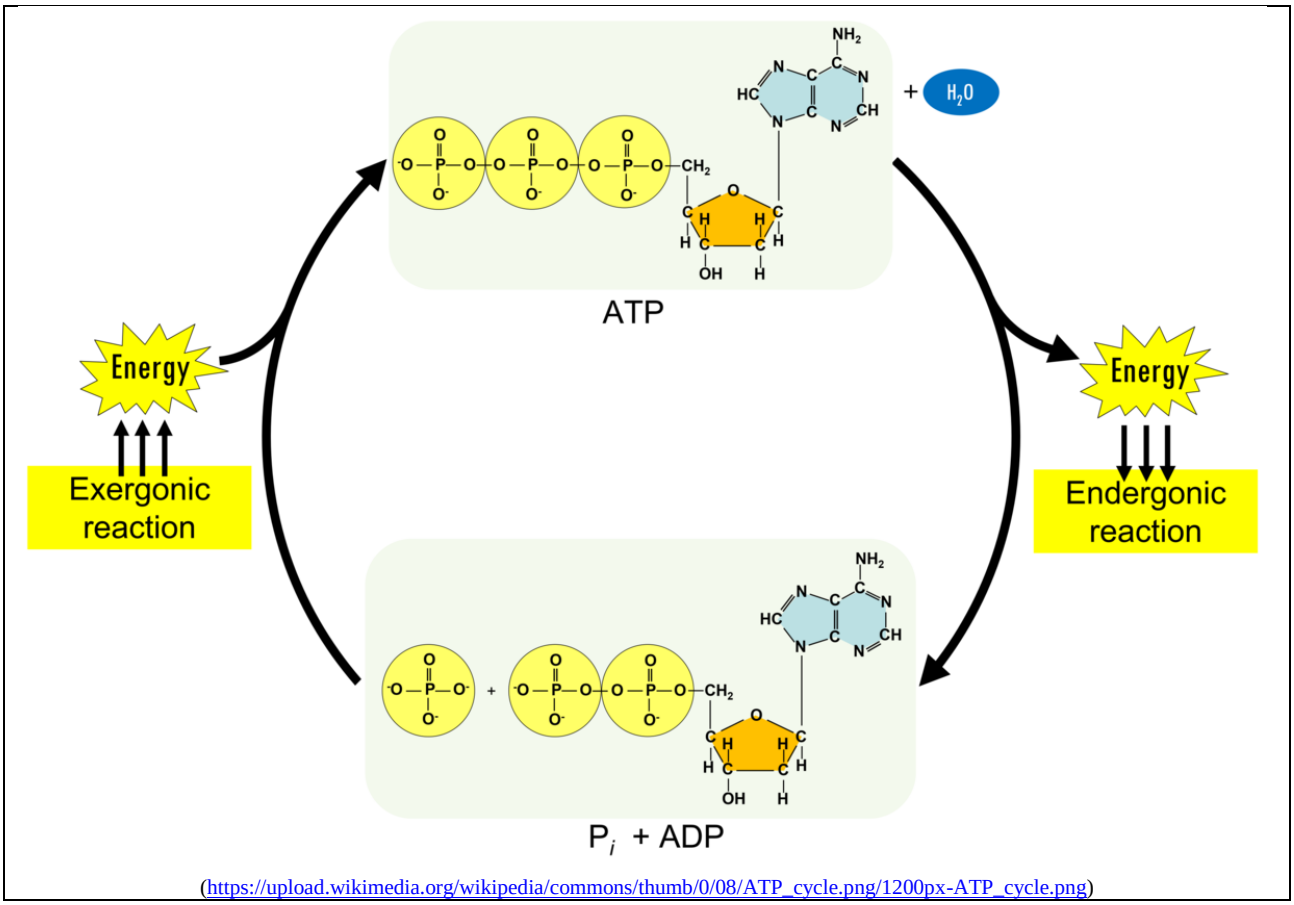
You may want to mention natural selection as the reason why structure matches function in biological organisms.

Slide 5 of the PowerPoint illustrates the principle that structure matches function also at the molecular level. The figure below is taken from the recommended 0.3-minute video (https://www.youtube.com/watch?v=y-uuk4Pr2i8);[5] this figure shows that the microtubule is very long, which matches its function as a track for the movement of the motor protein, kinesin. The motor protein walks along a microtubule carrying a vesicle with its molecular cargo. The motor protein and the vesicle are labeled in the video, but the microtubule is not labeled, so you will want to point out microtubule as you show the video. The long skinny parts of the motor protein are flexible for movement. Motor proteins and microtubules play an important role in intracellular transport, e.g., from the endoplasmic reticulum to the Golgi apparatus.

[5] This animation is generally scientifically accurate, but motor proteins actually step roughly 100 steps per second (http://book.bionumbers.org/how-fast-do-molecular-motors-move-on-cytoskeletal-filaments/).



Slide 5 shows that each step by the motor protein requires ATP. If your students are not familiar with ATP, you will probably want to mention that hydrolysis of ATP provides energy for many biological processes (see figure below).



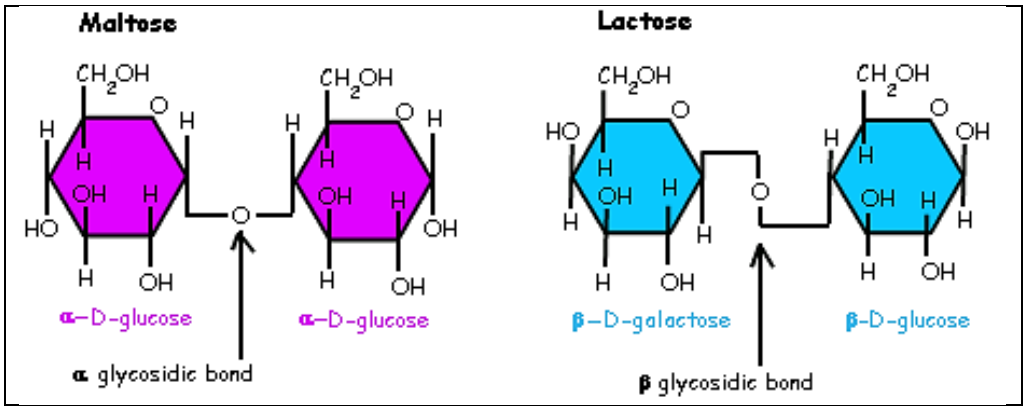
(https://upload.wikimedia.org/wikipedia/commons/thumb/0/08/ATP_cycle.png/1200px-ATP_cycle.png)

D. After slide 5, have your students complete page 1 of the Student Handout; this will reinforce student understanding of the functions of proteins and the relationships of protein function to protein structure. The following information will inform your class discussion of student answers to questions 1-4.

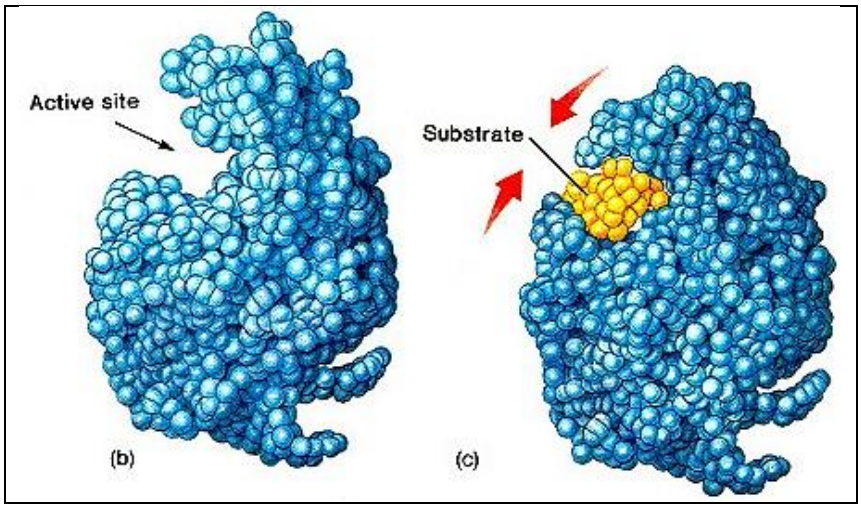
Collagen is a triple helix which forms long, cable-like fibers that provide tensile strength to tendons (which connect muscle to bone) and ligaments (which connect two bones). Collagen is also found in skin, bones and some other tissues (https://my.clevelandclinic.org/health/articles/23089-collagen).

Porin proteins provide channels for small polar or charged molecules (e.g., water) to cross the cell membrane.

To complete question 2 in the Student Handout, students need to recognize that collagen has a very different structure from a disaccharide, so collagen will not fit in the active site of the enzyme that breaks down maltose. Even a pair of amino acids joined by a peptide bond have a very different shape from the disaccharide and therefore will not fit in the active site of this enzyme. Indeed, the matching between the active site of an enzyme and the substrate is very precise, so different enzymes are required to break down maltose (a disaccharide derived from the digestion of starch) and lactose (the disaccharide in milk), despite the relatively modest differences between these disaccharides (see figure below). The specificity of the active site depends not only on the shape of the active site, but also on which specific amino acids surround the active site.



In discussing student answers to question 3, you may want to point out that other proteins, in addition to motor proteins, change shape or move in our cells. For example, the shape of the active site of an enzyme can change when the substrate molecule binds to the active site; this change can enhance binding and facilitate the reaction that the enzyme catalyzes. (This is called an induced fit.) (See figure below.) The end of a microtubule can lengthen or shorten as the tubulin proteins assemble or disassemble; these processes can separate chromatids during mitosis or result in some types of cell locomotion.



E. You may want to have your students complete the hands-on activity, "Enzymes Help Us Digest Food" (https://serendipstudio.org/sci_edu/waldron/#enzymes)

In this hands-on, minds-on activity, students investigate the biological causes of Maria's symptoms and Jayden's symptoms. To explore the causes of these symptoms, students carry out two experiments, interpret the results, and answer additional analysis and discussion questions. Students learn about enzyme function and enzyme specificity as they figure out that Maria's symptoms are due to lactase deficiency (resulting in lactose intolerance) and Jayden's symptoms are due to sucrase deficiency. In the final section, students are challenged to generalize their understanding of enzymes to interpret a video of an experiment with saliva, starch and iodine. (This activity is aligned with the NGSS (https://www.nextgenscience.org/).)

F. Show slide 6 and discuss student answers to the probe questions:

- Why do different people have different characteristics?
- Why are some people albino, but most people are not?[6]

In discussing these questions, students may mention that you can inherit conditions such as albinism from your parents; if they do, it will be useful to probe what it is that you get from your parents that can result in these conditions. If students mention the use of DNA in forensics, you will probably want to ask students why DNA is useful in forensics; this can lead to a discussion of how each person's DNA is unique.

G. Show slide 7 and discuss student answers to the probe questions:

- What is DNA?
- Why is DNA important?
- What is a gene?

You will want to mention that the figure shows only a small part of a DNA molecule, which is very long and narrow. A gene is also longer than shown, since genes have hundreds, thousands or up to 2 million nucleotides.

H. Show the videos at the links given on slide 8:

- "What are DNA and genes?" (https://learn.genetics.utah.edu/content/basics/dna; ~1 minute) and
- "What is DNA and how does it work?" (https://www.statedclearly.com/videos/what-is-dna/; ~5 minutes)

These brief animations provide a good basic understanding of DNA and genes. The second of these videos discusses RNA molecules as "partial copies" of the DNA; you will probably want to explain that each RNA molecule is a copy of a gene in the DNA. Also, for the second video, you may want to ask your students why the expressions that DNA "lives in" the nucleus and amino acids "live in" the cytoplasm are incorrect. (Obviously, the answer is that molecules are not alive.) This introductory activity does not mention that a typical gene codes for more than one protein (https://www.youtube.com/watch?v=lUcF6-PfC2M; https://www.nature.com/scitable/topicpage/rna-splicing-introns-exons-and-spliceosome-12375/). It also does not mention that much of the DNA does not code for proteins (https://medlineplus.gov/genetics/understanding/basics/noncodingdna/).

I. Show slides 9-10 and discuss the information about how different versions of a gene can result in albinism vs. normal skin and hair color (shown in slides 9-10 and near the top of page 2 of the Student Handout).

J. Have your students complete the second page in the Student Handout. Discuss the student answers to questions 5-7.

[6] "Why" can have two different meanings – "what is the mechanism?" or "for what purpose?" These questions are intended to focus on the first meaning.

K. You may want to conclude with additional examples that illustrate how different versions of a protein can have observable effects on our characteristics. The table below provides additional examples.

Protein Function	Examples	Effect if this Protein is Missing or Defective
Enzyme	Enzyme for synthesizing melanin (pigment that gives our skin and hair color)	Albinism (very pale skin and hair)*
	Lactase (breaks down lactose)	Lactose intolerance (difficulty digesting milk)*
	Acetaldehyde dehydrogenase (breaks down acetaldehyde, a harmful product of alcohol metabolism)	Alcohol sensitivity (skin flushing and unpleasant symptoms after drinking alcohol)*
Transport	Hemoglobin (protein in red blood cells which transports oxygen in the blood)	Sickle cell anemia (in homozygous individuals; heterozygous individuals have increased resistance to malaria)*
Clotting	Clotting proteins in blood	Hemophilia (excessive bleeding)*

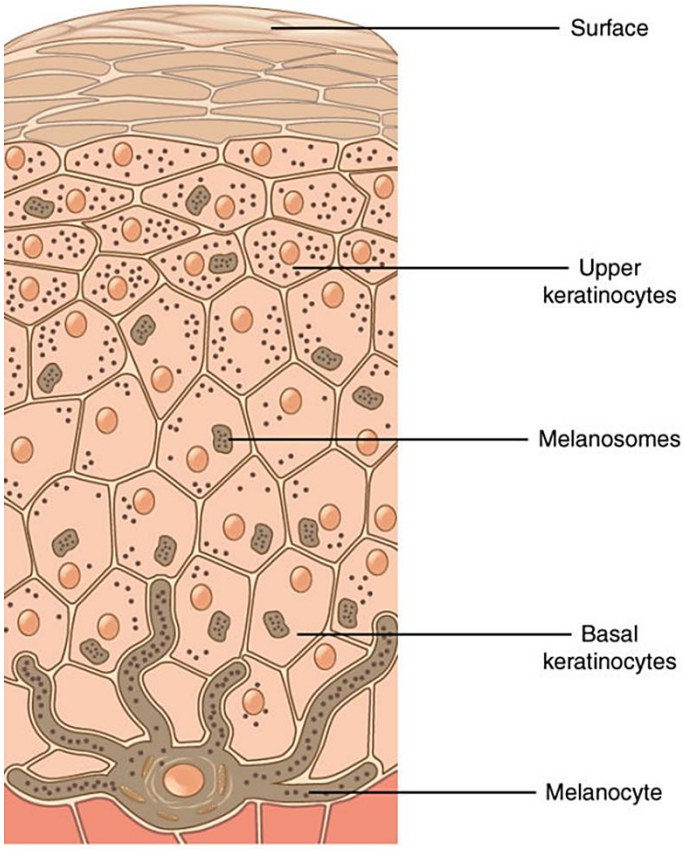
*Teacher information on these conditions is provided in the next section.

Teacher Information about Five Conditions that Illustrate the Effects of Proteins and DNA

Much of the information in this section is more sophisticated than would be appropriate for this introduction to proteins and DNA for high school students, but this information can be useful for your own understanding and for responses to questions from your students.

Albinism

This figure shows that melanocytes produce melanin which is packaged in melanosomes which are transferred to the keratinocytes that make up the bulk of our skin. Melanin protects the DNA of the keratinocytes from UV damage and helps to prevent the breakdown of folic acid. On the other hand, too much melanin can interfere with the production of vitamin D, which is needed for calcium absorption.



Melanin in the keratinocytes should be shown as clustered between the nucleus and the surface of the skin. (https://courses.lumenlearning.com/wm-biology2/chapter/pigmentation/)

In the most common form of albinism, the defective enzyme for producing melanin not only results in albino skin and hair color, but also affects the appearance and function of the eyes.

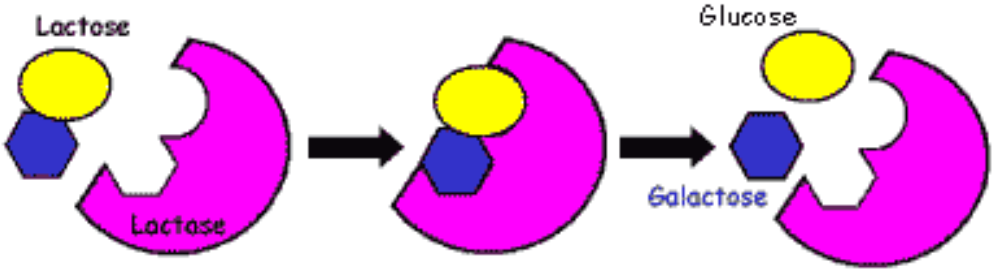
In a heterozygous individual, the normal allele is dominant because it codes for the functioning enzyme and, even when there is only one copy of the normal allele, there is enough of this functioning enzyme to produce enough melanin to prevent albinism. This illustrates the generalization that recessive alleles (e.g., the allele for albinism) often code for a non-functional protein, while dominant alleles often code for a functional protein.

Further information about albinism is available at https://medlineplus.gov/ency/article/001479.htm and http://omim.org/entry/203100.[7]

[7] Students may ask about the distinction between inherited albinism and vitiligo. Albinism is the inability of the body's cells to produce melanin and affects the whole body. Vitiligo is a patterned loss of melanin pigment resulting from the destruction of melanocytes; the hypopigmented areas appear on the skin of a person with normal pigmentation (http://www.mayoclinic.org/diseases-conditions/vitiligo/home/ovc-20319041).

Lactose Intolerance

To discuss lactose intolerance, your students need to understand the distinction between lactose and lactase. Lactose is the main sugar in milk and lactase is the protein enzyme that digests lactose into the simple sugars glucose and galactose. These simple sugars can be absorbed into the blood and utilized to provide energy for cellular processes such as muscle contraction.



Human babies and the babies of all other mammals depend on milk for their nutrition. Almost all babies produce lactase. In contrast, many adults produce very little lactase. The decrease in production of lactase as a person gets older is called lactase non-persistence.

The alleles of the gene for lactase differ in the nucleotide sequence in the regulatory DNA; this difference influences the rate of transcription of the coding DNA for the protein, lactase, and thus influences the rate of production of lactase.

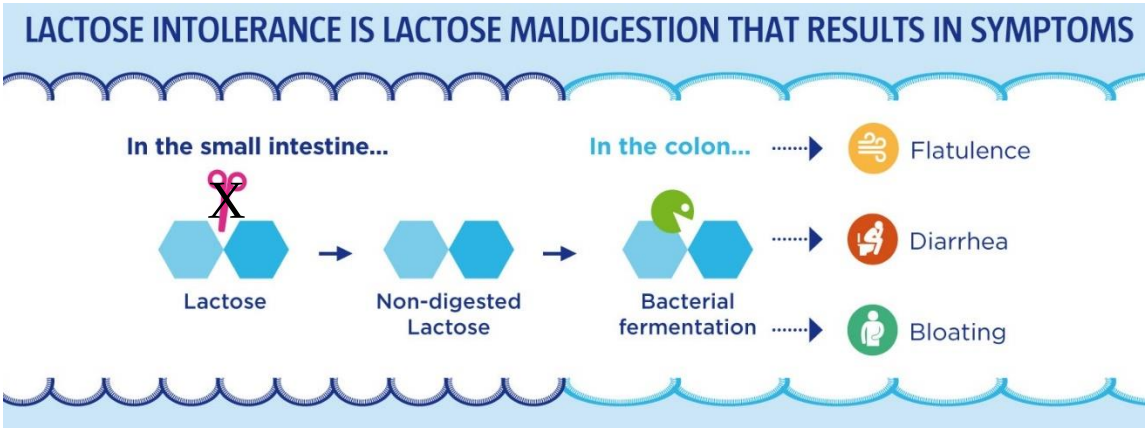
- Lactase persistence alleles result in substantial production of lactase throughout life.
- The lactase non-persistence allele results in substantial production of lactase by infants, but very low production of lactase in adults.

Thus, for virtually all infants and for adults with lactase persistence, the cells of the small intestine produce enough lactase, so all or most lactose molecules are broken down to glucose and galactose, which are absorbed from the lumen of the small intestine into the blood.

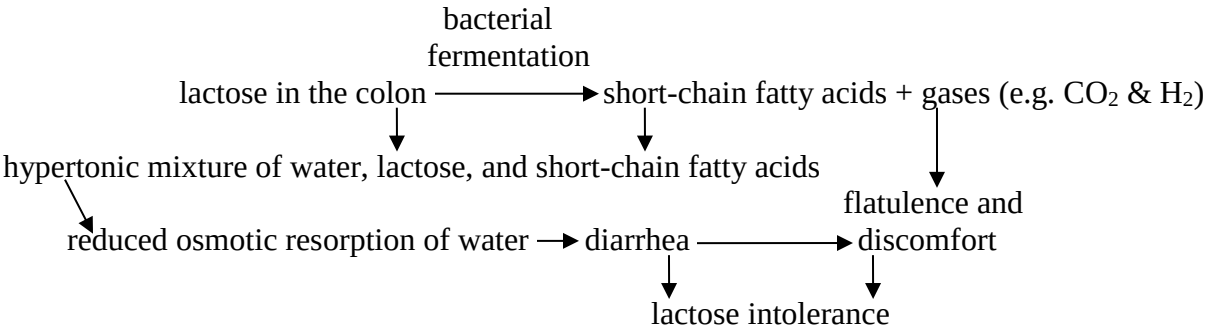
Notice that lactose intolerance is due to production of low amounts of the protein, lactase, whereas albinism and the other conditions described are due to the production of defective proteins (see table below).

Different Alleles have:					**Examples**
Different nucleotide sequence in DNA that codes for a protein	→	Different nucleotide sequence in mRNA	→	Different amino acid sequence in a protein	Albinism Alcohol sensitivity Hemophilia Sickle cell anemia
Or					
Different nucleotide sequence in regulatory DNA for a gene	→	Different amount of mRNA	→	Different amount of protein	Lactose intolerance

In lactase non-persistence, lactose that is not digested in the small intestine reaches the colon of the large intestine where lactose can cause symptoms (see graphic and flowchart below). This can result in lactose intolerance as a young child grows toward adulthood. Fewer than 1 in 60,000 newborns have lactose intolerance. However, lactose intolerance is very common among adults, especially in Asia and Africa, where most people are lactose intolerant.



(https://www.yogurtinnutrition.com/wp-content/uploads/2017/04/dii002-capsules_infographie_ang-5.jpg)



Given this physiology, it is surprising that lactase non-persistence is only loosely correlated with lactose intolerance. Some people who have lactase non-persistence do not have lactose intolerance, e.g., because lactase is produced by bacteria in their small intestines. Some people who think that they have lactose intolerance actually produce normal levels of lactase, so they can digest lactose and their symptoms presumably are due to other causes, such as:

- a chance coincidence between milk consumption and symptoms that gives rise to an inaccurate causal hypothesis
- an allergic reaction to one or more of the proteins in milk.

Lactose intolerance is not life-threatening, but milk allergies can be life-threatening. If a person has symptoms such as hives, wheezing, shortness of breath, or itching, tingling or swelling around the lips after consuming milk, he/she should seek medical advice and probably be tested for milk allergies. (A good summary of milk allergy is available at https://www.mayoclinic.org/diseases-conditions/milk-allergy/symptoms-causes/syc-20375101.)

Dairy products are an important source of calcium, protein and some vitamins. People with lactose intolerance can continue to gain the nutritional benefits of dairy products, but minimize symptoms by:

- using lactase supplements
- consuming dairy products with reduced lactose due to treatment with lactase (e.g. lactose-free milk) or due to fermentation by bacteria (e.g. traditionally made cheese or yogurt)

- consuming small amounts of dairy products at multiple times during the day
- gradually increasing regular consumption of modest amounts of dairy products which can select for lactase-producing bacteria in the small intestine.

Lactase persistence alleles provide an example of natural selection in humans. Lactase non-persistence alleles are nearly universal in mammals and were nearly universal in early humans. When some groups of humans began raising dairy animals, milk became available for consumption by older children, teens and adults. The ability to digest milk without diarrhea appears to have been particularly favored by natural selection during times of famine or prevalent diarrheal diseases. So, lactase persistence alleles were favored by natural selection and became common in many of the groups that raised dairy animals (https://www.nature.com/articles/s41586-022-05010-7). If you want to expand your students' understanding of natural selection and lactose intolerance, you can show them the video with review questions, "Got Lactase? The Co-Evolution of Genes and Culture" (https://media.hhmi.org/biointeractive/interactivevideo/gotlactasequiz/). Different lactase persistence alleles are observed in European and African herding groups. This illustrates convergent evolution – the independent evolution of similar characteristics in different populations.

For additional information on lactose intolerance, see:

- "Lactose Intolerance" (https://www.niddk.nih.gov/health-information/digestive-diseases/lactose-intolerance)
- "The Science behind Lactose Intolerance" (https://www.carolina.com/teacher-resources/Interactive/the-science-behind-lactose-intolerance/tr38902.tr?s_cid=em_ctgen1_201609)

Alcohol Sensitivity

The enzyme, acetaldehyde dehydrogenase, plays an important role in alcohol metabolism.

$$\text{alcohol} \xrightarrow{\text{alcohol dehydrogenase}} \text{acetaldehyde} \xrightarrow{\text{acetaldehyde dehydrogenase}} \text{acetic acid}$$

An inactive form of acetaldehyde dehydrogenase results in the accumulation of high levels of acetaldehyde after drinking alcohol. The accumulation of acetaldehyde results in unpleasant symptoms including increased heart rate and stroke volume and associated heart palpitations, increased blood flow to the skin and flushing, and a general "terrible feeling overall". This condition is called alcohol sensitivity or alcohol intolerance.

Heterozygous individuals have substantial accumulation of acetaldehyde and substantial symptoms, in large part because the functional enzyme is a tetramer and even one abnormal protein in the tetramer may inactivate the enzyme. Although heterozygous individuals are sensitive to alcohol, alcohol sensitivity is more severe in homozygous individuals who experience very unpleasant symptoms whenever they drink alcohol and consequently almost never develop alcoholism. The drug Antabuse (disulfiram), which is given to treat alcohol abuse, works by blocking the enzyme acetaldehyde dehydrogenase. This results in increased concentrations of acetaldehyde and the resultant highly unpleasant symptoms if a person drinks.

The allele that codes for the relatively inactive version of acetaldehyde dehydrogenase which results in alcohol sensitivity is relatively common in people of East Asian descent, but extremely rare in people of European descent.

Additional information is available at:

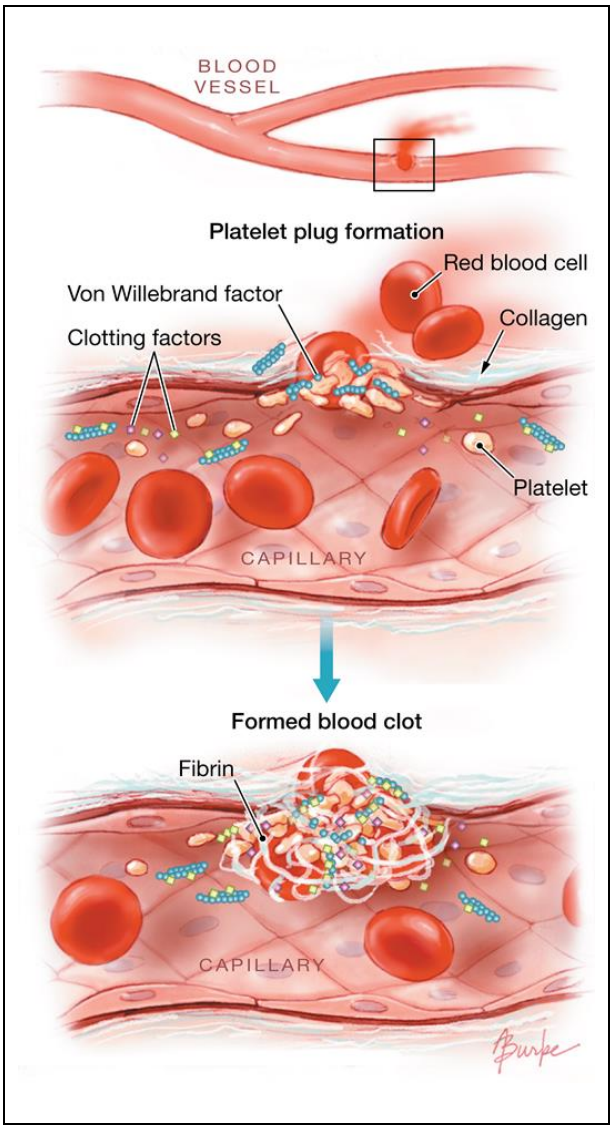
- http://www.mayoclinic.org/diseases-conditions/alcohol-intolerance/basics/definition/con-20034907
- http://en.wikipedia.org/wiki/Alcohol_flush_reaction

Hemophilia

Normally, an injury to a blood vessel triggers the activation of a series of clotting proteins which results in the formation of a clot.

Hemophilia is a bleeding disorder that results from defective blood clot formation. Mutated versions of the gene for one of the clotting factors can result in a protein which does not function properly and/or breaks down rapidly. If one of the blood-clotting proteins is defective, it takes an abnormally long time for a blood clot to form, resulting in excessive bleeding after injury or surgery. In severe cases, a person may experience spontaneous internal bleeding (e.g. in the joints). There are multiple different alleles that can cause hemophilia, resulting in varying degrees of severity of hemophilia. (https://www.ncbi.nlm.nih.gov/books/NBK1404/)

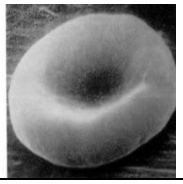
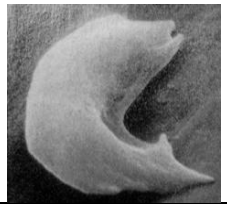
The most common causes of hemophilia are alleles of one of two genes on the X chromosome. Since a male has only one X chromosome in each cell, if his X chromosome has an allele that codes for defective clotting protein, he will not be able to make blood clots properly and he will have hemophilia. In contrast, a female has two X chromosomes; since the alleles for defective clotting protein are recessive, a woman generally only has hemophilia if both of her X chromosomes have a recessive allele for defective clotting protein.[8]



[8] In most heterozygous women, approximately half of her liver cells have the X chromosome with the normal allele active (due to random inactivation of one X chromosome in each cell); these cells are able to make enough blood clotting protein to prevent hemophilia. However, in ~30% of heterozygous females, random inactivation of one X chromosome in each cell has resulted in less than half the cells in her liver having the X chromosome with the allele for the normal clotting protein active and these women may have mild hemophilia (e.g. with heavy prolonged menstrual bleeding and frequent nosebleeds).

Sickle cell anemia

Sickle cell hemoglobin is less soluble in the watery cytosol of the red blood cells than normal hemoglobin, particularly when oxygen concentrations are low. Consequently, sickle cell hemoglobin tends to form long stacks or rods of hemoglobin molecules, which results in the sickled shape of some red blood cells in a person who is homozygous for the sickle cell allele and consequently has sickle cell anemia. The sickled red blood cells tend to clog the tiny capillaries, blocking the circulation in different parts of the body. Also, the sickled red blood cells do not survive as long as normal red blood cells, which contributes to anemia. Resulting symptoms include pain, physical weakness, impaired mental functioning, and damage to organs such as the heart and kidneys.

Genotype (genes)	→	Protein	→	Phenotype (characteristics)
2 copies of the allele that codes for normal hemoglobin (**SS**)	→	Normal hemoglobin dissolves in the cytosol of red blood cells. 	→	Disk-shaped red blood cells can squeeze through the smallest blood vessels → normal health 
2 copies of the allele that codes for sickle cell hemoglobin (**ss**)	→	Sickle cell hemoglobin can clump in long rods in red blood cells. 	→	When sickle cell hemoglobin clumps in long rods → sickle-shaped red blood cells → clogged small blood vessels + fragile red blood cells → pain, damage to body organs + anemia = sickle cell anemia 

In a person who is heterozygous for the sickle cell and normal hemoglobin alleles, each red blood cell has both sickle cell and normal hemoglobin. The amount of normal hemoglobin is sufficient to prevent the symptoms of sickle cell anemia in almost all cases. The sickle cell hemoglobin in each red blood cell decreases the severity of malaria in heterozygous individuals because the malaria parasite doesn't grow as well in red blood cells containing sickle cell hemoglobin. Decreased severity of malaria is an advantage that resulted in natural selection for the sickle cell hemoglobin allele in regions of Africa where malaria is prevalent.

-A good summary of the medical aspects of sickle cell anemia, including symptoms, diagnosis and treatment is available at http://www.mayoclinic.com/health/sickle-cell-anemia/DS00324.
-A video, "Sickle cell anemia" is available at https://www.biointeractive.org/classroom-resources/sickle-cell-disease.
-Recent progress in gene therapy for sickle cell anemia is described in https://www.nytimes.com/2019/01/27/health/sickle-cell-gene-therapy.html, https://www.nature.com/articles/d41586-018-07646-w, https://sicklecellanemianews.com/gene-therapy/.

Additional Teaching Resources

These learning activities will help students to meet the NGSS.

- **A Scientific Investigation – What types of food contain starch and protein?** (https://serendipstudio.org/sci_edu/waldron/#starch)
  In the first part of this activity, students answer analysis and discussion questions as they learn about the structure, functions, and synthesis of starch and proteins. They use this information to explain why certain parts of plants or animals contain a substantial amount of starch or protein. Then, students carry out key components of a scientific investigation, including generating hypotheses, designing and carrying out experiments to test their hypotheses, and, if needed, using experimental results to revise their hypotheses.
- **How do Siamese Cats Get Their Color?** (http://ngss.nsta.org/Resource.aspx?ResourceID=487)
  This is a 6 or 7-day unit in which students learn about the connections between genes, proteins and traits. This unit includes analysis and discussion activities, a hands-on experiment, and work with a paper model and a computer model. This unit can be used as an introduction to molecular biology, before discussing transcription and translation.
- **Molecular Biology: Major Concepts and Learning Activities** (https://serendipstudio.org/exchange/bioactivities/MolBio)
  This overview reviews key concepts and learning activities to help students understand how genes influence our traits by molecular processes. Topics covered include basic understanding of the important roles of proteins and DNA; DNA structure, function and replication; the molecular biology of how genes influence traits, including transcription and translation; the molecular biology of mutations; and genetic engineering. To help students understand the relevance of these molecular processes, the suggested learning activities link alleles of specific genes to human characteristics such as albinism, sickle cell anemia and muscular dystrophy. Suggested activities include hands-on laboratory and simulation activities, web-based simulations, discussion activities and a vocabulary review game.
- **Genetics – Major Concepts, Common Misconceptions, and Learning Activities** (https://serendipstudio.org/exchange/bioactivities/GeneticsConcepts)
  Part I summarizes key concepts in genetics. Part II presents common misconceptions. Part III recommends an integrated sequence of learning activities on the biological basis of genetics, plus seven human genetics learning activities. These learning activities develop student understanding of key concepts and counteract common misconceptions.