**Understanding the Functions of Proteins and DNA**

Ingrid Waldron, Biology Department, University of Pennsylvania, 2015[[1]](#footnote-1)

This overview provides a sequence of learning activities to help students understand that proteins and DNA are not just abstract concepts in biology textbooks, but rather crucial components of our bodies that affect functions and characteristics that students are familiar with. Students learn about the functions of proteins and how different versions of a protein can result in a characteristic such as albinism or sickle cell anemia. Then students learn that genetic information in DNA results in the different versions of these proteins, which is how genes influence our characteristics. These concepts are conveyed in discussion, web-based, and hands-on learning activities that can be used in an introductory unit on biological molecules or as an introduction to a unit on molecular biology.

**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.

Learning Goals Related to National Standards

In accord with the Next Generation Science Standards[[2]](#footnote-2):

* + - * 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 two Scientific Practices, planning and carrying out investigations and constructing explanations.
* This activity provides the opportunity to discuss the Crosscutting Concept, "structure and function".
* 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 among the role of DNA and chromosomes encoding the instructions for characteristic traits passed from parents to offspring."

I**. Proteins**

**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**.

**Teaching Approaches:**

1. Discussion of the probe questions:

* What are proteins?
* Why are proteins important?

Students may mention that you need to eat protein if you want to build muscles when you work out. To follow this up, it will be useful to ask them why you need to eat protein and what kinds of food contain protein, which can lead to the realization that muscles are full of protein and a brief discussion of the role of proteins in muscle contraction and movement.

2. Show YouTube video "Protein Functions in the Body" (available at <http://www.youtube.com/watch?v=T500B5yTy58> ). Omit the hormone section at the end, since it has inaccuracies. Ask students to identify 5 functions of proteins.

3. Introduce or reinforce a basic understanding of protein structure, using the 2 minute video available at <https://www.youtube.com/watch?v=FKwSIu_XxnY> .

4. Use the following examples to relate the structure and function of different types of proteins. This will help students to relate the information on structure in 3 to the information on function in 2.

|  |  |
| --- | --- |
| http://www.ibri.org/RRs/RR051/51bldgblks3.gif | The motor protein, kinesin, walks along a microtubule carrying a vesicle with its contents. The microtubule consists of two types of tubulin polypeptides. These intracellular proteins play an important role in intracellular transport, e.g. from the endoplasmic reticulum to that Golgi apparatus. You may want to show your students the animation of kinesin in action (<http://upload.wikimedia.org/wikipedia/commons/1/1c/Kinesin_walking.gif>).  |
| http://upload.wikimedia.org/wikipedia/commons/2/2c/Porin.qutemol.dl.png | A porin protein provides a channel for a small molecule to diffuse across a cell membrane. |
| http://www.mad-cow.org/collagen.gif | Collagen is a long protein with three polypeptides twisted together like a rope or cable. Collagen gives strength to the tendons and ligaments which connect bones and muscles. Collagen also gives strength to the extracellular matrix of animal cell membranes. |

5. Review protein functions and reinforce the idea that, if a protein is missing or defective, this has observable effects on our bodies:

|  |  |  |
| --- | --- | --- |
| **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\* |
| Clotting  | Clotting proteins in blood | Hemophilia (excessive bleeding)\* |

\*Teacher information on these conditions is provided, in section III, beginning on page 5.

6. You may also want to provide students with a hands-on experience with digestive enzymes.

* Hands-on activity: Enzymes Help Us Digest Food (available at <http://serendip.brynmawr.edu/sci_edu/waldron/#enzymes>)

Students learn about enzyme function, enzyme specificity and the molecular basis of lactose intolerance through experiments with the enzyme lactase and analysis and discussion questions. Students engage in the scientific practices of designing and carrying out experiments and interpreting data. Students also analyze how lactase functions in the digestive system and how the digestive and circulatory systems cooperate to provide cells all over the body with molecules that provide the energy for cellular processes.

or

* Have students experience the effects of the protein enzyme amylase in saliva on starch in bread or crackers – <http://ilovebacteria.com/amylase.htm>

7. Revisit probe questions.

II**. DNA**

**Key Concepts**:

* **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** (as illustrated in the above table)**.**

**Teaching Approaches:**

1. Discussion of probe questions:

* "Why do some people have albinism, lactose intolerance, sickle cell anemia, or hemophilia, and other people don't?"
* "What is DNA?"
* "What is a gene?"

In discussing the first question, students may mention that you can get conditions such as albinism or sickle cell anemia 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. Discussion of "What is a gene?" can be linked to the previous questions, since we inherit genes from our parents and genes are segments of DNA. You may want to introduce the concept of genes as segments of DNA that code for proteins which influence our characteristics.

2. Show "What is a gene?" available at <http://learn.genetics.utah.edu/content/molecules/gene/>

This illustrated brief lecture will help to clarify the concepts introduced in the discussion of the probe questions. This will further student understanding of both Key Concepts for this section.

3. Relate different versions of a gene to different proteins which result in different characteristics

As a follow-up to 2, have students complete this table. This will help them understand that genes influence an organism's characteristics by determining which types of proteins the organism makes.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  **Gene in DNA**  | **→** | **Protein** | **→** | **Characteristic** |
|  | **→** | http://www.lifl.fr/~htouzet/M1/hb.jpg | **→** | Normal Health vs. Sickle Cell Anemia |
| Version of the gene that provides instructions to make normal hemoglobin | **→** | **\_\_\_\_\_\_\_\_\_\_\_\_\_\_****\_\_\_\_\_\_\_\_\_\_** | **→** | Disk-shaped red blood cellscan squeeze through the small blood vessels **→** normal health | http://www.ama-cmeonline.com/pain_mgmt/images/pop_up/normal_vs_sickle_cell.jpg |
| Version of the gene that provides instructions to make \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | **→** | **\_\_\_\_\_\_\_\_\_\_\_\_\_\_****\_\_\_\_\_\_\_\_\_\_** | **→** | Sickle-shaped red blood cells **→** clog small blood vessels + red blood cells fragile**→** pain, damage to body organs  + anemia = sickle cell anemia | http://www.ama-cmeonline.com/pain_mgmt/images/pop_up/normal_vs_sickle_cell.jpg |

4. Revisit probe questions.

III. **Teacher Information about Conditions Resulting from Missing or Defective Proteins**

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 possibly also for responses to questions from your students.

**Albinism**

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 (such as the allele for albinism) often code for a non-functional protein, while dominant alleles often code for a functional protein.

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. Further information about the various forms of albinism, as well as a great deal of information on other aspects of human genetics, is available from OMIM = Online Mendelian Inheritance in Man ([www.ncbi.nlm.nih.gov/omim/](http://www.ncbi.nlm.nih.gov/omim/); search for 606952 (albinism), 223100 (lactose intolerance), 603903 (sickle cell anemia), or 306700 or 306900 (hemophilia)).

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. (Additional information from the National Vitiligo Foundation is available at www.nvfi.org.)

**Lactose Intolerance**

As background for understanding lactose intolerance, it is helpful to review 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.



In virtually all infants, lactase is produced by cells in the lining of the small intestine where lactose is digested. In contemporary humans, some teenagers and adults produce significant quantities of lactase. However, other teenagers and adults produce very little lactase; these individuals often have lactose intolerance, as explained in the following flowchart. (Lactose intolerance in infancy is very rare – less than 1 in 60,000 newborns.)

|  |
| --- |
| For virtually all infants and for adults with lactase persistence:– in the small intestine: lactase lactose glucose + galactose |
| For the roughly two-thirds of adults worldwide who have lactase nonpersistence:– in the small intestine, most lactose is not digested due to low levels of lactase – so, in the colon of the large intestine, lactose is fermented by anaerobic bacteria: fermentationlactose short-chain fatty acids + gases (e.g. CO2)  the mixture of water, partially digested  food, etc. in the colon is hypertonic flatulence and osmotic influx of water diarrhea discomfort  lactose intolerance |

The alleles for the gene for lactase differ in the nucleotide sequence in the regulatory DNA; this difference influences the age trend in 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 nonpersistence allele results in substantial production of lactase by infants, but very low levels of lactase in adults, resulting in lactose intolerance.

Notice that lactose intolerance is due to production of low amounts of the protein, lactase, whereas albinism and the other two conditions described are due to the production of defective proteins. Thus, the nature of the allele responsible for lactose intolerance differs from the alleles responsible for the other three conditions, as summarized in the following table.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Different Alleles****have:** |  |  |  |  | **Examples of Each****Type of Allele** |
| Different nucleotide sequence in DNA that codes for a protein | 🡪 | Different nucleotide sequence in mRNA | 🡪 | Different amino acid sequence in a protein | AlbinismAlcohol sensitivitySickle cell anemiaHemophilia |
| **or** |
| Different nucleotide sequence in regulatory DNA for a gene | 🡪 | Different amount of mRNA | 🡪 | Different amount of protein | Lactose intolerance |

Dairy products are an important source of calcium, as well as protein and some vitamins. People with lactose intolerance can continue to consume 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 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 lactose consumption of modest amounts of dairy products, which can result in adaptation of bacteria in the colon.

Lactose intolerance is different from a milk allergy which happens when the body's immune system reacts to proteins in milk. (A good summary of milk allergy is available at <http://kidshealth.org/PageManager.jsp?article_set=30372&lic=175&cat_id=20132> .)

For additional information on lactose intolerance, see Lactose Intolerance, available at http://digestive.niddk.nih.gov/ddiseases/pubs/lactoseintolerance/index.htm and <http://ghr.nlm.nih.gov/condition/lactose-intolerance>

**Alcohol Sensitivity**

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

 alcohol dehydrogenase acetaldehyde dehydrogenase

alcohol acetaldehyde 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.

Useful general introductions to this topic are available at <http://www.mayoclinic.org/diseases-conditions/alcohol-intolerance/basics/definition/con-20034907> and <http://en.wikipedia.org/wiki/Alcohol_flush_reaction>, and a more technical description is available at <http://www.omim.org/>; search for +100650.

**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, contributing to a tendency 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 allelethat codes fornormal hemoglobin (**SS**) | **→** | Normal hemoglobin dissolves in the cytosol of red blood cells. | **→** | Disk-shaped red blood cells can squeeze through the small blood vessels**→** normal health |
| 2 copies of the allelethat codes forsickle 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.

Additional information can be found in "Sickle cell anemia", available at [www.mayoclinic.com/health/sickle-cell-anemia/DS00324](http://www.mayoclinic.com/health/sickle-cell-anemia/DS00324)

A video, "Sickle cell anemia" is available at <http://www.hhmi.org/biointeractive/dna/DNAi_sicklecell.html>

**Hemophilia**

Hemophilia is a bleeding disorder due to defective blood clot formation. An injury to a blood vessel triggers the activation of a series of blood-clotting proteins which culminates in the activation of thrombin which converts fibrinogen to fibrin which forms a clot. When 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).

Hemophilia is due to alleles that code for defective clotting proteins, most commonly 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, so she generally only has hemophilia if she is homozygous for a recessive allele for a defective clotting protein. 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), and these cells are able to make enough blood clotting protein to prevent hemophilia. However, in some heterozygous women 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).

Additional information can be found in "Hemophilia", available at <http://ghr.nlm.nih.gov/condition/hemophilia>

 <http://www.hemophilia.org/NHFWeb/MainPgs/MainNHF.aspx?menuid=180&contentid=45>

**Additional Resource for Teaching about Macromolecules**

### A Scientific Investigation – What types of food contains starch and protein? (<http://serendip.brynmawr.edu/sci_edu/waldron/#starch>)

Students learn about scientific investigation by carrying out key components of the scientific method, including developing experimental methods, generating hypotheses, designing and carrying out experiments to test these hypotheses and, if appropriate, using experimental results to revise the hypotheses. Students design and carry out two experiments which test whether starch and protein are found in some or all foods derived from animals or plants or both.

* Who took Jerell’s iPod? **--** An Organic Compound Mystery (a hands-on activity available at <http://serendip.brynmawr.edu/sci_edu/waldron/#organic> )

In this activity, students learn how to test for triglycerides, glucose, starch, and protein and then use these tests to solve a mystery. The activity reinforces students understanding of the biological functions and food sources of these different types of organic compounds.

**Additional Resources for Teaching Molecular Biology**

Multiple activities for teaching about DNA structure, replication and function, transcription and translation, and the molecular biology of mutations are suggested in "Molecular Biology: Major Concepts and Learning Activities" (available at <http://serendip.brynmawr.edu/exchange/bioactivities/MolBio>).

1. These Teacher Notes and other activities for teaching biology are available at <http://serendip.brynmawr.edu/exchange/bioactivities>. Hands-on, minds-on activities for teaching biology are available at <http://serendip.brynmawr.edu/sci_edu/waldron/> [↑](#footnote-ref-1)
2. Next Generation Science Standards (<http://www.nextgenscience.org/next-generation-science-standards>) [↑](#footnote-ref-2)