**Teacher Preparation Notes for**

**“Were the babies switched? – The Genetics of Blood Types”¹**

In this minds-on, hands-on activity, students learn the genetics of the ABO blood type system. Students use simple chemicals to simulate blood type tests and then carry out genetic analyses to determine whether hospital staff accidentally switched two babies born on the same day. This activity reinforces student understanding of the fundamental concepts that genes code for proteins which influence an organism’s characteristics and Punnett squares summarize how meiosis and fertilization result in inheritance. Students also learn about codominance and multiple alleles of a single gene.

There are two versions of the Student Handout. The first version includes an introduction to the immunobiology of the ABO blood type system. The second version includes an analysis of the genetics of skin color in which students learn how fraternal twins could have very different skin colors, the concept of incomplete dominance, and how a single phenotypic characteristic can be influenced by multiple genes and the environment.² (This material is also available as an Optional Addition for the first version of the Student Handout; see the last two pages of these Teacher Preparation Notes.)

As background for this activity, students should have a basic understanding of:

- dominant and recessive alleles; heterozygous individuals have the same phenotype as homozygous dominant individuals
- how meiosis and fertilization result in inheritance and how these processes are summarized in Punnett squares.

To provide this background you may want to use the first three pages of our "Genetics" activity or the first four pages of "Genetics Supplement" (both available at [http://serendipstudio.org/sci_edu/waldron/#genetics](http://serendipstudio.org/sci_edu/waldron/#genetics)).

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**Learning Goals Related to National Standards**

In accord with the Next Generation Science Standards³ and A Framework for K-12 Science Education⁴:

- Students will gain understanding of several 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."

¹ By Dr. Jennifer Doherty and Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, 2016. These Teacher Preparation Notes and the related Student Handout are available at [http://serendipstudio.org/exchange/waldron/bloodtests](http://serendipstudio.org/exchange/waldron/bloodtests).

² The same genetic concepts are covered in an analysis and discussion activity ("Were the babies switched?" in "Soap Opera Genetics – Genetics to Resolve Family Arguments"; [http://serendipstudio.org/exchange/bioactivities/SoapOperaGenetics](http://serendipstudio.org/exchange/bioactivities/SoapOperaGenetics)).


- LS3.A: Inheritance of Traits – "The instructions for forming species' characteristics are carried in DNA."
- LS3.B: Variation of Traits – In sexual reproduction, meiosis can create new genetic combinations and thus more genetic variation.

- Students will engage in several Scientific Practices:
  - constructing explanations
  - engaging in argument from evidence
  - carrying out an investigation
  - analyzing and interpreting data.

- This activity provides the opportunity to discuss the Crosscutting Concept, "Structure and Function".

- 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…"

**Specific Learning Goals**

**Both versions of the Student Handout**

- Each person has one of the four blood types: A, B, AB, and O. These blood types refer to the presence or absence of two different versions of a carbohydrate molecule (A and B) on the surface of red blood cells.

- Genes code for proteins which influence a person's characteristics. The ABO blood type gene codes for a protein enzyme that can attach carbohydrates to the surface of red blood cells. This gene has three alleles: the \( I^A \) allele codes for a version of the enzyme that attaches the A carbohydrate; the \( I^B \) allele codes for a version of the enzyme that attaches the B carbohydrate; and the \( i \) allele codes for an inactive protein that does not attach either carbohydrate.

- As a result of meiosis and fertilization, each person inherits one allele of this gene from his/her mother and a second allele from his/her father. The results of meiosis and fertilization are summarized in Punnett squares.

- In red blood cell precursors, both inherited alleles code for the production of protein enzymes. In a person who has the \( I^A I^B \) genotype, both the \( I^A \) and \( I^B \) alleles are active, so their red blood cells have both the type A carbohydrate and the type B carbohydrate, and they have type AB blood. This is an example of codominance, in which two alleles of a gene each have a different observable effect on the phenotype of the heterozygous individual.

- In a heterozygous person with the \( I^A i \) or \( I^B i \) genotype, the single copy of the \( I^A \) or \( I^B \) allele in each cell codes for enough enzyme to result in type A or type B blood, respectively. Thus, the \( i \) allele is recessive relative to the \( I^A \) or \( I^B \) alleles.

**The immunobiology version of the Student Handout**

- Both the A and B carbohydrates are antigens which stimulate the formation of antibodies. Antibodies are special proteins that travel in the blood and react with specific antigens. For example, anti-A antibodies react specifically with A antigens on the surface of red blood cells, but not with B antigens.

- Normally, your body does not make antibodies against antigens which are part of your own body. For example, a person with type A blood does not make anti-A antibodies, but does make anti-B antibodies. A blood transfusion can harm a person if the donated red blood cells have antigens that react with antibodies in the person's blood.
The skin color genetics version of the Student Handout and the optional addition to the immunobiology version

- In incomplete dominance, the phenotype of a heterozygous individual is intermediate between the phenotypes of the two different types of homozygous individuals (observed for quantitative traits).
- Many characteristics are influenced by multiple genes and environmental factors.

**Supplies, Suggestions for Implementation, and Preparation**

**Note:** Throughout this section we will refer to the seven people listed in the table on the bottom of page 4 of the Student Handout as the subjects.

**Supplies**

- Synthetic blood (see below for information about types and amounts needed)
- Solutions with synthetic anti-A antibodies and anti-B antibodies
- Small dropper bottles (can be reused in multiple classes) (An alternative is small bottles, each with a dropper or pipette, but these will be more subject to contamination; if contamination occurs, you will need to wash and refill the bottles between classes.)
- Non-porous testing surfaces suitable for mixing two samples of blood with antibody solution, e.g. blood-typing trays, microscope slides or white or transparent plastic lids (can be washed and reused in multiple classes) (If you use the recommendations for implementation shown below, each student group will need a testing surface large enough for 14 tests (two tests for each subject) or several smaller testing surfaces.)
- One marker for each student group to identify the 14 specific spots to test for the type A antigen and for the type B antigen for each subject.
- Toothpicks for mixing blood and antibody solution (If you use the recommendations for implementation shown below, each student group will need 14 toothpicks, or they can use both ends of 7 toothpicks.)
- Containers such as plastic cups or water bottles to use as trash containers so the students can throw away their toothpicks immediately after use to avoid contamination

If you are using commercial simulated blood and antibody solutions:

To determine the amount of synthetic blood, antibody solutions and dropper bottles you will need, you should choose one of these recommendations for implementation (or decide on your own approach).

- Give each student group at their lab table:
  - 7 bottles with the blood samples, each labeled with the name of one of the subjects or Baby girl 1 or 2
  - 1 bottle with the anti-A antibody solution and another bottle with the anti-B antibody solution (each labeled appropriately)
- Or you can set up three stations:
  - one where each student group will get the blood samples for each of the seven subjects
  - one where they will get the anti-A antibody solution
  - one where they will get the anti-B antibody solution.

Please note that the Student Handout Procedure (on page 4) is written for the colored milk simulated blood. If you are purchasing simulated blood, you may need to modify the procedure;
for example you can use only two drops each of simulated blood and simulated antibody solution.

To determine the amount of supplies, you will also need to decide what blood types you will assign to each subject. You may want to vary the blood types for each subject in different classes, in order to maintain some variety and suspense. This table illustrates some possible combinations of blood types for each subject.

<table>
<thead>
<tr>
<th>Examples of Blood Type Combinations You Can Use</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danielle (mother of twins)</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>O</td>
<td>A</td>
<td>B</td>
<td>AB</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Michael (father of twins)</td>
<td>O</td>
<td>A</td>
<td>B</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>O</td>
<td>A</td>
</tr>
<tr>
<td>Denise (mother of daughter)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Earnest (father of daughter)</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Michael Jr. (boy twin)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Baby girl 1 (girl twin, according to hospital)</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Baby girl 2 (daughter of Denise and Earnest, according to hospital)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>B</td>
</tr>
</tbody>
</table>

You can make other combinations, provided that:
- Michael Jr. can be the son of Danielle and Michael
- One of the baby girls could be a daughter of one of the couples and could not be a daughter of the other couple. The other baby girl could be a daughter of the other couple.

For example, each column of this table will also work if you reverse the blood types for the two baby girls. This would mean that the hospital made a mistake, which could add some suspense in different classes. However, if the hospital made a mistake and the twins have similar skin color, and if you are using the Optional Addition to the Student Handout (provided on the last two pages of these Teacher Preparation Notes), you will need to change some of the wording on the first page of the Optional Addition.

You can purchase kits (and/or refills) from:
- Carolina for $43 (and/or $24); [http://www.carolina.com/blood-typing/carolina-abo-rh-blood-typing-with-synthetic-blood-kit/FAM_700101.pr?qusetion=700101](http://www.carolina.com/blood-typing/carolina-abo-rh-blood-typing-with-synthetic-blood-kit/FAM_700101.pr?qusetion=700101). (We recommend you not use the Rh antiserum included in this kit.)

These kits have additional supplies such as some dropper bottles and testing trays. You may want to contact these companies to verify that their kits have the blood types and quantities you will

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5 We recommend against purchasing these supplies from www.Neoscience.com. One teacher has reported problems with the Ward’s kit. Please send feedback about the Carolina or Ward’s kits to iwaldron@upenn.edu.
need. This table shows the amounts of antibody solution and blood type solution you will need per student group for each of the blood type combinations in the table above.

**Approximate Amount (mL) Needed of Each Type of Solution for Each Student Group for Blood Type Combinations Listed above**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anti-A Antibody Solution</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Anti-B Antibody Solution</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>A Blood</strong></td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.8</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B Blood</strong></td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AB Blood</strong></td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>O Blood</strong></td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You will want more of each solution, so you will be prepared for student error such as using too many drops of a solution.

If you are using colored milk as your simulated blood and water or vinegar as your simulated antibody solutions:
If you have insufficient budget for the commercial products, you can use the following economical alternative. You can make simulated blood by combining 25 mL of milk with red food coloring until the solution is bright red (about 15 drops), and then adding a drop of green food coloring for a dark red color. You will need different anti-A and anti-B simulated solutions for each subject, depending on what type blood the sample is supposed to contain.

<table>
<thead>
<tr>
<th>Type of Blood</th>
<th>Simulated anti-A solution contains:</th>
<th>Simulated anti-B solution contains:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>White vinegar</td>
<td>Water</td>
</tr>
<tr>
<td>B</td>
<td>Water</td>
<td>White vinegar</td>
</tr>
<tr>
<td>AB</td>
<td>White vinegar</td>
<td>White vinegar</td>
</tr>
<tr>
<td>O</td>
<td>Water</td>
<td>Water</td>
</tr>
</tbody>
</table>

We recommend that you set up seven stations, one for each of the seven subjects, with the blood sample and the anti-A and anti-B solutions. Before class you should prepare seven bottles with the simulated blood, labeled with the subject’s name or Baby girl 1 or 2. You will also need the corresponding bottles of simulated anti-A and anti-B solutions. We recommend that you label each bottle of anti-A and anti-B solution with a number which will help you keep track of which pair of antibody solutions goes with each subject.

You can use the various blood type combinations shown on the top of page 4. You can estimate amounts of simulated blood and antibody solution needed using the following information:

- For each blood type test, you will need 3 drops of anti-A antibody solution and 3 drops of anti-B antibody solution and 4 drops of blood.
- There are approximately 15-20 drops in each milliliter of solution.

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6 We have had success with fat-free milk. We have not tried other types of milk, but assume it would work fine.
General Instructional Suggestions
To maximize student learning, we recommend that you have your students complete groups of related questions in the Student Handout individually or in pairs and then have a class discussion for each group of related questions. In each discussion, you can probe student thinking and help them to develop a sound understanding of the concepts and information covered before moving on to the next part of the activity.

The PDF of the Student Handout shows the correct format; please check this if you use the Word document to make revisions.

If you would like to have a key with the answers to the questions in the Student Handout and the Optional Addition (see pages 11-12 of these Teacher Preparation Notes), please send your request to iwaldrongas.upenn.edu. The following paragraphs provide additional instructional suggestions and background information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

Biology Background and Suggestions for Discussion
Note: this information is relevant for both versions of the Student Handout, but the question and page numbers given are for the immunobiology version of the activity and the Optional Addition.

For the ABO blood group:

- The I^A allele codes for a version of an enzyme that plays a crucial role in synthesizing glycoprotein and glycolipid molecules that contain the Type A carbohydrate; these glycoproteins and glycolipids are located in the cell membrane of red blood cells, with the carbohydrate on the outer surface of the cell membrane.\(^7\)
- The I^B allele codes for a different version of this enzyme that plays a crucial role in synthesizing glycoproteins and glycolipids with the Type B carbohydrate molecules.
- The i allele codes for an inactive version of the enzyme.

The function of these carbohydrate molecules is unknown. In general, people who have Type O blood with neither Type A nor Type B carbohydrates are as healthy as people who have the Type A and/or Type B carbohydrates. Different blood types are correlated with certain illnesses and vary in frequency in different ethnic groups, but the reasons are unknown.

\(^7\) The I or i in the names of these alleles stands for isoagglutinogen, which refers to an antigen that can stimulate the production of antibodies in other members of the same species; these antibodies result in agglutination (clumping) upon exposure to the antigen.
Page 1, including question 1, provides the opportunity to reinforce student understanding that:
- genes code for proteins which influence an organism’s characteristics
- genes often have more than two alleles.

In discussing question 2, you should remind students that heterozygous individuals have the same phenotype as an individual who is homozygous for the dominant allele. You will probably also want to point out that recessive alleles often code for a nonfunctional protein. In a heterozygous individual a single dominant allele can code for enough functional protein to result in the same phenotype as the phenotype of the homozygous dominant individual. For example, the $i$ allele is recessive relative to the $I^A$ or $I^B$ alleles because, in a heterozygous individual, the single dominant $I^A$ or $I^B$ allele codes for enough functional enzyme to result in the same blood type as observed in a homozygous dominant individual.

This activity helps students to understand the molecular basis for codominance, as well as dominant-recessive alleles. Each cell in the body contains two copies of each gene and typically both alleles are transcribed. Thus, at a molecular level, the alleles of most genes are codominant. For example, the $I^A I^B$ genotype results in the production of both the version of the enzyme that puts Type A carbohydrate molecules on red blood cells and the version of the enzyme that puts Type B carbohydrate molecules on red blood cells. Therefore, the $I^A I^B$ genotype results in Type AB blood. This illustrates codominance at the phenotypic level.

Questions 5-6 and 12 provide the opportunity to discuss:
- how meiosis and fertilization result in new combinations of alleles, so children may have different blood types (and other phenotypic characteristics) than their parents have
- how transmission of genes via meiosis and fertilization result in similarities between offspring and parents. For example, a child can only have type A blood if one or both parents have type A or AB blood (i.e. a child with the $I^A$ allele must have at least one parent with this allele).

In discussing the immunobiology of blood type tests, you may want to point out that each type of antibody binds to a specific antigen because the shape of the two binding sites on the antibody match the shape of the antigen that it binds to. The importance of the specific shape of the binding sites of the antibodies illustrates the Crosscutting Concept of Structure and Function (function depends on shape/structure).

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8 For example, a person who is heterozygous for the allele for normal hemoglobin and sickle cell hemoglobin has both types of hemoglobin in their red blood cells. Due to the normal hemoglobin in the red blood cells of a heterozygous person, the hemoglobin molecules almost never clump into rods that distort the shape of the red blood cells, so the heterozygous person almost never develops the symptoms of sickle cell anemia. The sickle cell hemoglobin in the red blood cells of a heterozygous person inhibits the reproduction of the malaria parasite in the red blood cells, so the heterozygous person is protected against severe malaria infections.
You may want to mention that some types of antibody bind to the antigens on the surface of bacteria that have infected a person’s body. The other end of each antibody can bind to a protein on the surface of a macrophage. This facilitates phagocytosis of the bacteria by the macrophage. The macrophage kills and digests the ingested bacteria. This is one way that antibodies contribute to the destruction of bacteria and help to protect our bodies against infection.

Normally, your body does not make antibodies against any molecules that are part of your own body. This is useful because antibodies against antigens that are part of your body could trigger harmful reactions, such as an immune attack on your body’s cells. As would be expected, a person does not make antibodies against the blood type antigens present on their red blood cells. However, a person with type A blood does make anti-B antibodies since gut bacteria have antigens similar to type B antigens, which stimulates the production of anti-B antibodies.

If a person with type A blood is given a transfusion of type B blood, the person’s anti-B antibodies will cause problems. The two binding sites on the tips of a Y-shaped antibody can bind to two different red blood cells, so the person’s anti-B antibodies can cause the donated type A red blood cells to clump, which can block blood vessels. In addition, antibodies bound to the antigens on the donated red blood cells activate complement, a group of proteins that cause the red blood cells to burst and can cause shock and/or an uncontrollable clotting cascade (https://www.ncbi.nlm.nih.gov/books/NBK2265/). This transfusion reaction (shown on the bottom of page 3 of the immunobiology version of the Student Handout) can be very serious and even cause death. (Generally, the antibodies in the donated blood do not cause problems because the amount of these antibodies is relatively small.)

The ABO blood types are the major determinant of which type of blood will cause a transfusion reaction. However, the determination of blood type is more complex than the ABO blood types. For additional information on other blood group antigens and blood types see http://www.ncbi.nlm.nih.gov/books/NBK2264/.

On page 5 of the Student Handout, students use genetic analysis of the blood type results to determine whether the babies were switched. Modern methods use DNA testing to determine biological relatedness; these results are much more definitive than testing blood types (http://en.wikipedia.org/wiki/Parental_testing).
Optional Addition to the immunobiology version of the Student Handout
(= pages 5-6 of the genetics of skin color version of the Student Handout)

The Optional Addition is shown on the last two pages of these Teacher Preparation Notes. This analysis of the genetics of skin color introduces students to:

- the concept of incomplete dominance
- the difference between codominance vs. incomplete dominance
- the influence of multiple genes and environmental factors on a single phenotypic characteristic.

Skin color is influenced by multiple genes. For example, one gene that influences skin color codes for the enzyme tyrosinase, a crucial enzyme involved in the synthesis of melanin, the primary pigment in skin and hair. The normal allele codes for functional tyrosinase, and the allele for albinism codes for a defective, non-functional version of this enzyme. The allele for albinism is recessive because, even when there is only one copy of the normal allele, this allele codes for enough functioning enzyme to produce enough melanin to result in normal skin and hair color.

Another important gene that influences skin color is the MC1R gene which codes for the melanocortin receptor; when alpha melanocyte stimulating hormone binds to normal melanocortin receptor it stimulates melanocytes to produce melanin. More than 80 alleles of the MC1R gene have been identified, resulting in various levels of function of the melanocortin receptor and correspondingly varied skin tones. Heterozygotes for these alleles have intermediate skin color, between the lighter and darker homozygotes (called incomplete dominance or a dosage effect). The multiple alleles and the effects of incomplete dominance result in multiple different phenotypes for skin color (and hair color). (Additional information on this gene is available at https://ghr.nlm.nih.gov/gene/MC1R. Additional information on the complex genetics and molecular biology involved in regulation of skin color is available at http://www.jbc.org/content/282/38/27557.full and http://hmg.oxfordjournals.org/content/18/R1/R9.full.)

In discussing question 14, the following table may be helpful.

<table>
<thead>
<tr>
<th>Type of Dominance</th>
<th>Phenotype of Heterozygous Individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant-recessive</td>
<td>Same as phenotype of individual who is homozygous for the dominant allele</td>
</tr>
<tr>
<td>pair of alleles</td>
<td></td>
</tr>
<tr>
<td>Codominance</td>
<td>Shows different observable phenotypic effects of both alleles; phenotype different from either homozygous individual</td>
</tr>
<tr>
<td>Incomplete</td>
<td>Intermediate between phenotypes of the two types of homozygous individual (typically observed for quantitative traits); phenotype different from either homozygous individual</td>
</tr>
<tr>
<td>dominance⁹</td>
<td></td>
</tr>
</tbody>
</table>

This analysis of the genetics of skin color to the Student Handout provides the opportunity to reinforce student understanding that individual phenotypic characteristics are often influenced by multiple alleles of multiple genes, as well as environmental factors. Our introductory genetics teaching frequently focuses on inheritance and phenotypic effects of single genes, as illustrated by the first page of the analysis of the genetics of skin color. However, this is only a beginning for understanding the genetics of most traits. For example, as discussed on the second page of

⁹ Incomplete dominance can occur when each allele produces a set dose of protein product and the phenotype is proportionate to the amount of protein. The Student Handout uses a capital letter and lowercase letter to indicate the two alleles for a gene with incomplete dominance; you may prefer to use an alternate notation such as b/b⁺.
this analysis, a person with a \textit{Bb} genotype could have lighter or darker skin, depending on whether he or she:

- has developed a tan as a result of sun exposure or tanning booth use
- has alleles for other genes that contribute to darker skin color.

During your discussion of question 17, you may want to revisit the previous page of the Optional Addition to the Student Handout and explain that the genotype/phenotype table and question 15 provide a very simplified introduction to the genetics of skin color.

This figure provides a somewhat more accurate representation of the Punnett square for inheritance of skin color. Even this relatively complex Punnett square is a simplified representation of reality, since it assumes a simple additive model with only two alleles for each gene and incomplete dominance for all of the alleles.

**Additional Activities**

"Genetics – Major Concepts and Learning Activities"
(http://serendipstudio.org/exchange/bioactivities/GeneticsConcepts)

This overview summarizes important genetic concepts and proposes an integrated sequence of learning activities to develop student understanding of these key concepts. Part I provides an outline of key concepts needed to understand how genes influence phenotypic characteristics and how genes are transmitted from parents to offspring. Part II recommends an integrated sequence of learning activities to develop student understanding of these key concepts. These learning activities are aligned with the Next Generation Science Standards.\(^{10}\) Part III suggests supplementary and alternative learning activities.

\(^{10}\) http://www.nextgenscience.org/
Optional Addition to Student Handout

**Why do the twins look so different?**

Now Danielle wants to know how her twins could look so different, with Michelle having light skin and Michael Jr. having dark skin. First, Danielle needs to understand that there are two types of twins. Identical twins have exactly the same genes, since identical twins originate when a developing embryo splits into two embryos.

**13.** How do you know that Michelle and Michael Jr. are not identical twins?

Michelle and Michael Jr. are fraternal twins, the result of two different eggs, each fertilized by a different sperm. These different eggs and sperm had different alleles of the genes that influence skin color, so Michelle and Michael Jr. inherited different alleles of these genes.

To begin to understand how Michelle could have light skin and her twin brother, Michael Jr., could have dark skin, we will consider two alleles of one of the genes for skin color. Notice that, for this gene, a heterozygous individual has an intermediate phenotype, halfway between the two homozygous individuals.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype (skin color)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>dark brown</td>
</tr>
<tr>
<td>Bb</td>
<td>light brown</td>
</tr>
<tr>
<td>bb</td>
<td>tan</td>
</tr>
</tbody>
</table>

When the phenotype of a heterozygous individual is intermediate between the phenotypes of the two different types of homozygous individual, this is called **incomplete dominance**.

**14a.** Explain how incomplete dominance differs from a dominant-recessive pair of alleles. (Hint: Think about the phenotypes of heterozygous individuals.)

**14b.** Explain how incomplete dominance differs from co-dominance.

**15.** The parents, Michael and Danielle, both have light brown skin and the Bb genotype. Draw a Punnett square and explain how these parents could have two babies with different color skin – one dark brown and the other tan.
Obviously, people have many different skin colors, not just dark brown, light brown, or tan. The wide variety of skin colors results from:

- the multiple alleles of the multiple genes that influence skin color and
- environmental effects.

This flowchart summarizes the genetic and environmental influences on skin color.

![Flowchart](image)

This flowchart is based on the following scientific findings.

A. Different skin colors result from differences in the types and amounts of the pigment melanin in skin cells.

B. Several different proteins influence the production and processing of melanin molecules in skin cells. Each of these proteins is coded for by a different gene. Different alleles of these genes result in different types and amounts of melanin in skin cells.

C. Exposure to sunlight can change the activity of genes that influence skin color and increase the amount of melanin in skin cells.

16. Use the letter for each scientific finding to label the part of the flowchart that represents this scientific finding.

17. This information indicates that the chart on the previous page is oversimplified. Multiple factors influence skin color, so two people who both have the Bb genotype can have different skin colors. For example, Hernando and Leo both have the Bb genotype, but Hernando’s skin is darker than Leo’s. Explain two possible reasons why Hernando and Leo have different skin colors.