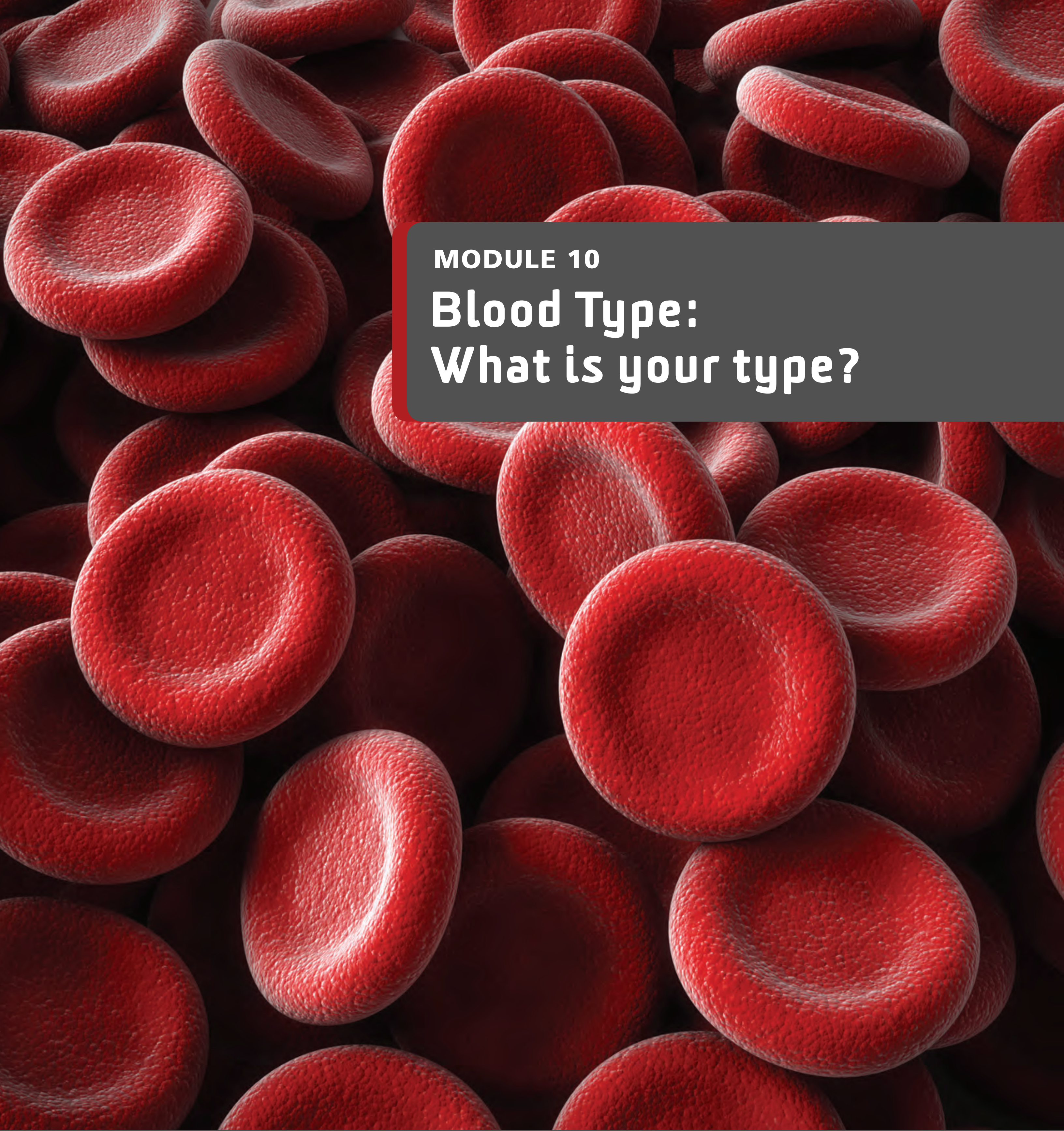

MODULE 10

Blood Type: What is your type?

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Genetics for Kids

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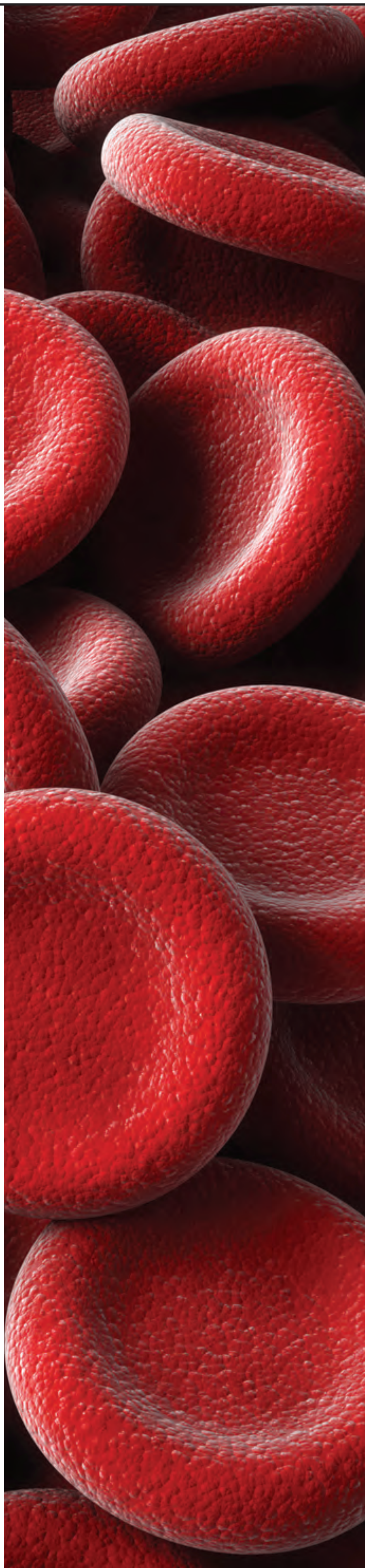


Blood Type: What is your type

Introduction

Genetic variation–the differences in DNA between individuals–is the basis for evolution by natural selection. Natural selection is the key mechanism of evolution and is the process that leads to changes in the frequency in which traits appear in a population. Traits that are beneficial to survival appear more frequently than traits that are detrimental to the survival of a population. Traits remain in a population and increase in frequency because they have adaptive value. Traits that are maladaptive, or reduce the fitness or survivability of an organism, are less likely to remain in a population and generally decrease in frequency.

Before humans were able to easily travel by automobile and air, there was less migration and inter-marriage between distant populations. Variations in certain traits were unique to isolated populations of people. Today people travel, inter-marry, and populate almost every area of the world. Thus, there are very few truly isolated populations of people. Traits once unique to a single population are now found in varying frequencies in most populations. Due to the amount of genetic variation in the human species, even sisters and brothers from the same biological parents may have distinctly different traits because there are so many possible gene combinations.

In this module, students will learn about genetic variation by studying the alleles that create human blood types. Students will calculate the probability that a person will inherit a particular blood type by completing Punnett Squares. Then students will create a graph to illustrate the frequency with which different blood types are found in the United States (U.S.), and then apply their knowledge of blood types and trait inheritance to solve a mystery.

Learning Objectives

- ✓ Define allele, phenotype, and genotype
- ✓ Understand the concepts of dominant and recessive traits
- ✓ Predict the phenotype of an individual given two alleles for a particular genotype
- ✓ Recognize that many traits are controlled by multiple genes

Prior Knowledge

To complete this module, students should already be able to:

- ✓ Understand the basic structure of a cell
- ✓ Recognize that genes are responsible for determining traits
- ✓ Understand that children inherit one allele from each parent for each gene
- ✓ Understand how to complete a Punnett Square

Relevant Standards of Learning

National Science Education Standards
Life Science, Content Standard C

Reproduction and heredity:

- Every organism requires a set of instructions for specifying its traits. Heredity is the passage of these instructions from one generation to another.
- Hereditary information is contained in genes, located in the chromosomes of each cell. Each gene carries a single unit of information. An inherited trait of an individual can be determined by one or by many genes, and a single gene can influence more than one trait. A human cell contains many thousands of different genes.

New York State Intermediate Science Standards (Grades 5 - 8)
Standard 4: The Living Environment

Major Understandings

- 2.2a: In all organisms, genetic traits are passed on from generation to generation.
- 2.2b: Some genes are dominant and some are recessive. Some traits are inherited by mechanisms other than dominance and recessiveness.
- 2.2c: The probability of traits being expressed can be determined using models of genetic inheritance. Some models of prediction are pedigree charts and Punnett Squares.

Materials List

- ✓ Student Handout
- ✓ Colored Pencils

Background

Genes are sequences of **DNA** that contain instructions that determine the physical traits of organisms. Traits include characteristics such as eye color, hair color, and blood type. The genetic makeup of a person is called the **genotype**. Observable physical traits, such as hair color and blood type, are called the **phenotype**.

Genes come in different forms called **alleles**. Offspring get one allele from the mother and one allele from the father. Alleles can be **dominant** or **recessive**. Dominant alleles are represented by capital letters (A). Recessive alleles are represented by lower case letters (a).

Traits may be **dominant**, which means that only a single copy of that dominant allele is needed in the genotype for the trait to be present in the phenotype. For example, if you have the dominant allele for dark hair, then your hair will be dark. A **recessive** trait is one that may be present in the genotype, but will not be present in the phenotype if the second allele is dominant. Dominant alleles are more powerful than recessive alleles. So, if an organism has one dominant allele and one recessive allele, the dominant allele is visible and the recessive allele is not. For example, if you have one allele for dark hair (dominant) and one allele for blonde hair (recessive), your hair will still be dark. If, on the other hand, there are two copies of the recessive allele, then the trait will be present in the phenotype. For example, if you have two copies of the allele for blonde hair, then your hair will be blonde. See Table 1 for a description of the differences between dominant and recessive traits.

Even though there is much phenotypic variation (physical differences) among people, human beings share 99 percent of genes with other human beings. All humans have the gene for hair color, but many traits, including hair color, are controlled by more than one gene. This means that there may be many different variations for a trait. For example, there are many different shades of brown hair, ranging from dark to light brown. Differences in the genotypes of humans are called genetic variation. Genetic variation can be measured in a population by looking at the frequency of a particular trait in that population. For example, the frequency of a certain blood type in the U.S. can be graphed to examine the genetic variation of blood type.

Table 1 - Dominant and Recessive Traits

Dominant (A)	Recessive (a)
Trait is visible when at least one allele is present **Genotype:** AA or Aa **Phenotype:** Dark eye color	Both alleles must be recessive for the trait to be visible **Genotype:** aa **Phenotype:** Light eye color

The ABO blood group

As with many other traits, a person inherits two alleles for the gene that determines her **ABO blood type**. One allele for each gene is inherited from the mother, and one allele for each gene is inherited from the father. The combination of alleles that a person has is her blood's genotype. A person's blood type is her blood's phenotype.

There are three alleles for the gene that determine blood type. A person inherits two of the three alleles for the gene that determines blood type. The three alleles for blood type are the A, B, and O alleles.

- The A allele and B allele are both dominant.
- The O allele is recessive.
- When the genotype contains both the A allele and the B allele, they are **codominant**, meaning both are expressed in the phenotype.

There are six possible blood type genotypes and four possible blood type phenotypes. Depending on a person's combination of alleles, a person can have **Type A**, **Type B**, **Type AB**, or **Type O** blood. This blood type system is called the ABO blood group. Table 2 shows the possible genotypes and the associated phenotypes for the ABO blood group.

Table 2 - ABO Blood Group

Genotype	Phenotype
AA	Type A
AO	Type A
BB	Type B
BO	Type B
AB	Type AB
OO	Type O

Punnett Squares

A Punnett Square is a table that determines the probability of an offspring having a particular genotype. For example, a Punnett Square for blood type is shown below. In this case, the father has the genotype BB, which results in the phenotype of blood type B. The mother has genotype AO, which results in the phenotype of Type A blood.

		Father	
		B	B
Mother	A	AB	AB
	O	AO	BO

The probability that the offspring will inherit certain blood types:

Type AB: 50 percent
Type A: 25 percent
Type B: 25 percent
Type O: 0 percent

Blood transfusions

If a person loses a lot of blood during surgery or from a major injury, she may need a blood transfusion. During a **blood transfusion**, doctors give a person additional blood from someone else by pumping it into a vein. People can donate their blood to the American Red Cross and to blood banks to make sure that there is blood for people who need blood transfusions.

For a blood transfusion to work, the person receiving the transfusion, the recipient, must have a **blood type** compatible to the blood type of the person donating the blood, the donor. Blood types are compatible if the person can receive donated blood and the body does not recognize the blood cells as foreign. The body recognizes foreign blood cells when the blood cells are not the correct ABO type. Some blood types are not compatible. If a person receives blood that is not compatible, the body will attack the donated blood cells because it recognizes the blood cells as foreign. This leads to complications and sometimes death.

People with all blood types can receive blood transfusions from people with Type O blood because the body does not recognize Type O as foreign.

- People with Type A blood can safely receive transfusions of Type A and Type O blood
- People with Type B blood can safely receive transfusions of Type B and Type O blood
- People with Type AB can safely receive Type A, Type AB, Type B, and Type O blood
- People with Type O can safely receive transfusions of only Type O blood

When determining compatibility of blood for transfusions, the **rhesus factor** also needs to be considered (see Table 3). Rhesus factor indicates whether or not a person has the gene that produces the rhesus protein. Rhesus factor is a dominant trait, meaning a person needs only one copy of the Rh+ allele to have the rhesus protein (Rh+ blood). A person who is Rh+ has the allele that does produce the Rh protein. Rh– is a recessive trait, meaning a person needs two copies of the Rh– allele to be Rh–. A person who is Rh– has the alleles that do not produce the Rh protein.

Table 3 - Rh+ and Rh-

Rhesus factor	Dominant or Recessive?	Punnett Square Representation	Genotype(s)	Phenotype
Rh+	Dominant	D	Dd or DD	Produces Rh Protein
Rh-	Recessive	d	dd	Does not Produce Rh Protein

Each of the four blood types in the ABO blood group (Type A, Type B, Type AB, and Type O) can be either Rh+ or Rh–. The gene for ABO blood type and the gene for the rhesus factor are inherited separately. Human blood type phenotype is a combination of ABO blood type and the rhesus factor.

Rh factor is an important factor in determining whether a patient can safely receive a blood transfusion from a blood donor.

- People who are Rh+ can safely receive transfusions of **both** Rh– blood and Rh+ blood.
- People who are **Rh–** can receive transfusions of **only** Rh– blood. People who are Rh– can receive only Rh– blood because Rh– people do not produce the Rh protein. If the person with Rh– blood receives Rh+ blood, the body may detect the Rh protein as foreign and attack the blood cells, causing complications and even death.

Table 4 (below) shows the blood types of a blood transfusion recipient, and the blood types that they can safely receive from a blood donor if they need a blood transfusion.

Table 4 - ABO and Rhesus Factor Blood Types

Recipient	Donor
A+	A+, A–, O+, O–
A–	A–, O–
B+	B+, B–, O+, O–
B-	B–, O–
AB+	A+, A–, B+, B–, AB+, AB–, O+, O–
AB–	A–, B–, AB–, O–
O+	O+, O–
O–	O–

Vocabulary

1. **ABO blood type**: A human trait important in determining the safety of blood transfusions. People can be Type A, Type B, Type AB, or Type O.
2. **Allele**: One of a person's two copies of a gene.
3. **Blood transfusion**: The transfer of blood from a donor to a recipient through an intravenous (IV) line in a blood vessel. Donor blood must be a compatible ABO and rhesus factor type to the recipient's blood for a successful transfusion to take place.
4. **Dominant trait**: Expressed when at least one allele for that trait is inherited.
5. **Genotype**: The genetic information from two alleles.
6. **Inheritance**: Passing traits from parents to children.
7. **Phenotype**: The physical manifestation of the genotype (i.e., blood type).
8. **Punnett Square**: A table used by geneticists to determine the probability that offspring will inherit a specific trait.
9. **Recessive trait**: Expressed when two alleles for that trait are inherited.
10. **Rhesus factor**: A human trait important in determining the safety of blood transfusions. People can be Rh positive (Rh+) or Rh negative (Rh–).

Procedure

Day of the Lesson

1. <u>Seat students in groups of four</u>.

   Inform students that in today's module, they will learn about genetic variation. They will complete Punnett Squares, create a graph, and solve a mystery to learn about genetic variation and blood type.

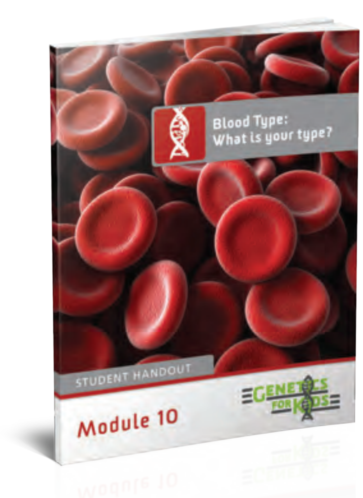
2. <u>Distribute a **Student Handout** to each student</u>.

3. <u>Instruct students to read **Part I: Introduction**</u>.

   Ask students to silently read **Part I: Introduction** on the **Student Handout**. Provide students with enough time to read the introduction. Circulate around the room as students read. Redirect students with questions, and check for comprehension, as needed.

4. <u>Emphasize key points from **Part I: Introduction**</u>.

   When all students are finished reading, address any questions students may have about genetic variation and human blood types.



Emphasize the following key points:

- Each person is genetically unique, but all humans share many genes. Humans have 99 percent of genes in common.
- Each person has a different genotype and phenotype due to the combination of alleles she inherits from her parents.
- Alleles and the traits they code for can be dominant or recessive.

5. Check students' understanding of **Part I: Introduction**.

   After you have emphasized the key points of the Introduction, ask students the following questions:

   - What is an allele?
   - What is a genotype?
   - What is a phenotype?
   - How many recessive alleles are needed for a trait to show in the phenotype?
   - How many dominant alleles are needed for a trait to show in the phenotype?

   After discussing the above questions, allow students a few moments to record the answers in **Part II: Check your understanding**.

6. Introduce **Part III: Activities**.

   Inform students that they will work in their groups to complete the activities.

7. Instruct students to complete ***Activity 1: Punnett Squares and blood types***.

   Ask students to silently read ***Activity 1: Punnett Square blood types*** on the **Student Handout**, and complete the Punnett Square. Instruct students to use the Punnett Square to determine the probability that offspring of the couple will inherit certain blood types.

   Circulate around the room while students answer the questions for ***Activity 1: Punnett Square blood types***. Redirect students with questions, and check for comprehension, as needed.

8. Instruct students to complete ***Activity 2: Blood transfusions***.

   Ask students to silently read ***Activity 2: Blood transfusions*** on the **Student Handout** and to complete the questions as a group. Provide students with enough time to read the content and answer the questions. Circulate around the room as students read. Redirect students with questions, and check for comprehension, as needed.

   Once students complete the reading and answer the questions in ***Activity 2: Blood transfusions***, you may go over the answers with them. The content in this section is important for ***Activity 3: Blood type in the U.S.*** and ***Activity 4: Solve a mystery***. The answers are explained in the answer key.

9. Instruct students to complete **Activity 3: Blood type in the U.S**.

   Instruct students to silently read ***Activity 3: Blood type in the U.S.*** When they are finished reading, instruct students to create a graph of the frequency of blood types in the U.S. using the data in Table 4. Distribute colored pencils to each group. Explain to students that they will be making a double bar graph. This means that for each blood type (A, B, AB, and O) they will have 2 bars, one for the frequency of Rh+ and one for the frequency of Rh–. Point out the example of a double bar graph on the ***Student Handout*****.**

Instruct students to follow the steps outlined in the **Student Handout** to create the graph:

- **Create a title for the graph**. Think carefully. Your title should reflect the information that your graph will demonstrate, and should sound interesting and catchy. Write the title on the line above the graph.
- **Create a key for the graph**. Chose one color to represent Rh+ and one color to represent Rh–. Color the boxes in the Key.
- **Label each axis**. You will graph blood type on one axis and percentage of the population on the other axis. Determine which axis should show which information, and label accordingly.
- **Number each axis**. Determine the number by which you will count percentage of the population. Mark these numbers on graph. Label the other axis with the different blood types.
- **Create your graph**.

  Circulate around the room as students create their graphs. Redirect students with questions, and check for comprehension, as needed.

  Once students have completed their graphs, instruct students to complete the four questions about the graph. Instruct students to work on the questions in small groups. Encourage students to discuss their answers with their small groups.

10. Instruct students to complete ***Activity 4: Solve a mystery***.

Inform students that they will be solving a mystery about birth parents of an adopted prince. They will apply their knowledge of blood types and Punnett Squares to determine the likelihood that three different couples are the prince's birth parents.

Instruct students to work in their small group to read the story about the prince. When they finish reading, instruct students to complete questions 1 through 3. Give students several minutes to complete the questions.

Once students have completed questions 1 through 3, ask students to share their answers. It is important that students understand this section. Emphasize that there is only one possible genotype for the prince because the prince has two recessive traits. The prince must have ABO genotype OO (ABO phenotype O) and Rh factor genotype dd (Rh factor phenotype Rh–). Explain that the prince's parents must have genotypes that would allow each parent to each pass on one O allele and one Rh– allele (d) to the prince.

Instruct students to continue with the activity to evaluate the likelihood that three different couples are the prince's parents. Circulate around the room as students complete the activity. When students are calculating the probability of a couple having a child with BOTH phenotypes, explain that the probability is a combination of the two separate probabilities. This probability can be determined by multiplying the two separate probabilities (see Teacher Note 1). Redirect students with questions, and check for comprehension, as needed.

11. Instruct students to complete **Part IV: Conclusion questions.**

When students are finished working on ***Activity 4: Solve a mystery***, instruct students to complete **Part IV: Conclusion questions**. Provide students with enough time to answer the conclusion questions.

12. Lead a closing class discussion about the module's activities.

Ask for students' responses to **Part IV: Conclusion questions**. Ask students to share their thoughts and reactions to the activities.

- Ask students whether they know their blood type.
- Ask students whether they would consider donating blood. If so, what are their motivations? If not, what is keeping them back?

Extension Lesson

Determine your blood type

Encourage students to use the information from the module to discover their own blood type phenotype. Provide students with these guided steps to help them determine their possible blood type phenotype.

1. What is your mother's blood type? ____________________
   - Possible ABO genotypes(s): ____________________
   - Possible Rh factor genotypes(s): ____________________
2. What is your father's blood type? ____________________
   - Possible ABO genotypes(s): ____________________
   - Possible Rh factor genotypes(s): ____________________

Encourage students to create Punnett Squares using the possible genotypes for their parents. If students know their blood type, they can use that information to determine more accurately the genotype of their parents. Students also can calculate the probability for their parents having a child with the student's blood type.

Once students have tried to determine their blood type, provide students with information about where they can confirm their blood type. Some students may have their blood type listed on their birth certificate. Their doctors may have their blood types on file. A medical professional can determine a person's blood type by using a "bed-side blood type test."

Addition to *Activity 4: Solving a mystery*

The Extension Lesson Handout for Addition to Activity 4: Solving a mystery, is located at the end of this module. For an optional homework or extra-credit assignment, provide students with additional information for Activity 4: Solving a mystery.

Teacher Notes

1. In this activity, students are looking at traits controlled by two genes. For simplicity, the probability of each couple having a child with the phenotype O and the phenotype Rh– are calculated separately. To determine the combined probability, the two probabilities must be multiplied together. Punnett Squares can be used also for traits that are controlled by more than one gene. The Punnett Squares for more than one gene are more complicated than a 2 x 2 Punnett Square.

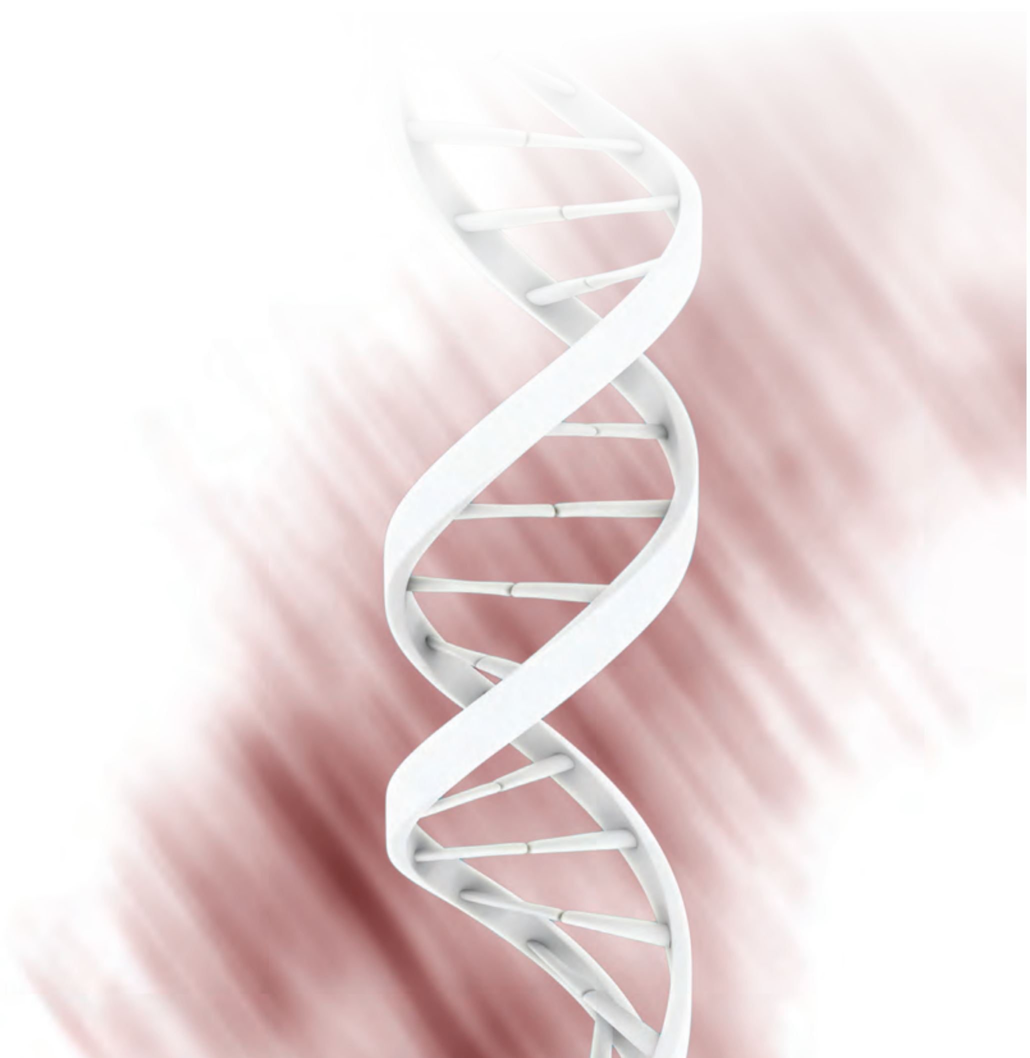
Additional Resources

1. American Red Cross. This link provides information about how, where, and when a person can donate blood. http://www.givelife2.org/donor/faq.asp

2. genes and Blood Type. This link provides information about blood types. http://learn.genetics.utah.edu/content/begin/traits/blood/

3. The University of Arizona Biology Project. This link provides information about cell biology and Mendelian genetics. http://www.biology.arizona.edu/

4. Monohybrid Cross Tutorial and Problem Set. This link provides tutorials and problem sets for Mendelian genetic crosses. http://www.biology.arizona.edu/mendelian_genetics/problem_sets/monohybrid_cross/01q.html



Part I: Introduction

Genes are sequences of **DNA** that contain instructions that determine the physical traits of organisms. Traits include characteristics such as eye color, hair color, and blood type. The genetic makeup of a person is called the **genotype**. Observable physical traits, such as hair color and blood type, are called the **phenotype**.

Genes come in different forms called **alleles**. Offspring get one allele from the mother and one allele from the father. Alleles can be **dominant** or **recessive**. Dominant alleles are represented by capital letters (A). Recessive alleles are represented by lower case letters (a).

Traits may be **dominant**, which means that only a single copy of that dominant allele is needed in the genotype for the trait to be present in the phenotype. For example, if you have the dominant allele for dark hair, then your hair will be dark. A **recessive** trait is one that may be present in the genotype, but will not be present in the phenotype if the second allele is dominant. Dominant alleles are more powerful than recessive alleles. So, if an organism has one dominant allele and one recessive allele, the dominant allele is visible and the recessive allele is not. For example, if you have one allele for dark hair (dominant) and one allele for blonde hair (recessive), your hair will still be dark. If, on the other hand, there are two copies of the recessive allele, then the trait will be present in the phenotype. For example, if you have two copies of the allele for blonde hair, then your hair will be blonde. See Table 1 below for a description of the differences between dominant and recessive traits.

Table 1 - Dominant and Recessive Traits

Dominant (A)	Recessive (a)
Trait is visible when at least one allele is present **Genotype:** AA or Aa **Phenotype:** Dark eye color	Both alleles must be recessive for the trait to be visible **Genotype:** aa **Phenotype:** Light eye color

Even though there is much phenotypic variation (physical differences) among people, human beings share 99 percent of genes with other human beings. All humans have the gene for hair color, but many traits, including hair color, are controlled by more than one gene. This means that there may be many different variations for a trait. For example, there are many different shades of brown hair, ranging from dark to light brown. Differences in the genotypes of humans are called genetic variation. Genetic variation can be measured in a population by looking at the frequency of a particular trait in that population. For example, the frequency of a certain blood type in the U.S. can be graphed to examine the genetic variation of blood type.

In today's module, you will learn about genetic variation by studying the alleles that create human blood types. You will calculate the probability that a person will inherit a particular blood type by completing Punnett Squares. You will create a graph to illustrate the frequency in which different blood types are found in the U.S., and you will apply your knowledge of blood types and trait inheritance to solve a mystery.

Part II: Vocabulary

1. **ABO blood type**: A human trait important in determining the safety of blood transfusions. People can be Type A, Type B, Type AB, or Type O.
2. **Allele**: One of a person's two copies of a gene.
3. **Blood transfusion**: The transfer of blood from a donor to a recipient through an intravenous (IV) line in a blood vessel. Donor blood must be a compatible ABO and rhesus factor type to the recipient's blood for a successful transfusion to take place.
4. **Dominant trait**: Expressed when at least one allele for that trait is inherited.
5. **Genotype**: The genetic information from two alleles.
6. **Inheritance**: Passing traits from parents to children.
7. **Phenotype**: The physical manifestation of the genotype (i.e., blood type).
8. **Punnett Square**: A table used by geneticists to determine the probability that offspring will inherit a specific trait.
9. **Recessive trait**: Expressed when two alleles for that trait are inherited.
10. **Rhesus factor**: A human trait important in determining the safety of blood transfusions. People can be Rh positive (Rh+) or Rh negative (Rh–).

Check your understanding:

1. A genotype is? ____________________
2. A phenotype is? ____________________
3. How many recessive alleles are needed for a trait to show in the phenotype?__________
4. How many dominant alleles are needed for a trait to show in the phenotype?__________

Part III: Activities

Activity 1: Punnett squares and blood type

The ABO blood group

As with many other traits, a person inherits two alleles for the gene that determines her **ABO blood type**. One allele for each gene is inherited from the mother and one allele for each gene is inherited from the father. The combination of alleles that a person has is her blood's genotype. A person's blood type is her blood's phenotype.

There are three alleles for the gene that determine blood type. A person inherits two of the three alleles for the gene that determines blood type. The three alleles for blood type are the A, B, and O alleles.

- The A allele and B allele are both dominant.
- The O allele is recessive.
- When the genotype contains both the A allele and the B allele, they are **codominant**, meaning both are expressed in the phenotype.

There are six possible blood type genotypes and four possible blood type phenotypes. Depending on a person's combination of alleles, a person can have **Type A**, **Type B**, **Type AB**, or **Type O** blood. This blood type system is called the ABO blood group. Table 2 below shows the possible genotypes and the associated phenotypes for the ABO blood group.

Table 2 - ABO Blood Group

Genotype	Phenotype
AA	Type A
AO	Type A
BB	Type B
BO	Type B
AB	Type AB
OO	Type O

Punnett Squares

A Punnett Square is a table that determines the probability of an offspring having a particular genotype. For example, a Punnett square for blood type is shown below. In this case, the father has the genotype BB which results in the phenotype of blood type B. The mother has genotype AO which results in the phenotype of Type A blood.

		Father	
		B	B
Mother	A	AB	AB
	O	BO	BO

The probability that the offspring will inherit certain blood types:

Type AB: 50 percent

Type A: 0 percent

Type B: 50 percent

Type O: 0 percent

Complete the Punnett Square below: A father has genotype BO, which results in the phenotype of blood type B. A mother has the genotype AO, which results in the phenotype of Type A blood.

Complete the Punnett Square, and calculate the blood type (phenotype) probability for a child from this couple:

		Father	
		B	O
Mother	A		
	O		

The probability that the offspring will inherit certain blood types:
Type AB: ______ percent
Type A: ______ percent
Type B: ______ percent
Type O: ______ percent

Activity 2: Blood transfusions

If a person loses a lot of blood during surgery or from a major injury, she may need a **blood transfusion**. During a blood transfusion, doctors give a person additional blood from someone else by pumping it into a vein. People can donate blood to the American Red Cross and to blood banks and to the Red Cross to make sure that there is blood for people who need blood transfusions.

For a blood transfusion to work, the person receiving the transfusion, the recipient, must have a blood type compatible to the **blood type** of the person donating the blood, the donor. Blood types are compatible if the person can receive donated blood and the body does not recognize the blood cells as foreign. The body recognizes foreign blood cells when the blood cells are not the correct ABO type. Some blood types are not compatible. If a person receives blood that is not compatible, the body will attack the donated blood cells because it recognizes the blood cells as foreign. This leads to complications and sometimes death.

People with all blood types can receive blood transfusions from people with Type O blood because the body does not recognize Type O as foreign.

- People with Type A blood can safely receive transfusions of Type A and Type O blood
- People with Type B blood can safely receive transfusions of Type B and Type O blood
- People with Type AB can safely receive Type A, Type AB, Type B, and Type O blood
- People with Type O can safely receive transfusions of only Type O blood

When determining the compatibility of blood for transfusions, the **rhesus factor** also needs to be considered (see Table 3). Rhesus factor indicates whether or not a person has the gene that produces the rhesus protein. Rhesus factor is a dominant trait, meaning a person only needs one copy of the Rh+ allele to have the rhesus protein (Rh+ blood). A person who is Rh+ has the allele that does produce the Rh protein. Rh– is a recessive trait, meaning a person needs two copies of the Rh– allele to be Rh–. A person who is Rh– has the alleles that do not produce the Rh protein.

Table 3 - Rh+ and Rh-				
Rhesus factor	**Dominant or Recessive?**	**Punnett Square Representation**	**Genotype(s)**	**Phenotype**
Rh+	Dominant	D	Dd or DD	Produces Rh Protein
Rh-	Recessive	d	dd	Does not Produce Rh Protein

Each of the four blood types in the ABO blood group (Type A, Type B, Type AB, and Type O) can be either Rh+ or Rh–. The gene for ABO blood type and the gene for rhesus factor are inheritied separately. Human blood type phenotype is a combination of ABO blood type and rhesus factor.

Rh factor is an important factor in determining whether a patient can safely receive a blood transfusion from a blood donor.

- People who are Rh+ can safely receive transfusions of **both** Rh– blood and Rh+ blood.
- People who are Rh– can receive transfusions of **only** Rh–blood. People who are Rh– can receive only Rh– blood because Rh– people do not produce the Rh protein. If the person with Rh– blood receives Rh+ blood, the body may detect the Rh protein as foreign and attack the blood cells causing complications and even death.

Table 4 (right) shows the blood types of a blood transfusion recipient, and the blood types that they can safely receive from a blood donor if they need a blood transfusion.

Table 4 - ABO and Rhesus Factor Blood Types	
Recipient	**Donor**
A+	A+, A–, O+, O–
A–	A–, O–
B+	B+, B–, O+, O–
B–	B–, O–
AB+	A+, A–, B+, B–, AB+, AB–, O+, O–
AB–	A–, B–, AB–, O–
O+	O+, O–
O–	O–

1. **Universal recipients** are people who can receive blood donations from any of the possible combinations of ABO and Rh blood types. Based on Table 4 (above), people with which blood type are universal recipients?

2. **Universal donors** are people who can donate to people with any combination of ABO and Rh blood types. Based on Table 4 (above), people with which blood type are universal donors?

3. Determine whether the following donor/recipient pairings in Table 5 are safe for a transfusion to take place.

Table 5 - Donor/Recipient Pairings for Transfusion

Recipient	Donor	Safe for Transfusion (Y/N)
O-	B+	
B+	O-	
AB+	A-	

4. Why might it be difficult for some people who need blood to receive a blood transfusion?

5. Would you consider donating blood? Why or why not?

Activity 3: Blood type in the U.S.

As you learned in Activity 2, some people can receive blood transfusions from people with many different blood types. Other people can receive blood transfusions only from people with a few blood types. This means that it is more difficult for some people in need of blood to safely receive a blood transfusion.

The frequency with which different blood types appear in the U.S. also affects whether someone who needs blood after surgery or injury can safely receive a blood transfusion. Table 6 shows the eight different ABO blood types and Rh factors, and the frequency with which they appear in the U.S. population. Study the table below to see the frequency of ABO blood types and Rh factors in the U.S.

Table 6 - Blood Type in the U.S.

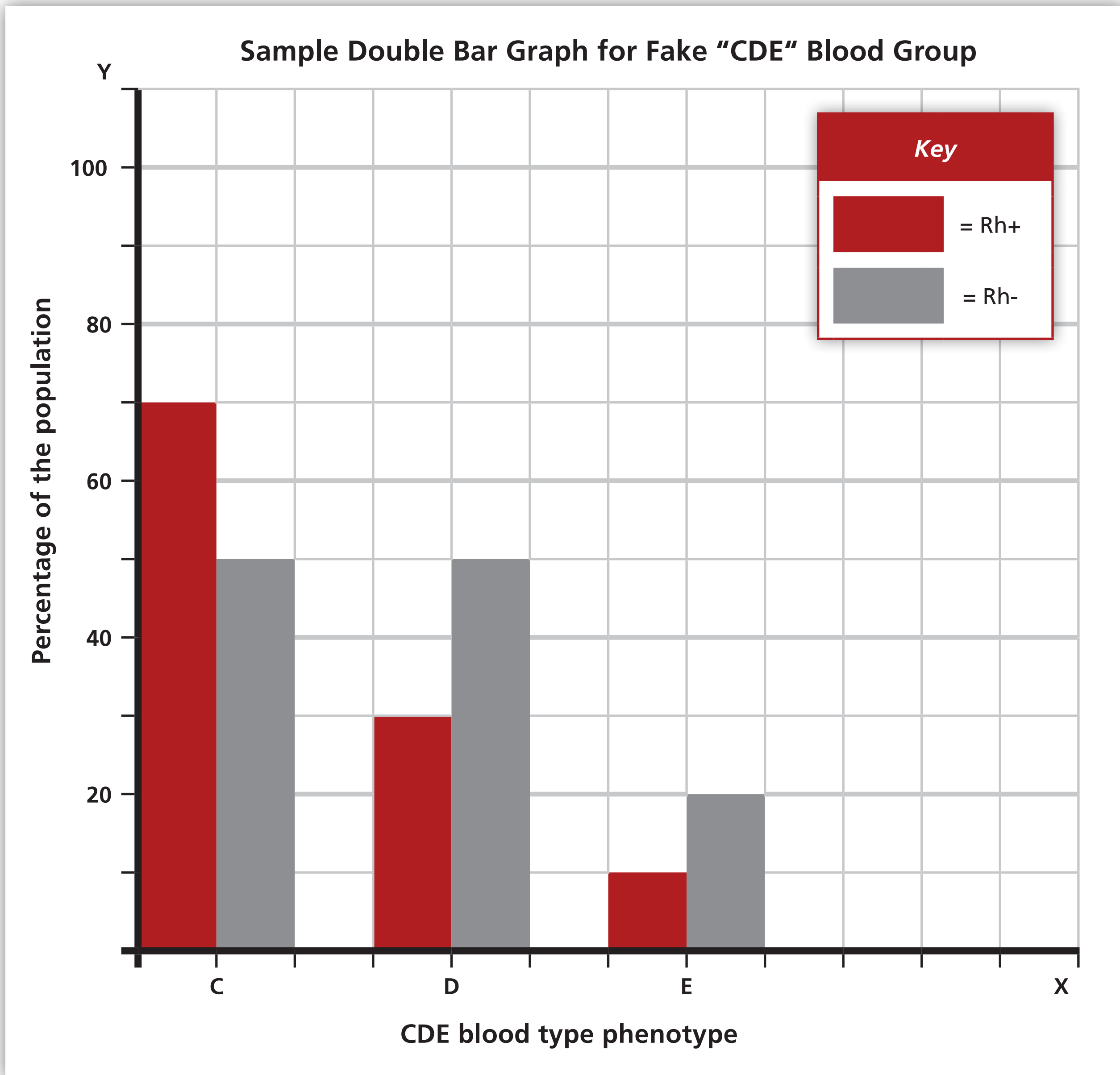
ABO Type	How Many have It?	Rh Factor	How Many Have It?
O	44%	O+	37.4%
		O–	6.6%
A	42%	A+	35.7%
		A–	6.3%
B	10%	B+	8.5%
		B–	1.5%
AB	4%	AB+	3.4%
		AB–	0.6%

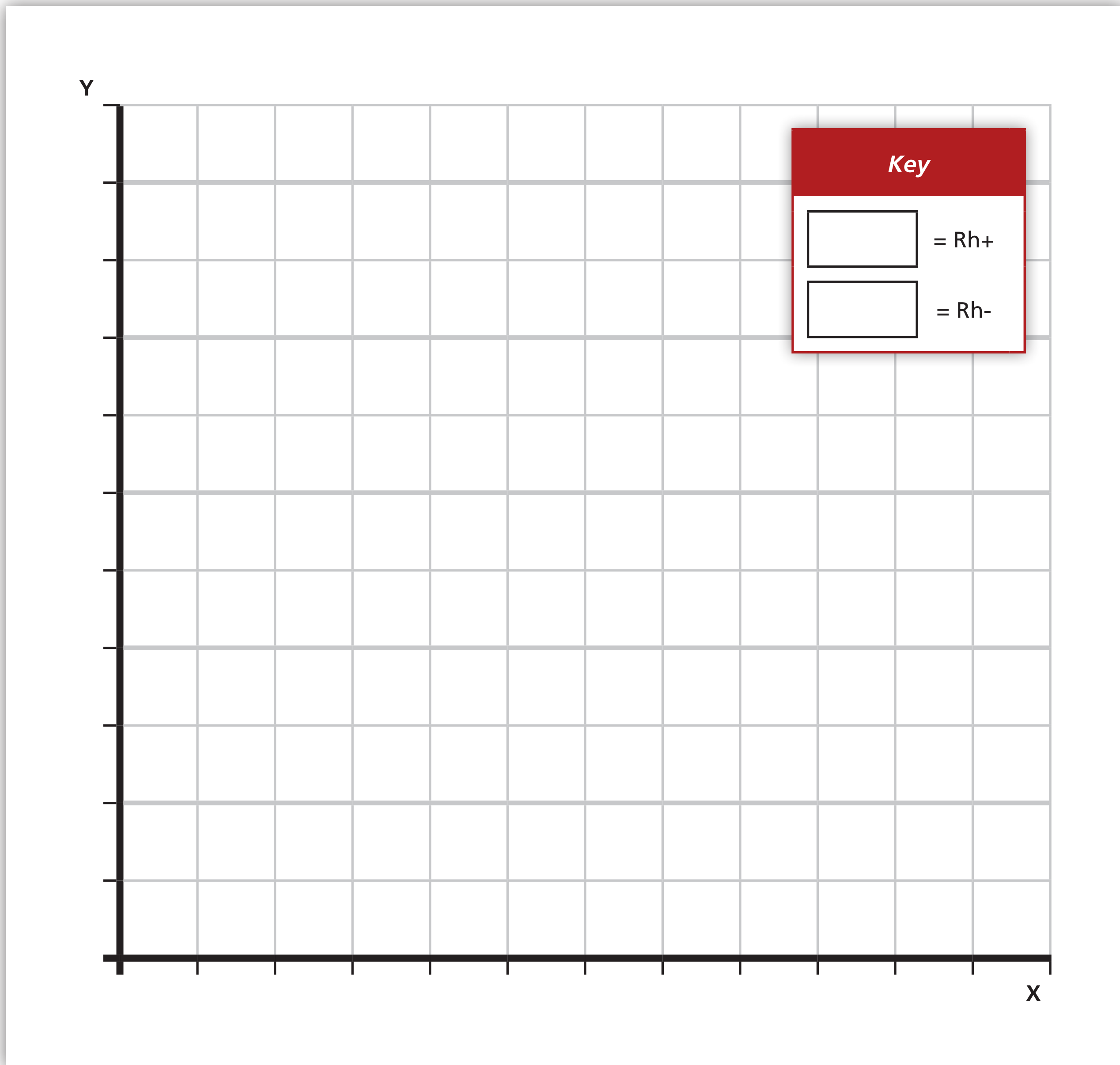
Using the information in Table 6, create a double bar graph to demonstrate the frequency with which ABO and Rh blood types are found in the U.S.. The steps below will guide you through the process.

Create a graph

1. **Create a title for the graph**. Think carefully. Your title should reflect the information that your graph will demonstrate. Write the title on the line above the graph.
2. **Create a key for the graph**. Chose one color to represent Rh+ and one color to represent Rh–. Color the boxes in the key.
3. **Label each axis**. You will graph blood type on one axis and percentage of the population on the other axis. Determine which axis should show which information, and label accordingly.
4. **Number each axis**. Determine the number by which you will count percentage of the population. Mark these numbers on graph. Label each bar on the other axis with the different blood types.

5. **Create your graph**. Create a double bar graph using the information in Table 4. An example of a double bar graph is shown below. The sample bar graph is not scientifically or mathematically accurate. Use it only as a reference for how to structure a double bar graph.




Y
X
Key
= Rh+
= Rh-

1. Looking at the graph that you just created, which blood type appears most frequently in the U.S.?

2. Looking at the graph that you just created, which blood type appears the least frequently in the U.S.?

3. Do you think that people have an ethical obligation or responsibility to donate blood? Why or why not?

4. Do some people have **more** of an ethical obligation to donate blood than other people? Why or why not? Be specific and reference your graph.

Activity 4: Solve a mystery

In Activities 1-3, you learned about the inheritance of blood type, used Punnett Squares to identify the probability that an offspring will inherit a particular blood type, and graphed the frequency with which certain blood types appear in the U.S. In Activity 4, you will apply the knowledge about the inheritance of blood type that you learned in Activities 1-3 to solve a mystery. Read the following story carefully, and then answer the questions to solve the mystery.

A prince living in the small nation of Genotopia has discovered that he was adopted at birth. The prince loves his royal life, but wishes to locate his birth parents. The prince would like to get to know his birth parents, and to share some of his royal fortune with them. However, there is a problem. The adoption agency that coordinated the prince's adoption is in disarray. Their paperwork is disorganized, and they cannot be positive about the identity of the prince's birth parents. They give the prince the names and blood types of three couples. One of the couples is the prince's birth parents.

The prince comes to you, a lead detective at the Punnett Squares Private Eyes detective agency, to lead the investigation into the identity of his birth parents. You reassure the prince that you will be discrete.

You are, after all, a scientific genius, and an expert at using blood types to solve mysteries. You tell the prince you will identify the probability that each couple is the prince's birth parents by using Punnett Squares, ABO blood type, and rhesus factor. The prince does not know his blood genotype, but he does know his blood type phenotype. He is Type O–.

Your first task is to determine the prince's possible genotype for ABO blood type and Rh factor. Blood type is a trait controlled by more than one gene. Remember, the gene for ABO blood type and the gene for rhesus factor are separate. When a person inherits an O allele, it does not mean he will inherit the Rh+ allele. Human blood type phenotype is a combination of ABO blood type and rhesus factor, therefore, you need to determine the genotypes for ABO blood type and Rh factor separately.

You will be given the blood type phenotypes of three couples who may be the prince's parents. Based on the phenotype, you must determine the possible genotypes for ABO blood type and Rh factor of the man and woman of each couple, and estimate the probability of the couple having a child with the prince's blood type phenotype (Type O–).

Use the ABO blood type alleles table and the Rhesus (Rh) factor alleles table (right) throughout your investigation.

ABO Blood Type Alleles	*Rhesus (Rh) Factor Alleles*
A = Type A (dominant)	D = Rh+ (dominant)
B = Type B (dominant)	d = Rh- (recessive)
O = Type O (recessive)	
*Possible ABO genotypes: AA, AO, BB, BO, AB, OO	*Possible Rh factor genotypes: DD, Dd, or dd

1. The prince has blood type phenotype O–. There is only 1 genotype for ABO blood type and for the Rh factor that can create the blood type phenotype O–. What is the genotype for the ABO blood type and Rh factor of the prince?

   a. ABO genotype: ____________________

   b. Rh factor genotype: ________________

2. What alleles should you look for in the genotype of the couples to determine whether they can be the prince's birth parents?

   a. Alleles for ABO genotype: ________________ from mother **and** __________ from father

   b. Alleles for Rh factor genotype: _____________ from mother **and** __________ from father

3. How do you know that your answer to number 1 is the genotype for the prince's ABO blood type and Rh factor? Why aren't there any other possibilities? Explain your answer.

____

____

____

____

Now that you have determined the ABO genotype and the Rh factor genotype for the prince, you can determine whether each couple could be the prince's birth parents. For each couple, you are given the blood type phenotype of the man and woman. Based on the blood type phenotypes of the man and woman in each couple, you must determine the possible ABO genotypes and Rh factor genotypes. There may be more than one ABO genotype or Rh factor genotype for each person. Then, consider whether the possible birth parents have the alleles needed to create the prince's blood type.

Couple #1

4. The man has a blood type phenotype of B+. The woman has a blood type phenotype of A+. Determine the possible ABO genotypes and Rh factor genotypes for the Couple #1, and write your answers in the boxes below. The possible genotypes for the man are completed for you.

Man
Blood type phenotype: B+
a. Possible ABO genotype(s): **BB or BO**
b. Possible Rh factor genotype(s): **DD or Dd**

Woman
Blood type phenotype: A+
a. Possible ABO genotype(s): ______________
b. Possible Rh factor genotype(s): __________

5. Consider the alleles in the possible genotypes for the man and the woman. Is it possible that Couple #1 could be the parents of the child based on ABO blood type and Rh factor? Refer to question 2 to determine your answer.

____

____

____

____

6. Which of the possible ABO and Rh factor genotypes does the man need in order to be the father of the prince?

   a. ABO genotype: ______________________

   b. Rh factor genotype: __________________

7. Which of the possible ABO and Rh factor genotypes does the woman need in order to be the mother of the prince?

   a. ABO genotype: ______________________

   b. Rh factor genotype: __________________

8. Complete the Punnett Squares for ABO blood type and Rh factor using the man and woman's genotypes from questions 6 and 7 to determine the probability that Couple #1 could have a child with the prince's ABO genotype O and her Rh factor genotype Rh–.

ABO blood type

		Father	
		____	____
Mother	____	________	________
	____	________	________

a. Probability of ABO phenotype O: ____________________

Rh factor

		Father	
		____	____
Mother	____	________	________
	____	________	________

b. Probability of Rh factor phenotype Rh-: ____________________

9. Using Punnett Squares in question 8, you determined the probability that a child from Couple #1 will have the ABO phenotype O and the probability that the child will have Rh factor phenotype Rh–. Now, you will combine these probabilities to determine the probability that Couple #1 will have a child with **both** ABO phenotype O and Rh factor phenotype Rh–, resulting in the blood type phenotype O–.

   First, you will have to convert the probabilities from 8a and 8b into decimals. For example, if the answer to 8a is 50.0 percent, then you would move the decimal point over 2 places to the left. Therefore the answer would be 0.50.

   a. Probability of phenotype O from 8a: ___________ percent = ___________ (in decimal form).

   b. Probability of phenotype Rh– from 8b: ___________ percent = ___________ (in decimal form).

   Now you can determine the combined probability by multiplying the two probabilities (in decimal form) together.

   c. (Probability of phenotype O) * (Probability of phenotype Rh–) = Probability of phenotype O–
   ___________ * ___________ = ___________

   Determine the probability of phenotype O– as a percentage by multiplying the answer to 8c by 100.

   d. 9c * 100 = ____________ percent

<u>Couple #2</u>

10. The man in Couple #2 has a blood type phenotype of O–. The woman in Couple #2 has a blood type phenotype of O+. Based on their blood type phenotypes, determine the possible ABO genotypes and Rh factor genotypes for the man and woman in Couple #2, and write your answers in the boxes below.

Man	***Woman***
Blood type phenotype: O-	Blood type phenotype: O+
a. Possible ABO genotype(s): ______________	a. Possible ABO genotype(s): ______________
b. Possible Rh factor genotype(s): __________	b. Possible Rh factor genotype(s): __________

11. Consider the alleles in the possible phenotypes for the man and the woman. Is it possible that Couple #2 could be the parents of the child based on ABO blood type and Rh factor? Refer to question 2 to determine your answer.

____

____

____

12. Which of the possible ABO and Rh factor genotypes does the man have to have to be to be the father of the prince?

    a. ABO genotype: ____________________

    b. Rh factor genotype: ________________

13. Which of the possible ABO and Rh factor genotypes does the woman have to have to be to be the mother of the prince?

    a. ABO genotype: ____________________

    b. Rh factor genotype: ________________

14. Complete the Punnett Squares for ABO blood type and Rh factor using the genotypes from questions 12 and 13 to determine the probably of Couple #2 could have a child with the prince's ABO blood type genotype O and her Rh factor genotype Rh–.

ABO blood type

		Father	
		___	___
Mother	___	______	______
	___	______	______

a. Probability of blood type phenotype O: ____________________

Rh factor

		Father	
		____	____
Mother	____	__________	__________
	____	__________	__________

b. Probability of Rh factor phenotype Rh-: ______________________

15. Using Punnett Squares in question 14, you determined the probability of the child from Couple #2 having blood type phenotype O, and the probability of the child having Rh factor phenotype Rh–. Now, you will combine these probabilities to determine the probability that Couple #2 will have a child with **both** blood type phenotype O and Rh factor phenotype Rh–.

    First you will have to convert the probabilities from 14a and 14b into decimals. For example, if the answer to 14a is 50.0 percent, then you would move the decimal point over 2 places to the left. Therefore the answer would be 0.50.

    a. Probability of phenotype O from 14a: __________ percent = __________ (in decimal form).

    b. Probability of phenotype Rh– from 14b: __________ percent = __________ (in decimal form).

    Now you can determine the combined probability by multiplying the two probabilities (in decimal form) together.

    c. (Probability of phenotype O) * (Probability of phenotype Rh–) = Probability of phenotype O–
    __________ * __________ = __________

    Determine the probability of phenotype O– as a percentage by multiplying the answer to 10c by 100.

    d. 15c * 100 = ____________ percent

16. Which couple has the greatest probability of being the prince's birth parents? Why?

____

____

17. Is there a phenotype or phenotypes that a person may have that would give him/her zero probability of having a child with the blood type phenotype O–? If you answered yes, please provide the phenotype(s).

Part IV: Conclusion questions

1. What are some reasons a person may want to know his or her blood type?

2. If you had your blood tested and found out that you have a universal blood type, would you be more likely or less likely to donate blood?

3. Blood type is a human trait. Is blood type controlled by one gene, or by several genes? Give examples from today's lesson.

Part V: Notes

Part I: Introduction

Genes are sequences of **DNA** that contain instructions that determine the physical traits of organisms. Traits include characteristics such as eye color, hair color, and blood type. The genetic makeup of a person is called the **genotype**. Observable physical traits, such as hair color and blood type, are called the **phenotype**.

Genes come in different forms called **alleles**. Offspring get one allele from the mother and one allele from the father. Alleles can be **dominant** or **recessive**. Dominant alleles are represented by capital letters (A). Recessive alleles are represented by lower case letters (a).

Traits may be **dominant**, which means that only a single copy of that dominant allele is needed in the genotype for the trait to be present in the phenotype. For example, if you have the dominant allele for dark hair, then your hair will be dark. A **recessive** trait is one that may be present in the genotype, but will not be present in the phenotype if the second allele is dominant. Dominant alleles are more powerful than recessive alleles. So, if an organism has one dominant allele and one recessive allele, the dominant allele is visible and the recessive allele is not. For example, if you have one allele for dark hair (dominant) and one allele for blonde hair (recessive), your hair will still be dark. If, on the other hand, there are two copies of the recessive allele, then the trait will be present in the phenotype. For example, if you have two copies of the allele for blonde hair, then your hair will be blonde. See Table 1 below for a description of the differences between dominant and recessive traits.

Table 1 - Dominant and Recessive Traits

Dominant (A)	Recessive (a)
Trait is visible when at least one allele is present **Genotype:** AA or Aa **Phenotype:** Dark eye color	Both alleles must be recessive for the trait to be visible **Genotype:** aa **Phenotype:** Light eye color

Even though there is much phenotypic variation (physical differences) among people, human beings share 99 percent of genes with other human beings. All humans have the gene for hair color, but many traits, including hair color, are controlled by more than one gene. This means that there may be many different variations for a trait. For example, there are many different shades of brown hair, ranging from dark to light brown. Differences in the genotypes of humans are called genetic variation. Genetic variation can be measured in a population by looking at the frequency of a particular trait in that population. For example, the frequency of a certain blood type in the U.S. can be graphed to examine the genetic variation of blood type.

Part II: Vocabulary

1. **ABO blood type**: A human trait important in determining the safety of blood transfusions. People can be Type A, Type B, Type AB, or Type O.
2. **Allele**: One of a person's two copies of a gene.
3. **Blood transfusion**: The transfer of blood from a donor to a recipient through an intravenous (IV) line in a blood vessel. Donor blood must be a compatible ABO and rhesus factor type to the recipient's blood for a successful transfusion to take place.
4. **Dominant trait**: Expressed when at least one allele for that trait is inherited.
5. **Genotype**: The genetic information from two alleles.
6. **Inheritance**: Passing traits from parents to children.
7. **Phenotype**: The physical manifestation of the genotype (i.e., blood type).
8. **Punnett Square**: A table used by geneticists to determine the probability that offspring will inherit a specific trait.
9. **Recessive trait**: Expressed when two alleles for that trait are inherited.
10. **Rhesus factor**: A human trait important in determining the safety of blood transfusions. People can be Rh positive (Rh+) or Rh negative (Rh–).

Check your understanding:

1. A genotype is **the genetic information from two alleles.**
2. A phenotype is **the physical manifestation of the genotype (i.e. detached earlobes).**
3. How many recessive alleles are needed for a trait to show in the phenotype? **2**
4. How many dominant alleles are needed for a trait to show in the phenotype? **1**

Part III: Activities

Activity 1: Punnett squares and blood type

The ABO blood group

As with many other traits, a person inherits two alleles for the gene that determines her **ABO blood type**. One allele for each gene is inherited from the mother and one allele for each gene is inherited from the father. The combination of alleles that a person has is her blood's genotype. A person's blood type is her blood's phenotype.

There are three alleles for the gene that determine blood type. A person inherits two of the three alleles for the gene that determines blood type. The three alleles for blood type are the A, B, and O alleles.

- The A allele and B allele are both dominant.
- The O allele is recessive.
- When the genotype contains both the A allele and the B allele, they are **codominant**, meaning both are expressed in the phenotype.

There are six possible blood type genotypes and four possible blood type phenotypes. Depending on a person's combination of alleles, a person can have **Type A, Type B**, **Type AB**, or **Type O** blood. This blood type system is called the ABO blood group. Table 2 below shows the possible genotypes and the associated phenotypes for the ABO blood group.

Table 2 - ABO Blood Group

Genotype	Phenotype
AA	Type A
AO	Type A
BB	Type B
BO	Type B
AB	Type AB
OO	Type O

Punnett Squares

A Punnett Square is a table that determines the probability of an offspring having a particular genotype. For example, a Punnett square for blood type is shown below. In this case, the father has the genotype BB which results in the phenotype of blood type B. The mother has genotype AO which results in the phenotype of Type A blood.

		Father	
		B	B
Mother	A	AB	AB
	O	BO	BO

The probability that the offspring will inherit certain blood types:

Type AB: 50 percent

Type A: 0 percent

Type B: 50 percent

Type O: 0 percent

Complete the Punnett Square below: A father has genotype BO, which results in the phenotype of blood type B. A mother has the genotype AO, which results in the phenotype of Type A blood.

Complete the Punnett Square, and calculate the blood type (phenotype) probability for a child from this couple:

		Father	
		B	O
Mother	A	AB	AO
	O	BO	OO

The probability that the offspring will inherit certain blood types:	
Type AB:	25 percent
Type A:	25 percent
Type B:	25 percent
Type O:	25 percent

Activity 2: Blood transfusions

If a person loses a lot of blood during surgery or from a major injury, she may need a **blood transfusion**. During a blood transfusion, doctors give a person additional blood from someone else by pumping it into a vein. People can donate blood to the American Red Cross and to blood banks and to the Red Cross to make sure that there is blood for people who need blood transfusions.

For a blood transfusion to work, the person receiving the transfusion, the recipient, <u>must have a blood type compatible to the **blood type** of the person donating the blood</u>, the donor. Blood types are compatible if the person can receive donated blood and the body does not recognize the blood cells as foreign. The body recognizes foreign blood cells when the blood cells are not the correct ABO type. Some blood types are not compatible. If a person receives blood that is not compatible, the body will attack the donated blood cells because it recognizes the blood cells as foreign. This leads to complications and sometimes death.

People with all blood types can receive blood transfusions from people with Type O blood because the body does not recognize Type O as foreign.

- People with Type A blood can safely receive transfusions of Type A and Type O blood
- People with Type B blood can safely receive transfusions of Type B and Type O blood
- People with Type AB can safely receive Type A, Type AB, Type B, and Type O blood
- People with Type O can safely receive transfusions of only Type O blood

When determining the compatibility of blood for transfusions, the **rhesus factor** also needs to be considered (see Table 3). Rhesus factor indicates whether or not a person has the gene that produces the rhesus protein. Rhesus factor is a dominant trait, meaning a person only needs one copy of the Rh+ allele to have the rhesus protein (Rh+ blood). A person who is Rh+ has the allele that does produce the Rh protein. Rh– is a recessive trait, meaning a person needs two copies of the Rh– allele to be Rh–. A person who is Rh– has the alleles that do not produce the Rh protein.

Table 3 - Rh+ and Rh-

Rhesus factor	Dominant or Recessive?	Punnett Square Representation	Genotype(s)	Phenotype
Rh+	Dominant	D	Dd or DD	Produces Rh Protein
Rh-	Recessive	d	dd	Does not Produce Rh Protein

Each of the four blood types in the ABO blood group (Type A, Type B, Type AB, and Type O) can be either Rh+ or Rh–. The gene for ABO blood type and the gene for rhesus factor are inheritied separately. Human blood type phenotype is a combination of ABO blood type and rhesus factor.

Rh factor is an important factor in determining whether a patient can safely receive a blood transfusion from a blood donor.

- People who are Rh+ can safely receive transfusions of **both** Rh– blood and Rh+ blood.
- People who are Rh– can receive transfusions of **only** Rh–blood. People who are Rh– can receive only Rh– blood because Rh– people do not produce the Rh protein. If the person with Rh– blood receives Rh+ blood, the body may detect the Rh protein as foreign and attack the blood cells causing complications and even death.

Table 4 (right) shows the blood types of a blood transfusion recipient, and the blood types that they can safely receive from a blood donor if they need a blood transfusion.

Table 4 - ABO and Rhesus Factor Blood Types

Recipient	Donor
A+	A+, A–, O+, O–
A–	A–, O–
B+	B+, B–, O+, O–
B–	B–, O–
AB+	A+, A–, B+, B–, AB+, AB–, O+, O–
AB–	A–, B–, AB–, O–
O+	O+, O–
O–	O–

1. **Universal recipients** are people who can receive blood donations from any of the possible combinations of ABO and Rh blood types. Based on Table 4 (above), people with which blood type are universal recipients?

People who are Type AB+ are the only true universal recipients.

2. **Universal donors** are people who can donate to people with any combination of ABO and Rh blood types. Based on Table 4 (above), people with which blood type are universal donors?

People who are Type O– are the only universal donors.

3. Determine whether the following donor/recipient pairings in Table 5 are safe for a transfusion to take place.

Table 5 - Donor/Recipient Pairings for Transfusion

Recipient	Donor	Safe for Transfusion (Y/N)
O-	B+	**No**
B+	O-	**Yes**
AB+	A-	**Yes**

4. Why might it be difficult for some people who need blood to receive a blood transfusion?

Some blood types, such as Type O– can receive only Type O– blood in a transfusion. If the hospital or blood bank is out of that blood type, the person can't safely receive a blood transfusion.

5. Would you consider donating blood? Why or why not?

The answer to this question will vary for each student.

Activity 3: Blood type in the U.S.

As you learned in Activity 2, some people can receive blood transfusions from people with many different blood types. Other people can receive blood transfusions only from people with a few blood types. This means that it is more difficult for some people in need of blood to safely receive a blood transfusion.

The frequency with which different blood types appear in the U.S. also affects whether someone who needs blood after surgery or injury can safely receive a blood transfusion. Table 6 shows the eight different ABO blood types and Rh factors, and the frequency with which they appear in the U.S. population. Study the table below to see the frequency of ABO blood types and Rh factors in the U.S.

Table 6 - Blood Type in the U.S.

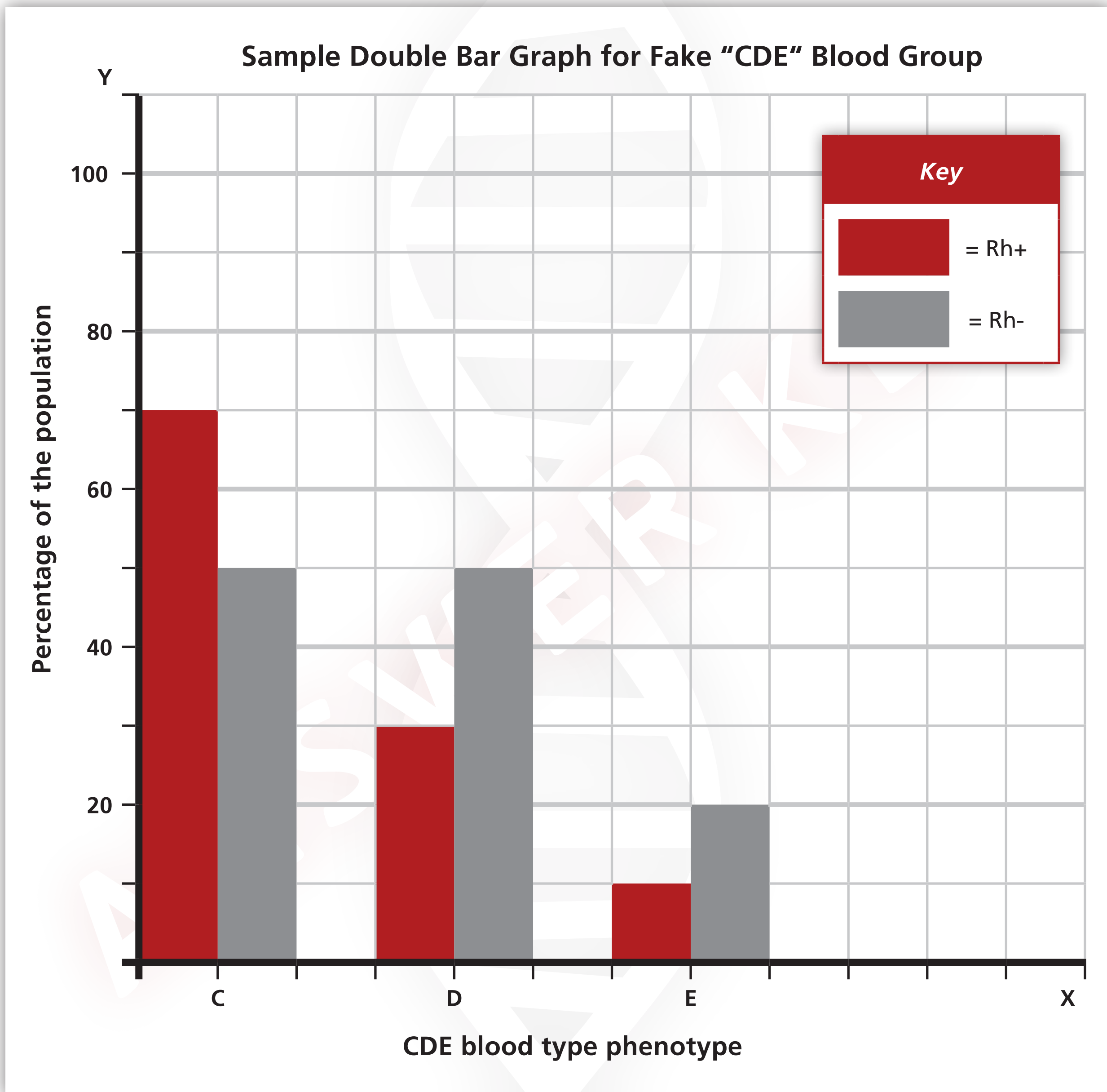
ABO Type	How Many have It?	Rh Factor	How Many Have It?
O	44%	O+	37.4%
		O–	6.6%
A	42%	A+	35.7%
		A–	6.3%
B	10%	B+	8.5%
		B–	1.5%
AB	4%	AB+	3.4%
		AB–	0.6%

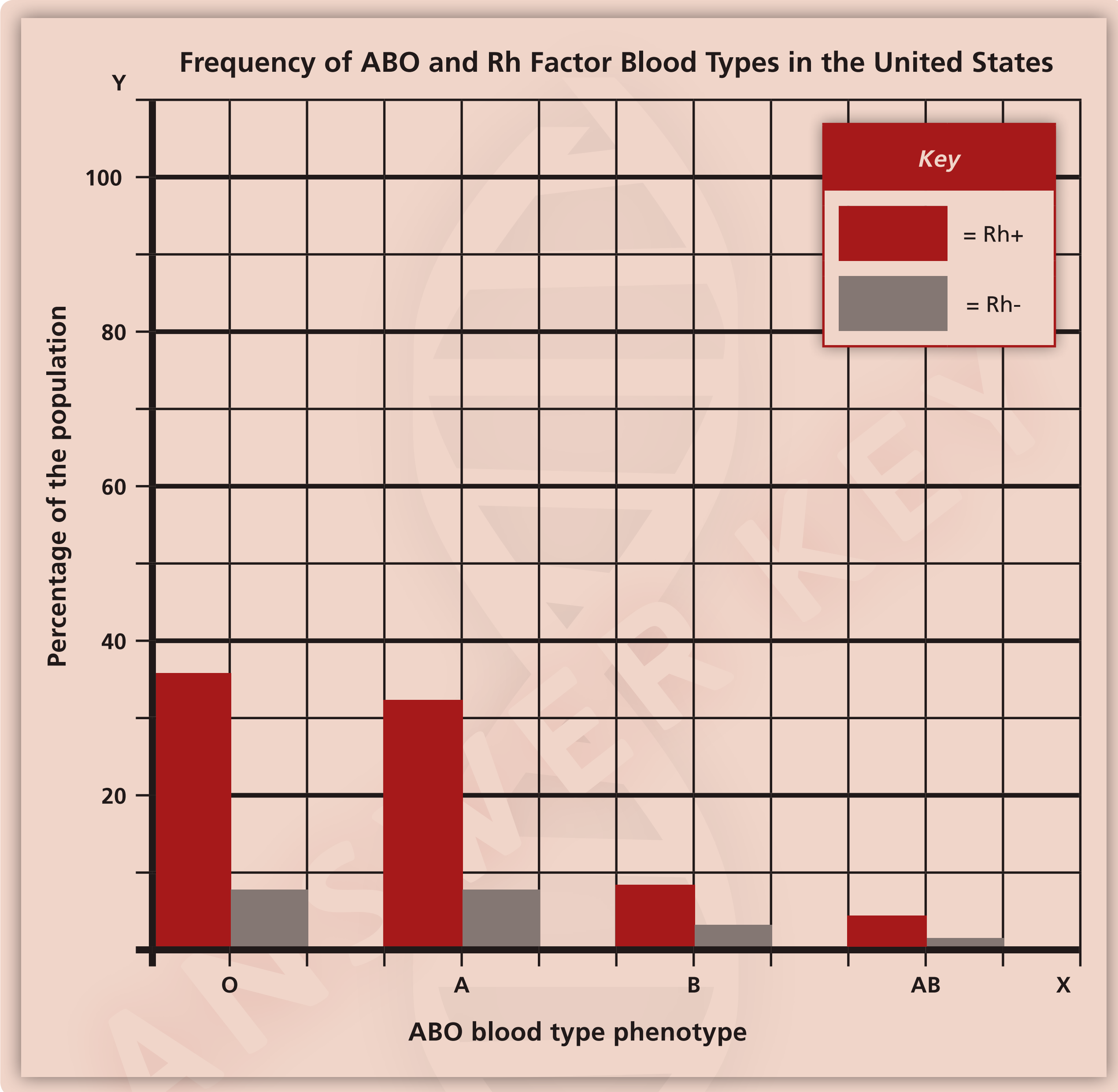
Using the information in Table 6, create a double bar graph to demonstrate the frequency with which ABO and Rh blood types are found in the U.S.. The steps below will guide you through the process.

Create a graph

1. **Create a title for the graph**. Think carefully. Your title should reflect the information that your graph will demonstrate. Write the title on the line above the graph.
2. **Create a key for the graph**. Chose one color to represent Rh+ and one color to represent Rh–. Color the boxes in the key.
3. **Label each axis**. You will graph blood type on one axis and percentage of the population on the other axis. Determine which axis should show which information, and label accordingly.
4. **Number each axis**. Determine the number by which you will count percentage of the population. Mark these numbers on graph. Label each bar on the other axis with the different blood types.

5. **Create your graph**. Create a double bar graph using the information in Table 4. An example of a double bar graph is shown below. The sample bar graph is not scientifically or mathematically accurate. Use it only as a reference for how to structure a double bar graph.




Frequency of ABO and Rh Factor Blood Types in the United States
Y
100
80
60
40
20
Percentage of the population
Key
= Rh+
= Rh-
O
A
B
AB
X
ABO blood type phenotype

1. Looking at the graph that you just created, which blood type appears most frequently in the U.S.?

Blood Type O+ appears the most frequently in the U.S.

2. Looking at the graph that you just created, which blood type appears the least frequently in the U.S.?

Blood Type AB – appears the least frequently in the U.S.

3. Do you think that people have an ethical obligation or responsibility to donate blood? Why or why not?

The answer to this question will vary for each student.

4. Do some people have **more** of an ethical obligation to donate blood than other people? Why or why not? Be specific and reference your graph.

The answer to this question will vary for each student.

Activity 4: Solve a mystery

In Activities 1-3, you learned about the inheritance of blood type, used Punnett Squares to identify the probability that an offspring will inherit a particular blood type, and graphed the frequency with which certain blood types appear in the U.S. In Activity 4, you will apply the knowledge about the inheritance of blood type that you learned in Activities 1-3 to solve a mystery. Read the following story carefully, and then answer the questions to solve the mystery.

A prince living in the small nation of Genotopia has discovered that he was adopted at birth. The prince loves his royal life, but wishes to locate his birth parents. The prince would like to get to know his birth parents, and to share some of his royal fortune with them. However, there is a problem. The adoption agency that coordinated the prince's adoption is in disarray. Their paperwork is disorganized, and they cannot be positive about the identity of the prince's birth parents. They give the prince the names and blood types of three couples. One of the couples is the prince's birth parents.

The prince comes to you, a lead detective at the Punnett Squares Private Eyes detective agency, to lead the investigation into the identity of his birth parents. You reassure the prince that you will be discrete.

You are, after all, a scientific genius, and an expert at using blood types to solve mysteries. You tell the prince you will identify the probability that each couple is the prince's birth parents by using Punnett Squares, ABO blood type, and rhesus factor. The prince does not know his blood genotype, but he does know his blood type phenotype. He is Type O–.

Your first task is to determine the prince's possible genotype for ABO blood type and Rh factor. Blood type is a trait controlled by more than one gene. Remember, the gene for ABO blood type and the gene for rhesus factor are separate. When a person inherits an O allele, it does not mean he will inherit the Rh+ allele. Human blood type phenotype is a combination of ABO blood type and rhesus factor, therefore, you need to determine the genotypes for ABO blood type and Rh factor separately.

You will be given the blood type phenotypes of three couples who may be the prince's parents. Based on the phenotype, you must determine the possible genotypes for ABO blood type and Rh factor of the man and woman of each couple, and estimate the probability of the couple having a child with the prince's blood type phenotype (Type O–).

Use the ABO blood type alleles table and the Rhesus (Rh) factor alleles table (right) throughout your investigation.

ABO Blood Type Alleles	*Rhesus (Rh) Factor Alleles*
A = Type A (dominant)	D = Rh+ (dominant)
B = Type B (dominant)	d = Rh– (recessive)
O = Type O (recessive)	
*Possible ABO genotypes: AA, AO, BB, BO, AB, OO	*Possible Rh factor genotypes: DD, Dd, or dd

1. The prince has blood type phenotype O–. There is only 1 genotype for ABO blood type and for the Rh factor that can create the blood type phenotype O–. What is the genotype for the ABO blood type and Rh factor of the prince?

   a. ABO genotype: **OO**

   b. Rh factor genotype: **dd**

2. What alleles should you look for in the genotype of the couples to determine whether they can be the prince's birth parents?

   a. Alleles for ABO genotype: **O** from mother and **O** from father

   b. Alleles for Rh factor genotype: **d** from mother and **d** from father

3. How do you know that your answer to number 1 is the genotype for the prince's ABO blood type and Rh factor? Why aren't there any other possibilities? Explain your answer.

The prince's blood type phenotype is O–. The ABO phenotype O is a recessive trait, therefore the person needs to have two of the recessive O alleles in his genotype to have the O phenotype. The rhesus factor phenotype Rh– is also a recessive trait, therefore, the person needs to have two of the recessive Rh– (d) alleles in his genotype to have the Rh– phenotype. There are no other possible combinations that result in the recessive traits in the phenotype.

Now that you have determined the ABO genotype and the Rh factor genotype for the prince, you can determine whether each couple could be the prince's birth parents. For each couple, you are given the blood type phenotype of the man and woman. Based on the blood type phenotypes of the man and woman in each couple, you must determine the possible ABO genotypes and Rh factor genotypes. There may be more than one ABO genotype or Rh factor genotype for each person. Then, consider whether the possible birth parents have the alleles needed to create the prince's blood type.

Couple #1

4. The man has a blood type phenotype of B+. The woman has a blood type phenotype of A+. Determine the possible ABO genotypes and Rh factor genotypes for the Couple #1, and write your answers in the boxes below. The possible genotypes for the man are completed for you.

Man	*Woman*
Blood type phenotype: B+	Blood type phenotype: A+
a. Possible ABO genotype(s): **BB or BO**	a. Possible ABO genotype(s): **AA or AO**
b. Possible Rh factor genotype(s): **DD or Dd**	b. Possible Rh factor genotype(s): **DD or Dd**

5. Consider the alleles in the possible genotypes for the man and the woman. Is it possible that Couple #1 could be the parents of the child based on ABO blood type and Rh factor? Refer to question 2 to determine your answer.

Yes, it is possible for Couple #1 to be the parents of the child based on ABO blood type and Rh factor.

6. Which of the possible ABO and Rh factor genotypes does the man need in order to be the father of the prince?

   a. ABO genotype: **BO**

   b. Rh factor genotype: **Dd**

7. Which of the possible ABO and Rh factor genotypes does the woman need in order to be the mother of the prince?

   a. ABO genotype: **AO**

   b. Rh factor genotype: **Dd**

8. Complete the Punnett Squares for ABO blood type and Rh factor using the man and woman's genotypes from questions 6 and 7 to determine the probability that Couple #1 could have a child with the prince's ABO genotype O and her Rh factor genotype Rh–.

ABO blood type

		Father	
		B	O
Mother	A	AB	AO
	O	BO	OO

a. Probability of ABO phenotype O: 25 percent

Rh factor

		Father	
		D	d
Mother	D	DD	Dd
	d	Dd	dd

b. Probability of Rh factor phenotype Rh–: 25 percent

9. Using Punnett Squares in question 8, you determined the probability that a child from Couple #1 will have the ABO phenotype O and the probability that the child will have Rh factor phenotype Rh–. Now, you will combine these probabilities to determine the probability that Couple #1 will have a child with **both** ABO phenotype O and Rh factor phenotype Rh–, resulting in the blood type phenotype O–.

   First, you will have to convert the probabilities from 8a and 8b into decimals. For example, if the answer to 8a is 50.0 percent, then you would move the decimal point over 2 places to the left. Therefore the answer would be 0.50.

   a. Probability of phenotype O from 8a: **25** percent = **0.25** (in decimal form).

   b. Probability of phenotype Rh– from 8b: **25** percent = **0.25** (in decimal form).

   Now you can determine the combined probability by multiplying the two probabilities (in decimal form) together.

   c. (Probability of phenotype O) * (Probability of phenotype Rh–) = Probability of phenotype O–

   0.25 * **0.25** = **0.0625**

   Determine the probability of phenotype O– as a percentage by multiplying the answer to 8c by 100.

   d. 9c * 100 = **6.25** percent

Couple #2

10. The man in Couple #2 has a blood type phenotype of O–. The woman in Couple #2 has a blood type phenotype of O+. Based on their blood type phenotypes, determine the possible ABO genotypes and Rh factor genotypes for the man and woman in Couple #2, and write your answers in the boxes below.

Man	***Woman***
Blood type phenotype: O-	Blood type phenotype: O+
a. Possible ABO genotype(s): **OO**	a. Possible ABO genotype(s): **OO**
b. Possible Rh factor genotype(s): **dd**	b. Possible Rh factor genotype(s): **DD or Dd**

11. Consider the alleles in the possible phenotypes for the man and the woman. Is it possible that Couple #2 could be the parents of the child based on ABO blood type and Rh factor? Refer to question 2 to determine your answer.

Yes, it is possible for Couple #1 to be the parents of the child based on ABO blood type and Rh factor.

12. Which of the possible ABO and Rh factor genotypes does the man have to have to be to be the father of the prince?

a. ABO genotype: **OO**

b. Rh factor genotype: **dd**

13. Which of the possible ABO and Rh factor genotypes does the woman have to have to be to be the mother of the prince?

a. ABO genotype: **OO**

b. Rh factor genotype: **Dd**

14. Complete the Punnett Squares for ABO blood type and Rh factor using the genotypes from questions 12 and 13 to determine the probably of Couple #2 could have a child with the prince's ABO blood type genotype O and her Rh factor genotype Rh–.

ABO blood type

Mother \ Father	O	O
O	OO	OO
O	OO	OO

a. Probability of blood type phenotype O: **100 percent**

Rh factor

		Father	
		d	d
Mother	D	Dd	Dd
	d	dd	dd

b. Probability of Rh factor phenotype Rh-: **50 percent**

15. Using Punnett Squares in question 14, you determined the probability of the child from Couple #2 having blood type phenotype O, and the probability of the child having Rh factor phenotype Rh–. Now, you will combine these probabilities to determine the probability that Couple #2 will have a child with **both** blood type phenotype O and Rh factor phenotype Rh–.

    First you will have to convert the probabilities from 14a and 14b into decimals. For example, if the answer to 14a is 50.0 percent, then you would move the decimal point over 2 places to the left. Therefore the answer would be 0.50.

    a. Probability of phenotype O from 14a: **100** percent = **1.0** (in decimal form).

    b. Probability of phenotype Rh– from 14b: **50** percent = **0.50** (in decimal form).

    Now you can determine the combined probability by multiplying the two probabilities (in decimal form) together.

    c. (Probability of phenotype O) * (Probability of phenotype Rh–) = Probability of phenotype O–

    1.0 * **0.50** = **0.50**

    Determine the probability of phenotype O– as a percentage by multiplying the answer to 10c by 100.

    d. 15c * 100 = **50** percent

16. Which couple has the greatest probability of being the prince's birth parents? Why?

Couple #2 has the greatest probability of being the prince's birth parents. The probability of Couple #2 having a child with blood type phenotype O– is 50 percent. The probability of Couple #1 having a child with blood type phenotype O– is only 6.25 percent.

17. Is there a phenotype or phenotypes that a person may have that would give him/her zero probability of having a child with the blood type phenotype O–? If you answered yes, please provide the phenotype(s).

Yes, is a person has blood type phenotype AB. There is zero probability that this person can pass on an O allele to his or her child. This person will always pass on an A or a B allele and, therefore, will never produce a child with the ABO phenotype O.

Part IV: Conclusion questions

1. What are some reasons a person may want to know his or her blood type?

A person may want to know his or her blood type for medical reasons. If the person needs a blood transfusion, it is very important to know blood type.

2. If you had your blood tested and found out that you have a universal blood type, would you be more likely or less likely to donate blood?

The answer to this question will vary for each student.

3. Blood type is a human trait. Is blood type controlled by one gene, or by several genes? Give examples from today's lesson.

Blood type is controlled by more than one gene. For example in today's activity we looked at two genes that control blood type. ABO blood type is controlled by one gene and rhesus factor is controlled by another gene.

Part V: Notes

Addition to Activity 4

Solving a mystery

One afternoon, the woman from Couple #2 comes to the office of the Punnett Square Private Eyes. The woman knows the ABO and rhesus factor genotypes of both her mother and father. Your job is to determine whether this new information changes your conclusions of which couple has the greatest probability of being the prince's parents.

Table 1 - ABO Blood Group	
Genotype	**Phenotype**
AA	**Type A**
AO	**Type A**
BB	**Type B**
BO	**Type B**
AB	**Type AB**
OO	**Type O**

ABO Blood Type Alleles	***Rhesus (Rh) Factor Alleles***
A = Type A (dominant) B = Type B (dominant) O = Type O (recessive)	D = Rh+ (dominant) d = Rh- (recessive)
*Possible ABO genotypes: AA, AO, BB, BO, AB, OO	*Possible Rh factor genotypes: DD, Dd, or dd

The woman from Couple #2 is blood type phenotype O+. Remember the prince is blood type phenotype O–.

1. What ABO and Rh factor genotypes does the woman from Couple #2 have to have to be to be the mother of the prince?

   a. ABO blood type genotype:____________________

   b. Rh factor genotype:__________________________

2. The woman from Couple #2 knows that her father's phenotype is B+. His ABO genotype is BO and his Rh factor genotype is DD. The woman also knows her mother's phenotype is A+. The mother's ABO genotype is AO and her Rh factor genotype is DD

   Complete a Punnett Square to determine the possible genotypes for the woman from Couple #2.

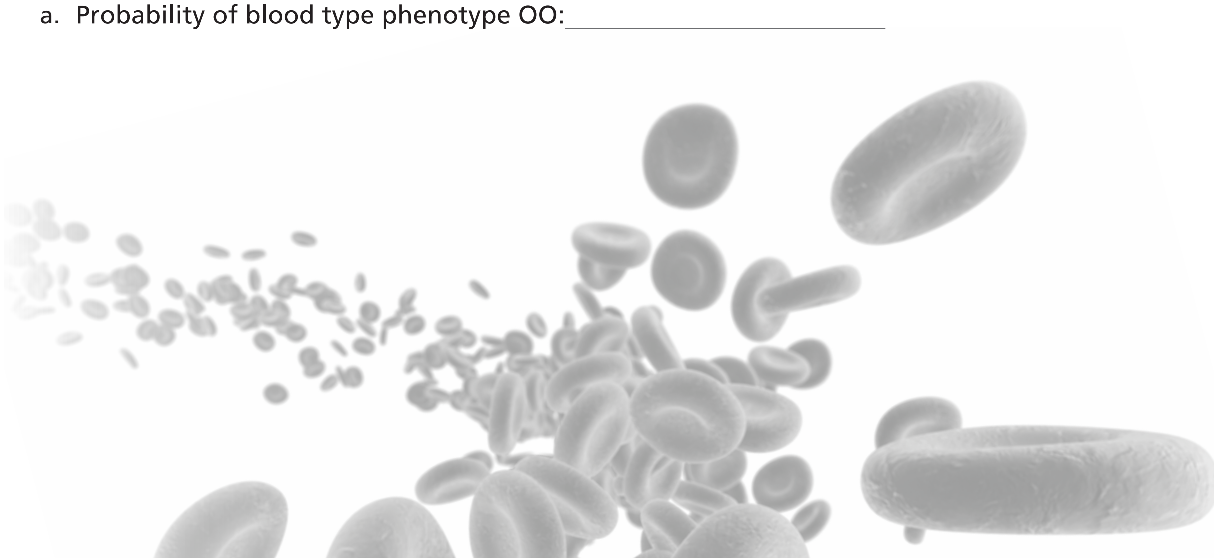
Father
Blood type phenotype: B+
a. Possible genotype: **BO**
b. Rh factor genotype: **DD**

Mother
Blood type phenotype: A+
a. ABO genotype: **AO**
b. Rh factor genotype: **DD**

ABO blood type

		Father	
Mother			

a. Probability of blood type phenotype OO:____________________



Rh factor

		Father	
Mother			

b. Probability of Rh factor genotype Dd: ____________________

1. Can the woman from Couple #2 be the mother of the prince? Why or why not?

2. Does this information change which couple can possibly be the parents of the prince? Why or why not?

Addition to Activity 4

Solving a mystery

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AB	**Type AB**
OO	**Type O**

ABO Blood Type Alleles	*Rhesus (Rh) Factor Alleles*
A = Type A (dominant) B = Type B (dominant) O = Type O (recessive)	D = Rh+ (dominant) d = Rh- (recessive)
*Possible ABO genotypes: AA, AO, BB, BO, AB, OO	*Possible Rh factor genotypes: DD, Dd, or dd

The woman from Couple #2 is blood type phenotype O+. Remember the prince is blood type phenotype O–.

1. What ABO and Rh factor genotypes does the woman from Couple #2 have to have to be to be the mother of the prince?
   a. ABO blood type genotype: **OO**
   b. Rh factor genotype: **Dd**

2. The woman from Couple #2 knows that her father's phenotype is B+. His ABO genotype is BO and his Rh factor genotype is DD. The woman also knows her mother's phenotype is A+. The mother's ABO genotype is AO and her Rh factor genotype is DD

   Complete a Punnett Square to determine the possible genotypes for the woman from Couple #2.

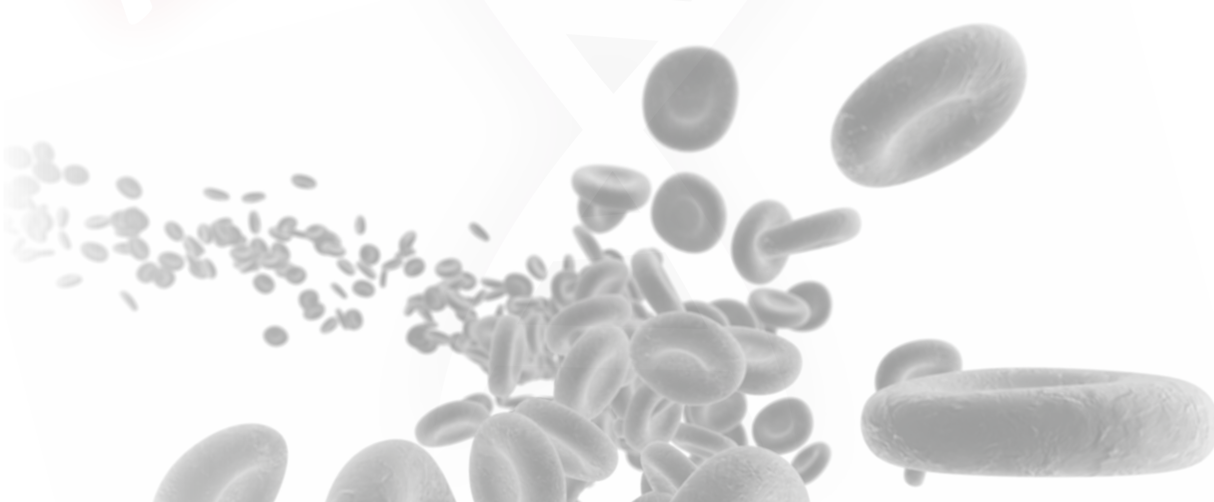
Father
Blood type phenotype: B+
a. Possible genotype: **BO**
b. Rh factor genotype: **DD**

Mother
Blood type phenotype: A+
a. ABO genotype: **AO**
b. Rh factor genotype: **DD**

ABO blood type

		Father	
		B	**O**
Mother	**A**	**AB**	**AO**
	O	**BO**	**OO**

a. Probability of blood type phenotype OO: **25 percent**



Rh factor

		Father	
		D	D
Mother	D	DD	DD
	D	DD	DD

b. Probability of Rh factor genotype Dd: **0 percent**

1. Can the woman from Couple #2 be the mother of the prince? Why or why not?

No, the woman from Couple #2 cannot be the mother of the prince. Based on her parent's genotypes, we know that there is no probability that her rhesus factor genotype can be Dd. Therefore, there is no way that she can have a child with the rhesus factor phenotype Rh– .

2. Does this information change which couple can possibly be the parents of the prince? Why or why not?

Yes, based on this information we can determine that Couple #2 is definitely not the parent's of the prince.

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Blood Type: What is your type?

Module 10