

Teacher Notes for Understanding How Genes Are Inherited via Meiosis and Fertilization¹

In this minds-on activity, students answer analysis and discussion questions to learn how a child inherits one copy of each gene from each parent via the processes of meiosis and fertilization. They analyze how the processes of meiosis and fertilization result in the alternation between diploid and haploid cells in the human lifecycle. To learn how meiosis produces genetically diverse gametes, students analyze the results of crossing over and independent assortment. Then, students follow the alleles of a human gene from the parents' body cells through gametes and zygote to a child's cells. They learn how the outcomes of meiosis and fertilization can be represented in a Punnett square. A brief final section contrasts sexual reproduction with asexual reproduction.

This activity can be used to introduce meiosis and fertilization or to review these processes. If you are using the activity to introduce meiosis and fertilization, you may want to use three 50-minute periods as follows:

- Introduction – pages 1-3 of the Student Handout + possibly pages 5-6 of these Teacher Notes
- Meiosis – pages 4 through the top of page 6 of the Student Handout
- Inheritance – bottom two-thirds of page 6 through page 8 of the Student Handout

We recommend that, before your students begin this activity, you have them complete "Mitosis – How the Trillions of Cells in a Human Body Developed from a Single Cell" (<https://serendipstudio.org/exchange/bioactivities/MitosisRR>). Hands-on versions of the mitosis and the meiosis activities are available at https://serendipstudio.org/sci_edu/waldron/#mitosis and https://serendipstudio.org/sci_edu/waldron/#meiosis, respectively.

These Teacher Notes include:

- Learning Goals (pages 1-3)
- Instructional Suggestions and Background Biology
 - General (pages 3-4)
 - Introduction (pages 4-5)
 - Three Human Genes (pages 5-6)
 - How Meiosis Makes Haploid Eggs and Sperm (pages 6-7)
 - Genes are inherited via meiosis and fertilization. (pages 7-8)
 - Sexual vs. Asexual Reproduction (page 8)
 - Background Information on Albinism, Sickle Cell Anemia and Alcohol Intolerance (pages 8-11)
- Follow-Up activities and Sources for Student Handout Figures (pages 11-12)

Learning Goals

In accord with the Next Generation Science Standards²:

- Students will gain understanding of several Disciplinary Core Ideas:

¹ By Drs. Ingrid Waldron, Jennifer Doherty, Scott Poethig and Lori Spindler, Department of Biology, University of Pennsylvania, 2022. These Teacher Notes and the Student Handout are available at <https://serendipstudio.org/exchange/bioactivities/meiosisRR>

² Quotations from <https://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>. For middle school students, you can use this activity to help your students prepare for the NGSS Performance Expectation, MS-LS3-2, "Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation."

- 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."
- LS3.B: Variation of Traits – "In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation."
- Students will engage in the Scientific Practices:
 - "Developing and Using Models – Develop, revise, and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems."
 - "Constructing Explanations – Apply scientific ideas, principles and/or evidence to provide an explanation of phenomena..."
- This activity provides the opportunity to discuss the Crosscutting Concepts
 - "Systems and system models – ... Models can be valuable in predicting a system's behaviors..."
- This activity helps to prepare students for the Performance Expectations:
 - 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."
 - HS-LS3-2, "Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis..."

More Detailed Content Learning Goals

- Each cell contains chromosomes and each chromosome contains a long DNA molecule. Each DNA molecule has many genes. A gene provides the instructions for making a protein. Different versions of a gene are called alleles, and different alleles give the instructions for making different versions of a protein. These different versions of a protein can result in different phenotypic characteristics.
- Chromosomes come in pairs of homologous chromosomes. In each pair of homologous chromosomes, both chromosomes have the same genes at the same locations, but a gene may have different alleles in the two chromosomes of a homologous pair.
- Understanding how gene-carrying chromosomes behave during meiosis and fertilization provides the basis for understanding inheritance.
- Meiosis produces haploid gametes (sperm and eggs). Each haploid gamete contains one from each pair of homologous chromosomes. Thus, when a sperm fertilizes an egg, the resulting zygote has the normal diploid number of chromosomes.
- The DNA is replicated before meiosis begins. Then, meiosis I separates pairs of homologous chromosomes and meiosis II separates sister chromatids.
- Different gametes produced by the same person have different genetic makeup due to the separation of homologous chromosomes with different alleles into different gametes, independent assortment, and crossing over.
- When a haploid sperm fertilizes a haploid egg, the resulting diploid zygote receives one copy of each gene from the mother and one from the father. Repeated cell cycles (with DNA replication, mitosis and cytokinesis) produce the trillions of genetically identical cells in the body of the offspring. In this way, each person receives half of his/her genes from his/her mother and half from his/her father. As a result, children tend to resemble their parents and

their siblings. However, the genetic diversity of the sperm and eggs produced by each parent results in genetic diversity of the different offspring produced by the same mother and father. This activity will help students overcome the following common misconceptions:³

- Students don't understand the role that meiosis plays in heredity (e.g. why offspring resemble their parents and why there are genetic differences between siblings).
- Students do not understand the role of chance in producing new heritable characteristics by forming new combinations of existing genes... Sexual reproduction is not recognized as a source of variation.
- In general students do not appreciate the chemical basis of inheritance.

Instructional Suggestions and Background Information

To maximize student learning and participation, we recommend that you have students work in pairs to answer each group of related questions. Student learning is increased when students discuss scientific concepts to develop answers to challenging questions; furthermore, students who actively contribute to the development of conceptual understanding and answers to questions gain the most.⁴ After pairs of students have worked together to answer a group of related questions, we recommend that you have a class discussion to probe student thinking and help students develop a sound understanding of the concepts and information covered.

If your students are learning online, we recommend that they use the Google Doc version of the Student Handout available at <https://serendipstudio.org/exchange/bioactivities/MitosisRR>. To answer questions 3, 5-6, 11-12, 15, 17, 19-20, students can either print the relevant pages, draw on it and send you pictures, or they will need to know how to modify a drawing online. To answer online, they can double-click on the relevant drawing in the Google Doc to open a drawing window. Then, they can use the editing tools to answer the questions.⁵ If you are using the Word version of the Student Handout to make revisions, please check the PDF version to make sure that all formatting and figures are displayed properly in the Word version on your computer.

³ These misconceptions are paraphrased from a useful discussion of key concepts, common misconceptions, and learning activities for meiosis and variation in Chapter 3 of Hard to Teach Biology Concepts by Susan Koba with Ann Tweed, 2009, NSTA Press.

⁴https://education.asu.edu/sites/default/files/the_role_of_collaborative_interactions_versus_individual_construction_on_students_learning_of_engineering_concepts.pdf

⁵To draw a line

1. At the top of the page, find Select line and pick the type of line you want.
2. Place the line on your drawing:
 - Line, Elbow Connector, Curved Connector or Arrow: Click to start, then drag across the canvas.
 - Scribble: Click to start, then drag across the canvas.

To draw a shape

1. At the top of the page, find and click Shape.
2. Choose the shape you want to use.
3. Click and drag on the canvas to draw your shape.

To insert text

1. At the top of the page, click Insert.
 - To place text inside a box or confined area, click Text Box and drag it to where you want it.
2. Type your text.
3. You can select, resize and format the word art or text box, or apply styles like bold or italics to the text.

When you are done, click Save and Close.

If you would like to have a key with the answers to the questions in the Student Handout, please send a message to iwaldron@upenn.edu. The following paragraphs provide additional background information and instructional suggestions.

Introduction

Question 1b presents the driving question for this activity. Discussion of student answers will alert you to what your students already know and any misconceptions they may have.

Answering questions 1a and 2 should remind students of information they learned in the prerequisite mitosis activity (<https://serendipstudio.org/exchange/bioactivities/MitosisRR>). As discussed in the Teacher Notes for the mitosis activity, the definition of a gene has changed as scientific understanding has progressed; we are using the definition that a gene is a segment of a DNA molecule that gives the instructions for making a protein.

A key concept is that each cell in the child's body has all of the genes that were present in the zygote, which had all of the genes that were present in the sperm and egg. As discussed in the prerequisite activity on mitosis, not all of the genes are active in every cell; for example, during differentiation of the precursors of red blood cells the genes for hemoglobin become active, whereas during differentiation of skin cells and hair follicle cells the gene for the enzyme to make melanin becomes active.

Page 2 of the Student Handout introduces the terms diploid and haploid and reinforces student understanding of the significance of meiosis and fertilization in the human lifecycle.⁶ Ploidy refers to the number of complete sets of chromosomes in a cell. Question 5b should help your students notice that a haploid cell has half as many chromosomes as a diploid cell.

You may need to help your students notice that the flowchart on page 2 is another version of the flowchart on page 1. Your class discussion of question 6d provides the opportunity to point out that human cells are produced by mitosis (almost all cells), meiosis (gametes), or fertilization (zygote). Thus, all cells are derived from other cells.

To answer question 7, students should integrate the information from questions 3-6, using the hints provided in question 7. If question 7 is too challenging for your students, you can provide scaffolding as follows.

- If your students have trouble learning vocabulary, you may want to precede question 7 with a question that asks for definitions of the terms listed (or perhaps a matching question in which you provide your preferred definitions for these terms).
- As an introduction to this question, you may want to provide a concept map or graphic organizer for your students to review or complete (e.g., https://o.quizlet.com/JILLvNBPCEHGKuELPzblxQ_b.png, <https://d2vlcm6117u1fs.cloudfront.net/media%2Ffcb%2Ffcb8bc87-2c52-4e1b-9cee-5290ecc18677%2FphpMxHJUc.png>, https://www.easynotecards.com/uploads/111/63/25c4e1b0_158bcac4ea7_8000_00000674.PNG or <https://d2vlcm6117u1fs.cloudfront.net/media%2F294%2F2949b06c-a511->

⁶ The Student Handout includes the statement that "Almost all the cells in your body are diploid." This simplification ignores important exceptions in order to avoid undue complexity in this introductory activity. For example, during the development of red blood cells the diploid nucleus is ejected, so the numerous red blood cells have no chromosomes.

[4ecb-aead-b4a53c241b6f%2FphpYrroRn.png](#); you will need to omit parts of these concept maps that haven't been taught yet).

- You may want to provide an initial sentence stem to help your students begin their answers.
- Students may benefit from a preliminary small group discussion of the points they want to include in their answers, using the vocabulary list to suggest relevant concepts.

However, each student should prepare a written answer in his or her own words.

As your students answer question 7, they may want to cross off each term after they have included it in their answer.

Three Human Genes

In our experience, our emphasis on understanding how specific genes are transmitted by meiosis and fertilization contributes to student interest, enhances understanding, and provides an excellent introduction to Punnett squares. Human chromosome 11 has the genes that can result in albinism and/or sickle cell anemia, as well as more than 1000 other genes. Human chromosome 12 has more than 1000 additional genes, including a gene that can result in alcohol intolerance. Humans have a total of 23 pairs of homologous chromosomes, with a total of roughly 20,000 genes.

At the beginning of this section, the Student Handout asserts “Everyone has the same genes in the same chromosomes, but different people can have different versions of a gene.” This statement helps to counteract a common misconception that some people have a gene for a condition and other people lack that gene. Although this statement is generally true for autosomes, it is clearly not true for the sex chromosomes. In rare cases, part of a chromosome may be missing or an extra chromosome may be present (e.g., trisomy 21). These complexities are not mentioned to facilitate student understanding in this introductory activity.

In the Student Handout, we introduce the terms genotype and phenotype, but we do not introduce the terms homozygous, heterozygous, dominant or recessive.⁷ Instead we introduce the latter terms in our Genetics activity (https://serendipstudio.org/sci_edu/waldron/#genetics). If you prefer, these terms can easily be introduced when you discuss page 3 of the Student Handout. For this purpose, you may want to include the following prose and questions after question 9.

If both copies of a gene have the same allele, the person is **homozygous** for that gene. If the two copies of a gene have different alleles, the person is **heterozygous**.

10. Match each item in the list on the left with the best match from the list on the right.

Aa genotype ____

a. heterozygous

HH genotype ____

b. homozygous

⁷ In a heterozygous individual, typically both alleles are transcribed and both versions of the protein are produced. For many genes, the allele that codes for a functional protein results in the production of enough normal protein to produce a normal phenotype. In these cases, the allele that codes for a functional protein is dominant and the allele that codes for a nonfunctional protein is recessive. An exception, where the allele for the nonfunctional protein is dominant, is the gene for the enzyme that disposes of a harmful molecule produced by alcohol metabolism. The functional enzyme consists of four normal polypeptides bound together; even one nonfunctional polypeptide in this tetramer may inactivate the enzyme. This helps to explain why the allele for the nonfunctional protein is dominant. The sickle cell allele could best be described as co-dominant, since both alleles affect the phenotype of a heterozygous person; a heterozygous person does not have sickle cell anemia (due to the allele for normal hemoglobin) and also has increased resistance to malaria (due to the sickle cell allele).

Often, in a heterozygous individual a **dominant** allele determines the observable characteristic and the other **recessive** allele does not affect the phenotype. Thus, a heterozygous person has the same phenotype as a person who is homozygous for the dominant allele. In our example, the **A** allele is dominant because it codes for normal, functional enzyme and, even in a heterozygous individual, there is enough of this normal, functional enzyme to produce enough melanin to result in normal skin and hair color. The **a** allele is recessive because it codes for a non-functional enzyme which does not affect skin or hair color in a heterozygous individual.

11a. For the albinism gene, what are two different genotypes that result in the same phenotype?

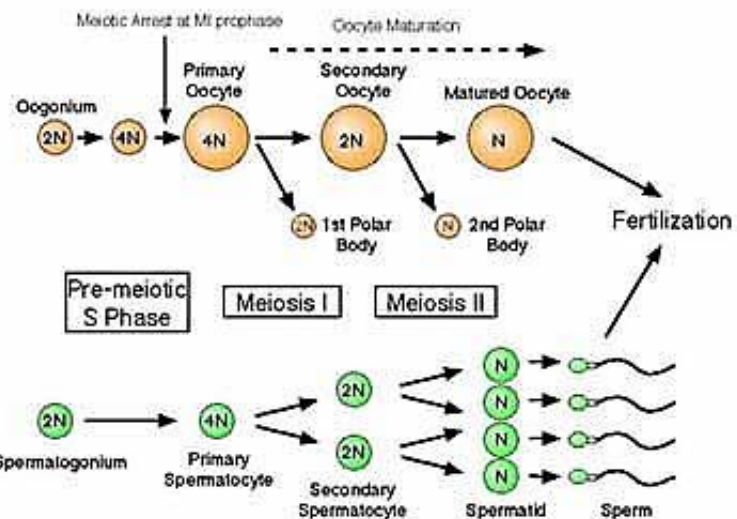
11b. Explain how two people with different genotypes can have the same phenotype.

For more information about the phenotypic effects of the alleles introduced in this section, see pages 8-11 of these Teacher Notes. You will probably want to mention that other genes and the environment also affect phenotypic characteristics such as skin color.

How Meiosis Makes Haploid Eggs and Sperm

The figure on page 4 of the Student Handout shows the basic processes of meiosis; crossing over and independent assortment will be introduced on page 5. You should explain that, although this figure shows only one pair of homologous chromosomes, the same processes are occurring simultaneously for each pair of homologous chromosomes.

The Student Handout implies that meiosis results in the production of four gametes. This is accurate for meiosis in males. However, in females each meiotic division produces one cell which has most of the cytoplasm and another tiny polar body cell. Thus, meiosis produces a single egg with a lot of cytoplasm. This is useful since the egg provides the cytoplasm for the multiple cells produced by the cell divisions that transform the zygote into the very early embryo. We have omitted this information from the Student Handout to avoid excessive complexity in this introductory activity.



The secondary oocyte or spermatocyte is labeled as 2N because it has two copies of the genome. However, these two copies are in two sister chromatids; there is only one chromosome from each pair of homologous chromosomes, so these cells are haploid.

Question 12b introduces the genetic diversity of gametes, which will be discussed further on page 5 of the Student Handout.

In discussing question 13, you may want to contrast mitosis (which involves one cell division for each time the DNA is replicated) with meiosis (which involves two cell divisions, but only one replication of DNA). Additional comparisons between mitosis and meiosis are provided in

question 14 of this activity and also in the analysis and discussion activity, “Comparing Mitosis and Meiosis” (<https://serendipstudio.org/exchange/waldron/MitosisMeiosis>).

Student answers to question 17 should show that independent assortment of two pairs of homologous chromosomes results in $2^2 = 4$ different combinations of alleles. Similarly, independent assortment of the 23 human chromosomes results in $2^{23} = 8.4$ million different combinations of alleles.

If you want to introduce the phases of meiosis I and meiosis II, you can use a different video in place of the 2-minute video recommended in the third paragraph of page 6 of the Student Handout. The 7-minute video, “Meiosis” (<https://www.youtube.com/watch?v=VzDMG7ke69g>), provides a clear basic introduction to the phases of meiosis I and meiosis II.

Genes are inherited via meiosis and fertilization.

This section helps students understand how meiosis and fertilization result in the inheritance of genes, using the example of two parents who each have the **Aa** genotype. The flowchart on the bottom half of page 6 of the Student Handout shows one possible outcome of meiosis and fertilization in a context that will be familiar from pages 1-2 of the Student Handout. Other possible outcomes are shown on page 7 of the Student Handout.

The figure on the top of page 7 of the Student Handout will help students understand how meiosis and fertilization work together to determine the genetic makeup of a zygote and the child that develops from a zygote. It is important to make sure that students understand that the four zygotes are the possible alternative outcomes of fertilization. Typically, a woman only ovulates one egg at a time, so only one of the fertilization events would actually occur; occasionally, a woman will ovulate two eggs simultaneously and fraternal twins may result. We recommend postponing further discussion of Punnett squares to one of our introductory genetics activities (available at https://serendipstudio.org/sci_edu/waldron/#genetics and <https://serendipstudio.org/exchange/bioactivities/geneticsFR>).

Question 24 will stimulate students to synthesize what they have learned about how meiosis and fertilization contribute to genetic diversity among siblings. During meiosis, independent assortment of the 23 pairs of homologous chromosomes can produce more than 8 million different combinations of chromosomes in the different eggs or sperm produced by one person. If each of the different types of egg from one mother could be fertilized by each different type of sperm from one father, this would produce zygotes with approximately 70 trillion different combinations of chromosomes! Crossing over results in an even greater amount of genetic diversity. Thus, it is easy to understand why no two people are genetically identical (except for identical twins who both developed from the same zygote).

Question 24 can be used for formative assessment. If this question is too challenging for your students, you can provide scaffolding for your students as follows.

- If your students have trouble learning vocabulary, you may want to precede question 24 with a question that asks for definitions of the terms listed (or perhaps a matching question in which you provide your preferred definitions for these terms).
- As an introduction to this question, you may want to provide a concept map or graphic organizer for your students to review or complete (e.g., https://o.quizlet.com/JILLvNBPcEHGKuELPzblxQ_b.png or

<https://d2vlcm6117u1fs.cloudfront.net/media%2Ffcb%2Ffcb8bc87-2c52-4e1b-9cee-5290ecc18677%2FphpMxHJUc.png>).

- You may want to provide an initial sentence stem to help your students begin their answers.
- Students may benefit from a preliminary small group discussion of the points they want to include in their answers, using the vocabulary list to suggest relevant concepts. However, each student should prepare a written answer in his or her own words.

Sexual vs. Asexual Reproduction

This brief introduction summarizes crucial differences between sexual and asexual reproduction.⁸ For question 25, sophisticated students may point out that there might be some genetic differences due to mutations; however, the main point is that mitosis produces genetically identical (or nearly identical) daughter cells, in contrast to the abundant genetic diversity of offspring produced by sexual reproduction. If your students are familiar with natural selection, you may want to follow up question 26b, with a discussion of how sexual reproduction provides much of the raw material for natural selection.

Additional information and examples are available at:

- [https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_\(CK-12\)/2%3A_Cell_Biology/2.36%3A_Asexual_vs._Sexual_Reproduction](https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_(CK-12)/2%3A_Cell_Biology/2.36%3A_Asexual_vs._Sexual_Reproduction)
- <http://education.seattlepi.com/five-examples-organisms-use-asexual-reproduction-5849.html>
- <http://www.nature.com/scitable/knowledge/library/case-study-the-glorious-golden-and-gigantic-13261308>).

An interactive activity for review and to learn more about asexual vs. sexual reproduction is available at <https://learn.genetics.utah.edu/content/basics/reproduction/>.

Background Information on Albinism, Sickle Cell Anemia and Alcohol intolerance

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

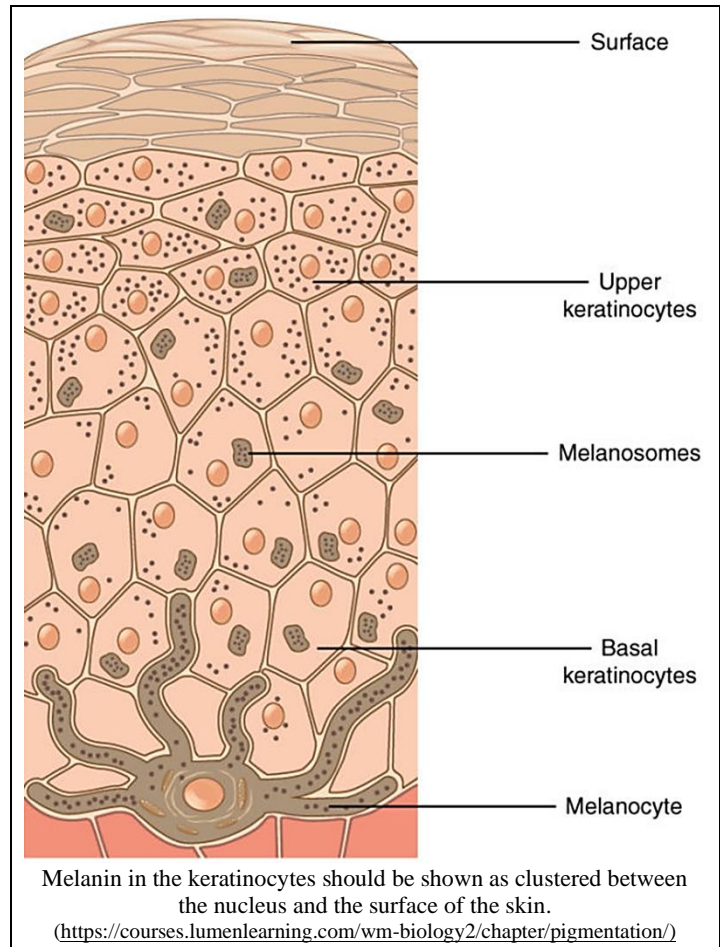
⁸ This section will help middle school students prepare for NGSS Performance Expectation, MS-LS3-2, "Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation." (Quotation from <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>)

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.

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>.⁹

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.

⁹ 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>).

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>.

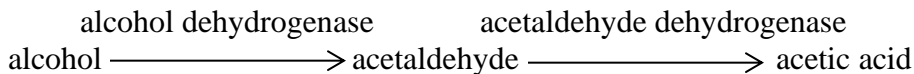
-Recent progress in gene therapy for sickle cell anemia is described in

<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/>.

Alcohol Intolerance

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



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 alcohol intolerance, due to substantial accumulation of

acetaldehyde. One major reason why the allele for the nonfunctional enzyme is dominant is that 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 allele that results in alcohol sensitivity is relatively common in people of East Asian descent, but extremely rare in people of European descent.

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.

Useful general introductions to this topic are available at <https://www.mayoclinic.org/diseases-conditions/alcohol-intolerance/symptoms-causes/syc-20369211> and http://en.wikipedia.org/wiki/Alcohol_flush_reaction, and a more technical description is available at <https://omim.org/entry/100650?search=100650&highlight=100650>.

Follow-Up Activities

Comparing Mitosis and Meiosis

(<https://serendipstudio.org/exchange/bioactivities/MitosisMeiosisC>)

In this minds-on analysis and discussion activity, students review the mitosis and meiosis as they compare and contrast meiosis and mitosis. The Teacher Notes for this activity include an optional mitosis and meiosis card sort.

How Mistakes in Meiosis Can Result in Down Syndrome or Death of an Embryo

(<https://serendipstudio.org/exchange/bioactivities/mmfmistakes>)

In this minds-on analysis and discussion activity, students learn how a mistake in meiosis can result in Down syndrome. Students also analyze karyotypes to learn how other mistakes in meiosis can result in the death of an embryo. Finally, students consider how a health problem can be genetic, but not inherited.

We recommend that the mitosis and meiosis activities be followed by one of our introductory genetics activities:

- Genetics (https://serendipstudio.org/sci_edu/waldron/#genetics) or
- Introduction to Genetics – Similarities and Differences Between Family Members (<https://serendipstudio.org/exchange/bioactivities/geneticsFR>).

Either of these activities will further demonstrate how meiosis and fertilization provide the basis for understanding inheritance. These activities are part of an integrated sequence of learning activities for teaching genetics, presented in "Genetics – Major Concepts and Learning Activities" (available at <https://serendipstudio.org/exchange/bioactivities/GeneticsConcepts>).

A Mitosis, Meiosis and Fertilization Vocabulary Game to reinforce learning of relevant vocabulary is available at <https://serendipstudio.org/exchange/bioactivities/mmfvocabgame>.

Sources for Figures in the Student Handout

- Figure on the top of page 5 modified from http://biologyequalslife.weebly.com/uploads/3/7/8/5/37850945/884166_orig.gif
- Figure on the bottom of page 8 from https://haygot.s3.amazonaws.com/questions/1076814_1197021_ans_cc52a7b7db7b47c5b858c61f554d9ab2.jpg

The other figures were prepared by the authors.