MODULE 9

Inheritance–It's the law!

FACILITATOR'S GUIDE

GENETICS FOR KIDS

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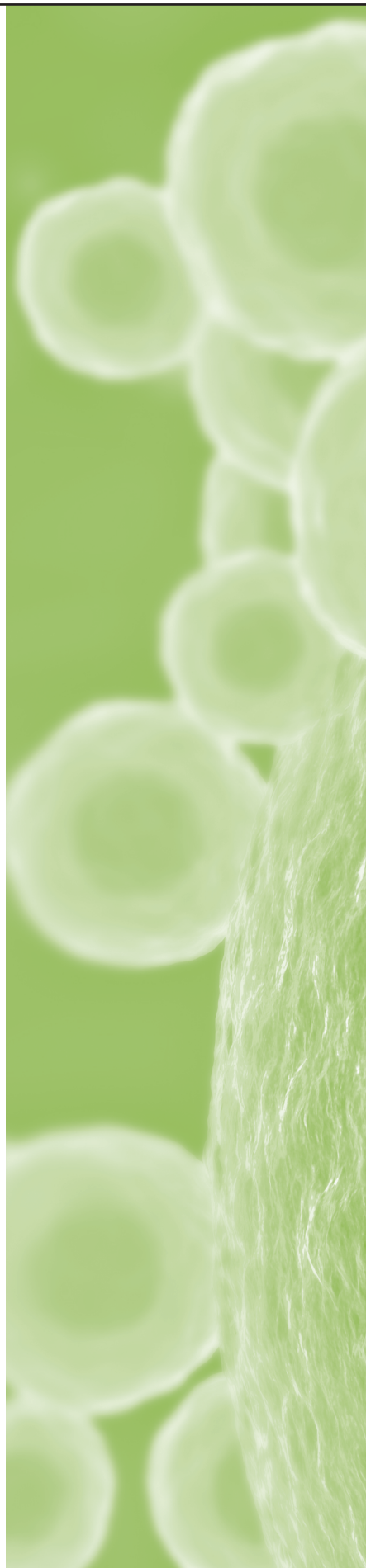
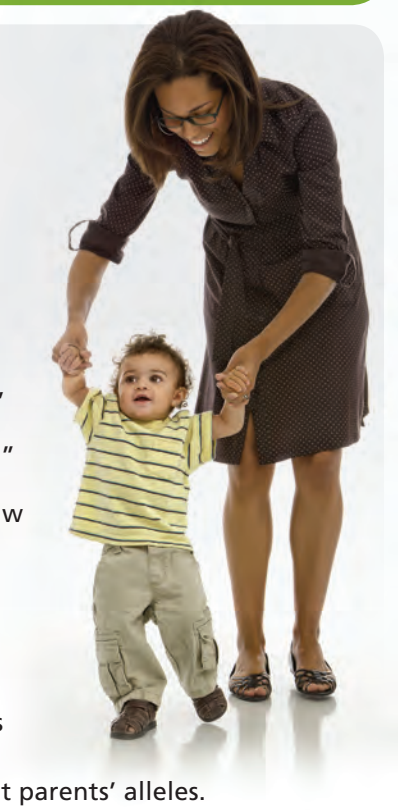


Inheritance–It's the law!

Introduction



For generations, people have observed that children inherit certain traits or physical characteristics from each parent. Passing traits from a parent to a child is called heredity. Human heredity is complicated, but in the 1860's, an Austrian monk, named Gregor Mendel, studied the inheritance of traits in pea plants. In pea plants, the hereditary process is easier to observe than in humans. Mendel discovered that he could learn about hereditary patterns in humans by studying hereditary patterns in pea plants. Based on his research, Mendel determined that traits are inherited in separate units from each parent. Since Mendel's time, scientists have called the basic hereditary units that determine human traits "genes." Because of his research, Mendel is often called the "father of genetics."

In this module, students explore two laws of heredity–Mendel's First Law, the Law of Segregation, and Mendel's Second Law, the Law of Independent Assortment. Students will learn about the First and Second Laws using separate diagrams to demonstrate the segregation and independent inheritance of alleles. To determine the outcome of an offspring's genotype, the students will model both processes by flipping coins that represent parents' alleles.

Learning Objectives

- ✓ Know the role of chromosomes and genes in the cellular environment
- ✓ Understand that sperm and egg cells each contribute chromosomes to the offspring
- ✓ Recognize that children resemble their parents due to the genetic inheritance of their parents' DNA

Prior Knowledge

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

- ✓ Understand that heredity is the inheritance of traits from one generation to the next
- ✓ Understand that chromosomes are structures inside the nucleus of a cell that contain genetic information
- ✓ Recognize that genes are regions of the DNA that give the cell instructions

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

- 2.1a: Hereditary information is contained in genes. Genes are composed of DNA that makes up the chromosomes of cells.
- 2.1e: In sexual reproduction typically half of the genes come from each parent. Sexually produced offspring are not identical to either parent.

Background

The History of Heredity

During the 1860's, an Austrian monk named Gregor Mendel determined that traits (physical characteristics of organisms) are passed from one generation to the next. The passage of traits from one generation to the next is called **heredity**. From Mendel's research on heredity in pea plants, he discovered two important laws governing heredity. Mendel determined that each parent plant contained two factors that contributed to the traits of the offspring plant. From the combination of parental traits Mendel observed in the offspring plants, he determined that each parent plant contributes one factor to the traits that are observable in the offspring. Scientists now know that the factors or units of inheritance that Mendel noted in his research are **genes**.

Mendel's First Law (The Law of Segregation) states that when a **gamete** (egg or sperm cell) forms during **meiosis**, each gamete contains only one copy of each gene. A copy of a gene is called an **allele**. Mendel's Second Law (The Law of Independent Assortment) states that different alleles are inherited independently of each other. The alleles (copies of a gene) that control one trait are inherited independently of the alleles (copies of a gene) controlling another trait. For example, the allele for eye color is not inherited with the allele for hair color, so if a person inherits the alleles for blue eyes, it does not mean they will inherit the alleles for blonde hair.

Mendel's Laws

First Law	(The Law of Segregation)
States that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (allele).	

Second Law	(The Law of Independent Assortment)
States that different alleles (copies of a gene) are inherited independently of each other.	

Heredity and Genes

Genes are regions of the **DNA** that provide instructions for the cell. Scientists estimate that five percent of human DNA codes for genes. Genes contain instructions to create a trait and are located at specific places on a **chromosome**. Chromosomes are tightly coiled strands of DNA, which are an effective way to package DNA to fit into the nucleus of a cell. During cell division, DNA is tightly coiled into chromosomes. This process effectively copies, divides, and verifies accuracy for genetic information. For example, during meiosis chromosomes divide so that each gamete contains 23 chromosomes with one copy of each allele.

Humans have 46 chromosomes in 23 pairs in each cell. When the sperm of the father fertilizes the egg of the mother, the result is an offspring with 46 chromosomes. One set of 23 chromosomes comes from the mother and the other set of 23 chromosomes comes from the father. Each set of 23 chromosomes contains the same genes, but the set from the mother may have different copies of the gene (alleles) than the set from the father (see Table 1).

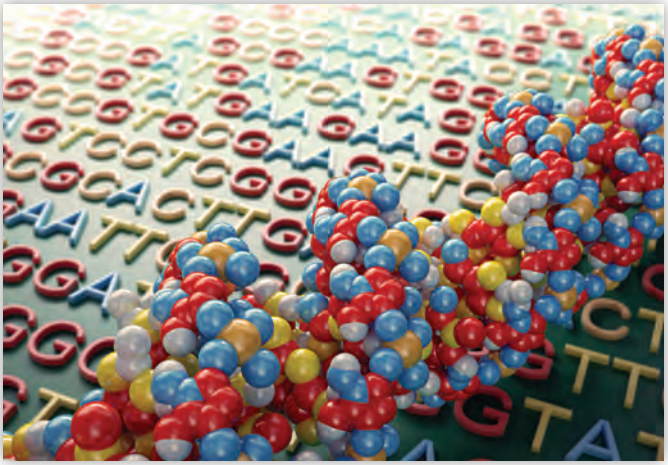
Table 1 – Inheritance of Chromosomes and Alleles

Egg	+	Sperm	=	Offspring
23 chromosomes		23 chromosomes		46 total chromosomes 23 pairs of chromosomes
1 allele for each gene		1 allele for each gene		2 alleles for each gene

Children often resemble one or both parents because of the inheritance of genes. Humans have about 30,000 genes that provide information for traits, including physical traits, blood type, and immunity to diseases. The 23 chromosomes inherited from the mother have one allele for each of the 30,000 genes. The 23 chromosomes inherited from the father also have one allele for each of the 30,000 genes.

The Importance of Heredity

Heredity is the passage of genes from one generation to the next, but human beings are not genetically identical. Genetic variation, or differences in DNA, makes it unlikely that the entire human species would die from a single disease or environmental change, since some people may have an allele that makes them more resistant to a particular disease. Mendel's Laws explain the reasons a child may look like her parents and have similar traits (Law of Segregation), and why a child is genetically unique from her parents (Law of Independent Assortment). Understanding the inheritance of genes allows scientists to determine the probability of children inheriting genetic diseases from their parents. The more scientists understand about the inheritance of traits and diseases, the closer they come to finding ways to treat and cure complicated genetic problems.



Vocabulary

1. **Allele**: One of the multiple forms of a gene (humans usually have two copies of every gene). One allele or copy comes from the mother and one allele or copy comes from the father.
2. **Chromosomes**: A single molecule of DNA and its associated proteins which condense and become visible during mitosis. Chromosomes determine traits, including gender, hair color, and eye color.
3. **DNA (deoxyribonucleic acid)**: A double-stranded nucleic acid that contains the genetic information for cell growth, division, and function.
4. **Gamete**: A sex cell (egg or sperm) that has 23 chromosomes contains only one copy of each gene.
5. **Gene**: A DNA sequence that is transcribed to produce a functional product (proteins).
6. **Heredity**: The inheritance of traits from one generation to the next.
7. **Meiosis**: A process of cell division that results in the production of sex cells (gametes) with 23 chromosomes.

Materials List

Before you begin, ensure that you have all of the items necessary to complete the module.

- ✓ **Student Handout**
- ✓ **Pennies (one for each pair of students)**
- ✓ **Nickels (one for each pair of students)**
- ✓ **Markers**

Procedure

Day of the Lesson

1. Seat students in pairs.

   Inform students that in today's module, they will learn about units of heredity called genes. Genes carry genetic information from one generation of an organism to the next. Genes are regions of DNA. DNA is coiled tightly into chromosomes during cell division, so that genetic information from the parents is copied correctly and divided.
   Inform students that they will learn about the inheritance of genetic information and why children share traits with their parents.

2. Distribute a **Student Handout** to each student.

3. Instruct students to read **Part I: Introduction.**

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

4. Emphasize key points from **Part I: Introduction.**

   When all students are finished reading, address any questions that students may have about heredity. Emphasize the following key points:

   - Genes are regions of DNA that contain the instructions for creating traits.
   - Chromosomes are tightly coiled DNA found in the nucleus during cell division.
   - Humans have 46 total chromosomes in 23 pairs.
   - An egg cell from the mother contributes 23 chromosomes and a sperm cell from the father contributes 23 chromosomes to an offspring. When the egg and sperm cells join, the resulting offspring has a total of 46 chromosomes.
   - Children resemble their parents due to the inheritance of the parents' DNA.

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

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

   - How many chromosomes does a child obtain from each parent?
   - Why do children resemble their parents?
   - What is heredity?

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

6. Instruct students to complete **Part III: *Activity 1: Gene sequence*** with their partner.

   Inform students that in ***Activity 1: Gene sequence***, they will learn how chromosomes in an organism pair with each other. Based on gene sequence, the 23 chromosomes that an organism inherits from its mother will pair with the 23 chromosomes the organism inherits from its father. Students will review two pairs of chromosomes to identify the gene sequence, and a set of five chromosomes to determine whether the chromosomes can be paired.

   Instruct students to take turns reading aloud the explanation of gene sequence to each other.

   Instruct students to answer Questions 1 through 5 to further their understanding of gene sequence and the relationship between genes and alleles.

   Circulate around the room as students work to ensure students are on task. Redirect students and answer questions as needed.

7. Once students have completed ***Activity 1: Gene Sequence*** with their partners, gather the class together and reinforce the concept of gene sequence.

   Lead a class discussion to reinforce the concept of gene sequence. Gene sequence is the order of genes in a chromosome. Each of the 23 chromosomes an offspring inherits from its mother has the same gene sequence as one of the 23 chromosomes an offspring inherits from its father. The chromosomes with the same gene sequence pair together.

   The specific genes that an offspring has in its chromosomes are its alleles. For example, the mother has a separate allele for dimples, blue eyes, thick hair, and brown hair.

8. Instruct students to complete **Part III: *Activity 2: The Law of Segregation***, with their partner.

   Inform students that in ***Activity 2: The Law of Segregation***, they will read about Mendel's Law of Segregation. Students will answer questions and complete a diagram that illustrates the Law of Segregation.

   Instruct students to read the explanation of the Law of Segregation aloud to each other. Each partner will take a turn to read aloud.

   Instruct students to complete the diagram, "Offspring's pair of chromosomes," to illustrate the way in which chromosomes inherited from an offspring's mother and father are inherited independently, but pair together.

   Instruct students to answer the questions for ***Activity 2: The Law of Segregation*** with their partner.

   Circulate around the room as students work to ensure students are on task. Redirect students and answer questions as needed.

9. Once students have completed ***Activity 2: The Law of Segregation***, gather the class together and reinforce Mendel's First Law, the Law of Segregation.

   Lead a class discussion to reinforce Mendel's First Law, the Law of Segregation. Ask students to share their descriptions of Mendel's Law of Segregation from ***Activity 1: Gene Sequence***.

   Guide students towards a common understanding of Mendel's Law of Segregation. Students should understand that Mendel's Law of Segregation states that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one allele for a gene. The mother's gamete contains the alleles that she will pass to the offspring, and the father's gamete contains the alleles that he will pass to the offspring. When an egg is fertilized by a sperm, the 23 chromosomes in the mother's egg and the 23 chromosomes in the father's sperm combine. After fertilization, there are 46 total chromosomes, and each of the chromosomes inherited from the mother pairs with a chromosome inherited from a father.

10. Ask students to share their answers for Question 3: "Do you think parents pass individual alleles or entire chromosomes to their offspring?"

    Ask students if they think parents pass individual alleles or entire chromosomes to their offspring. Students should observe that the mother's gamete is identical to the mother's chromosome I. However, the father's gamete is different from the father's chromosome I and chromosome II. The father's gamete has the allele for thin hair from chromosome I and the allele for red hair from chromosome II. The father's gamete has alleles from chromosome I and chromosome II because alleles are inherited independently. This is part of Mendel's Law of Independent Assortment and it will be explained in more detailed in ***Activity 3: The Law of Independent Assortment***.

11. Instruct students to complete **Part III: *Activity 3: The Law of Independent Assortment***.

    Inform students that in ***Activity 3: The Law of Independent Assortment***, they will read about Mendel's Second Law, the Law of Independent Assortment. Students will complete a diagram that illustrates Mendel's Law of Independent Assortment. Students will also answer questions to demonstrate their knowledge of Mendel's Law of Independent Assortment.

    Instruct students to take turns reading the explanation of the Law of Independent Assortment aloud to each other.

    Instruct students to complete the diagram, "Independent Inheritance of Alleles," to illustrate the way in which alleles are inherited independently of each other.

    Instruct students to answer the questions for ***Activity 3: The Law of Independent Assortment*** with their partner.

    Circulate around the room as students work to ensure students are on task. Redirect students and answer questions as needed.

12. Once students have completed ***Activity 3: The Law of Independent Assortment***, gather the class together and reinforce Mendel's Second Law, the Law of Independent Assortment.

    Lead a class discussion to reinforce Mendel's Second Law, the Law of Independent Assortment. Ask students to share the descriptions of Mendel's Law of Independent Assortment that they wrote for ***Activity 3: The Law of Independent Assortment***.

    Guide students towards a common understanding of Mendel's Law of Independent Assortment. Emphasize that alleles (copies of a gene) are inherited independently. For example, the offspring in the diagram may inherit the allele that codes for no dimples from their father, while also inheriting the allele that codes for brown hair.

Mendel's Laws

First Law	(The Law of Segregation)
States that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (Remember each chromosome in a pair contains a copy of a gene).	

Second Law	(The Law of Independent Assortment)
States that different alleles are inherited separately of each other.	

13. Give each pair of students a penny and a nickel. Instruct students to complete ***Activity 4: Determine an Offspring's Genes with their partner***.

    Pass out a penny and a nickel to each pair of students, and explain to students that they will use the penny and nickel to determine a possible set of alleles that an offspring could receive for 25 genes on human chromosome I. Emphasize that in real life, chromosome I contains 4,220 genes. In this module, students will only look at 25 of the 4,220 genes inherited from the mother and father to simplify the activity.

14. Explain to the students that for each of the 25 genes, they will flip the penny and the nickel to discover what alleles the child will receive from each parent.

    Explain that the penny will represent the mother's pair of alleles for a gene. The nickel will represent the father's pair of alleles for a gene. The two alleles that the offspring can inherit for each gene are "heads" and "tails."

    For each gene, a student will flip the penny to determine which allele the mother passes to the offspring. The same student will also flip the nickel to determine which allele the father passes to the offspring. Then, the other student will flip the penny and the nickel to determine which alleles the mother and father pass to the offspring.

    Instruct students to use Table 2 in the ***Student Handout*** to record their results. For each gene, students should record "H" for "heads" or "T" for "tails." For example, the outcome of the toss for gene 1 might be *Allele from Mother* = H and *Allele from Father* = T.

15. Emphasize the connection between the ***Activity 4*** and the Law of Inheritance and the Law of Segregation.

    Before students begin the game, emphasize that the activity demonstrates both of Mendel's laws. The activity demonstrates the Law of Segregation (the inheritance of one allele from each parent) because the offspring inherits one allele for a gene from each parent. The activity demonstrates the law of independent assortment because an offspring can inherit the allele "tails" for gene 1 without inheriting allele "heads" for gene 2. Inheriting the "tails" or "heads" allele for a particular gene does not influence what allele will be inherited for another gene.

16. Direct students to begin playing the game. Circulate around the room and answer questions as students work through ***Activity 4: Determine an Offspring's Genes***.

    Students should take turns flipping the penny and the nickel to determine the alleles that the mother and the father pass to an offspring, for a total of 25 genes.

    Circulate around the room as students work to ensure each partner is participating in flipping the coins and recording the results.

    As students complete the penny toss, emphasize that the DNA (genes) from both parents creates the collective traits that make up a child.

17. Compile class data.

When students have completed their tables, bring the students together as a group. Inform students that they will calculate the likelihood of an offspring inheriting the "heads" allele and the "tails" allele.

Instruct students to count the number of times they flipped the allele "heads" for genes from the mother. Students should record the number of "heads" for the mother and then count the number of times they flipped the allele "heads" for genes from the father.

Ask each group for the number of "heads" alleles from the mother. Record the number of "heads" alleles, then calculate the total number of times the "heads" allele was selected for the entire class.

Ask each group for the number of "heads" alleles from the father. Record the numbers of "heads" alleles, then calculate the number of times the "heads" allele was selected for the entire class.

Calculate the percentage that the allele "heads" was passed on to the offspring:

(Class total numbers of heads) / (25 * number of student pairs completing the activity) =	Multiply the above answers by 100.
Mother: _____	Mother: _____ percent
Father: _____	Father: _____ percent

Explain to the students that the calculations show that, on average, about 50 percent of the time the allele "heads" is selected and passed on to the next generation. Emphasize that each of the alleles of a gene contained in a parental cell has about a 50 percent chance of being passed on to an offspring.

Highlight that the combination of alleles inherited from the mother and father is not dependent on the other alleles inherited, due to the Law of Segregation and the Law of Independent Assortment. An offspring can inherit the allele "tails" for gene 1 without inheriting allele "heads" for gene 2. Inheriting the "tails" or "heads" allele for a particular gene does not influence which allele will be inherited for another gene.

Emphasize that neither the parents, nor the offspring, have any control over the combination of alleles that an offspring inherits.

18. Lead a closing class discussion about the module's activity.

Start by asking for students' responses to **Part IV: Conclusion questions**. Ask students the following additional questions:

- Why is it important that the inheritance of genes can occur in many possible combinations?

It makes each person unique and that is why there are so many differences among people.

Students should realize that the offspring for each group will have different allele combinations. No child will have the same heads/tails allele combinations for ALL of the 25 genes *(see Teacher Note 1)*.

Extension Lesson

The Importance of Genes

Have students make a list of why they think genes are important. If available, have students write their ideas on the blackboard or overhead projector. Students can then decide whether each statement is true (T) or false (F). The following provides an example of such statements.

Genes are important because:

- Information about genes will help researchers determine how to treat diseases. (T)
- They determine what we will look like. (T)
- They determine what our future will be like. (F: Genes are only one of the factors that contribute to our future destinations).
- DNA evidence can convict someone of a crime. (T)

History of Genes

Have students complete a biography on a famous geneticist. Some examples include James Watson, Francis Crick, Rosalind Franklin, Gregor Mendel, Sir Alec Jeffries, Ian Wilmut, and Craig Venter.

Teacher Notes

1. Students may notice that there are many combinations of alleles that arise from activity. Be sure to point out that the genetic variation between humans is even greater when the size and diversity of the world's population is taken into consideration. Also, while there is genetic variation between each person, humans still share over 99 percent of their genes.

Additional Resources

1. National Human Genome Research Institute, 3D Animation: http://www.genome.gov/Education/
2. QuickTime movie "Our Molecular Selves," which introduces basic molecular biology principles and genes in relation to the sequencing of the human genome. http://www.genome.gov/25520211

Part I: Introduction

The History of Heredity

In the 1860's, an Austrian monk, named Gregor Mendel, studied **heredity**, the inheritance of traits from one generation to the next. While experimenting with pea plants, Mendel discovered two important principles of genetics, which are known as Mendel's Laws. Mendel was able to determine that each parent plant contained two "factors" that controlled the plants' traits. In addition, he was able to determine that each parent contributes one "factor" to the offspring. Scientists now know that the factors, or units of inheritance, that Mendel noted in his research are **genes**.

Mendel's First Law is the Law of Segregation. It states that an organism gets one copy of a gene from each parent. When a **gamete** (egg or sperm cell) forms during **meiosis**, each gamete contains only one copy of each gene. A copy of a gene is called an **allele**. Mendel's Second Law is the Law of Independent Assortment. It states that different alleles are inherited independently of each other. The alleles (copies of a gene) that control one trait are inherited independently of the alleles (copies of a gene) controlling another trait. For example, the allele for eye color is not inherited with the allele for hair color, so if a person inherits the alleles for blue eyes, it does not mean they will inherit the alleles for blonde hair.

Mendel's Laws

First Law	(The Law of Segregation)
States that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (allele).	

Second Law	(The Law of Independent Assortment)
States that different alleles (copies of a gene) are inherited independently of each other.	

Heredity and Genes

Genes are regions of the **DNA** that provide instructions for the cell. A gene contains instructions that are used to create a trait. Each person has two alleles (copies) of each gene. Genes are located at specific places on a **chromosome**. Chromosomes are tightly-coiled strands of DNA, which is an effective way to package DNA to fit into the nucleus. DNA is tightly coiled into chromosomes to effectively copy and divide the genetic information, and ensure that new cells contain the correct genetic information. For example, during meiosis chromosomes are divided so that each gamete contains 23 chromosomes with one allele for each gene. Humans have 46 chromosomes or 23 pairs.

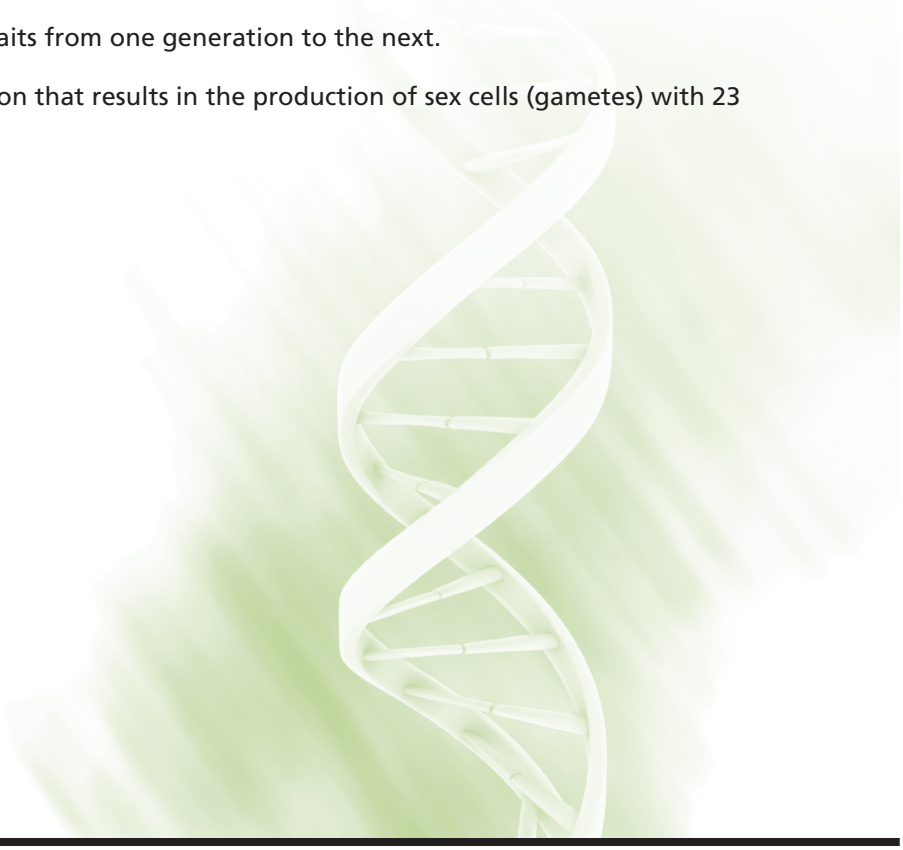
The Importance of Heredity

Genetic inheritance is important, but it is also important that humans not be genetically identical. Genetic variation, or differences in our DNA, makes human beings collectively more resistant to disease. It is unlikely that the entire species may die from a single disease because individuals may have alleles that make them more resistant to a particular disease. Because of genetic variation, no one disease affects all people the same way. Mendel's Laws explain the reasons a child may look like her parents and have similar traits (Law of Segregation), and why a child is genetically unique from her parents (Law of Independent Assortment).

Understanding the inheritance of genes may allow scientists to improve health. For example, scientists can determine the probability of children inheriting genetic diseases from their parents. The more scientists understand about the inheritance of traits and diseases, the closer they come to finding ways to treat and cure complicated genetic problems that affect thousands of people each year.

Part II: Vocabulary

1. **Allele**: One of multiple forms of a gene (humans usually have two copies of every gene). One allele or copy comes from your mother and one allele or copy come from you father.
2. **Chromosomes**: A single molecule of DNA and its associated proteins which condense and become visible during mitosis. Chromosomes determine traits, including gender, hair color, and eye color.
3. **DNA (deoxyribonucleic acid)**: A double-stranded nucleic acid that contains the genetic information for cell growth, division, and function.
4. **Gamete**: A sex cell (egg or sperm) that has 23 chromosomes; contains only one copy of each gene.
5. **Gene**: A DNA sequence that is transcribed to produce a functional product (proteins).
6. **Heredity**: The inheritance of traits from one generation to the next.
7. **Meiosis**: A process of cell division that results in the production of sex cells (gametes) with 23 chromosomes.



Check your understanding:

A human has _____ pairs of chromosomes for a total of _____ chromosomes. One chromosome from each pair comes from the _____ and one comes from the _____.

A child looks like his/her parents because of inheritance of _____.

Part III: Activities

Activity 1: Gene Sequence

Humans have a total of 46 chromosomes that contain all of their genes. A person inherits 23 of her chromosomes from her mother and 23 chromosomes from her father. Therefore, a person has 23 pairs of chromosomes. The mother's 23 chromosomes contain all of the alleles for genes that the mother passes to the offspring. The father's 23 chromosomes contain all of the alleles for the genes that the father passes to the offspring (*see Table 1*). Based on **gene sequence**, each chromosome from the mother pairs with a chromosome from the father. Gene sequence is the order of genes in a chromosome.

Genes are sections of DNA that code for a particular trait. For example, everyone has a gene that codes for hair color. A person may have an allele for brown hair and an allele for red hair.

Table 1 – Inheritance of Chromosomes and Alleles

Mother	+	Father	=	Offspring
23 chromosomes		23 chromosomes		23 pairs of chromosomes 46 total chromosomes
1 allele for each gene		1 allele for each gene		2 alleles for each gene

Consider the diagram below as an example of the possible gene sequence for traits, such as dimples, eye color, hair color, and hair thickness. The diagram shows the way in which a mother and father's chromosomes pair together, based on gene sequence. The pair of chromosomes for the mother and father illustrate possible combinations of two alleles for one gene. Study the diagram below, and then answer the questions that follow to identify the gene sequence of the chromosomes shown.

Gene Sequence

	A pair of **mother's** chromosomes	
	Chromosome I	**Chromosome II**
1	Allele for **dimples**	Allele for **no dimples**
2	Allele for **blue eyes**	Allele for **brown eyes**
3	Allele for **thick hair**	Allele for **thick hair**
4	Allele for **brown hair**	Allele for **brown hair**

	A pair of **father's** chromosomes	
	Chromosome I	**Chromosome II**
1	Allele for **no dimples**	Allele for **no dimples**
2	Allele for **green eyes**	Allele for **green eyes**
3	Allele for **thin hair**	Allele for **thick hair**
4	Allele for **brown hair**	Allele for **red hair**

1. Look carefully at the mother's pair of chromosomes and the father's pair of chromosomes. Can you identify the gene sequence?

   The gene that appears first codes for _____

   The gene that appears second codes for _____

   The gene that appears third codes for _____

   The gene that appears fourth codes for _____

2. Can a person have two identical alleles for a gene? Provide an example to support your answer.

   _____

   _____

3. Can a person have two different alleles for one gene? Provide an example to support your answer.

   _____

   _____

4. There are five chromosomes shown below. Pair the chromosomes together, based on gene sequence. One of the chromosomes cannot be paired.

	Chromosome A	Chromosome B	Chromosome C	Chromosome D	Chromosome E
1	Allele for **no dimples**	Allele for **widow's peak**	Allele for **no dimples**	Allele for **widow's peak**	Allele for **no dimples**
2	Allele for **green eyes**	Allele for **tall height**	Allele for **black eyes**	Allele for **average height**	Allele for **thin hair**
3	Allele for **thin hair**	Allele for **long fingers**	Allele for **thick hair**	Allele for **short finger**	Allele for **blue eyes**
4	Allele for **brown hair**	Allele for **curly hair**	Allele for **blond hair**	Allele for **straight hair**	Allele for **brown hair**

a. Chromosome _____ pairs with chromosome _____

b. Chromosome _____ pairs with chromosome _____

c. Chromosome _____ cannot pair because: _____

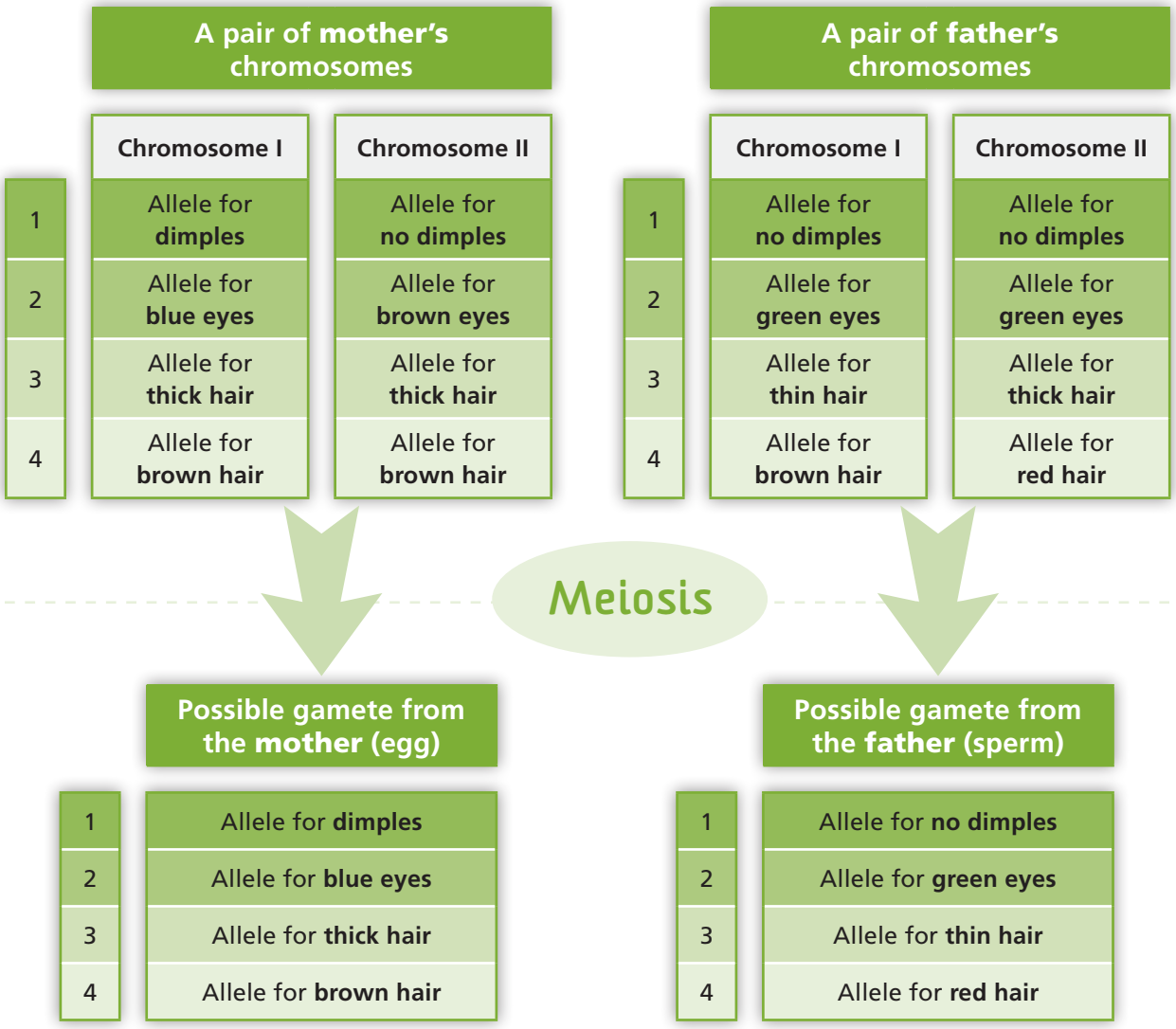
5. What are genes and alleles? How are they similar and different? Use the gene sequence diagram and your answers in question 1 to help explain your answer.

Activity 2: The Law of Segregation

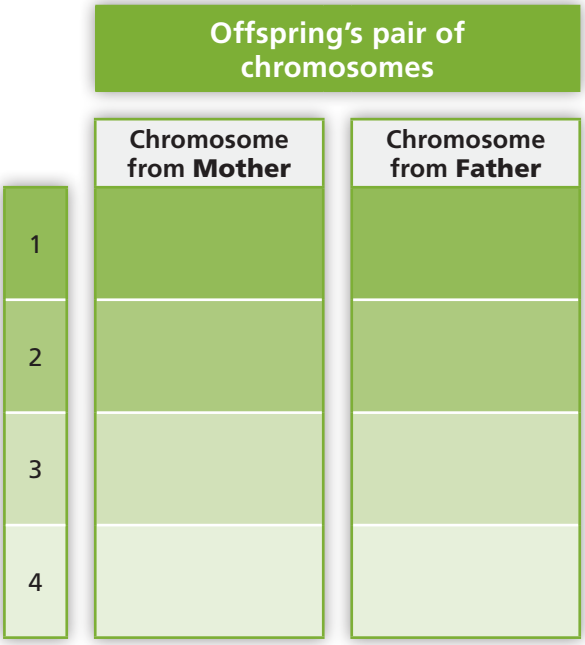
Mendel's Law of Segregation states that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (allele). This means that the mother and father each pass only one allele for a gene to their offspring.

The top of the diagram below shows a pair of chromosomes for a mother and a pair of chromosomes for a father. The diagram shows a possible combination of alleles for genes, such as dimples, eye color, hair color, and hair thickness. The chromosomes are paired together according to gene sequence. The bottom of the diagram shows potential gametes that a mother and father may pass to an offspring.

Mendel's Law of Segregation



Fill in the diagram below with the alleles the offspring would inherit from the mother and father's gametes (egg and sperm) from the bottom of the previous page. Be sure to place the alleles in the correct order, so the chromosomes can pair up.



Use Mendel's Law of Segregation to explain your answers to the following questions:

1. Could the mother's gamete (egg) have an allele for black eyes? Why or why not?

2. Can the father pass on the allele for brown hair **and** the allele for red hair? Why or why not?

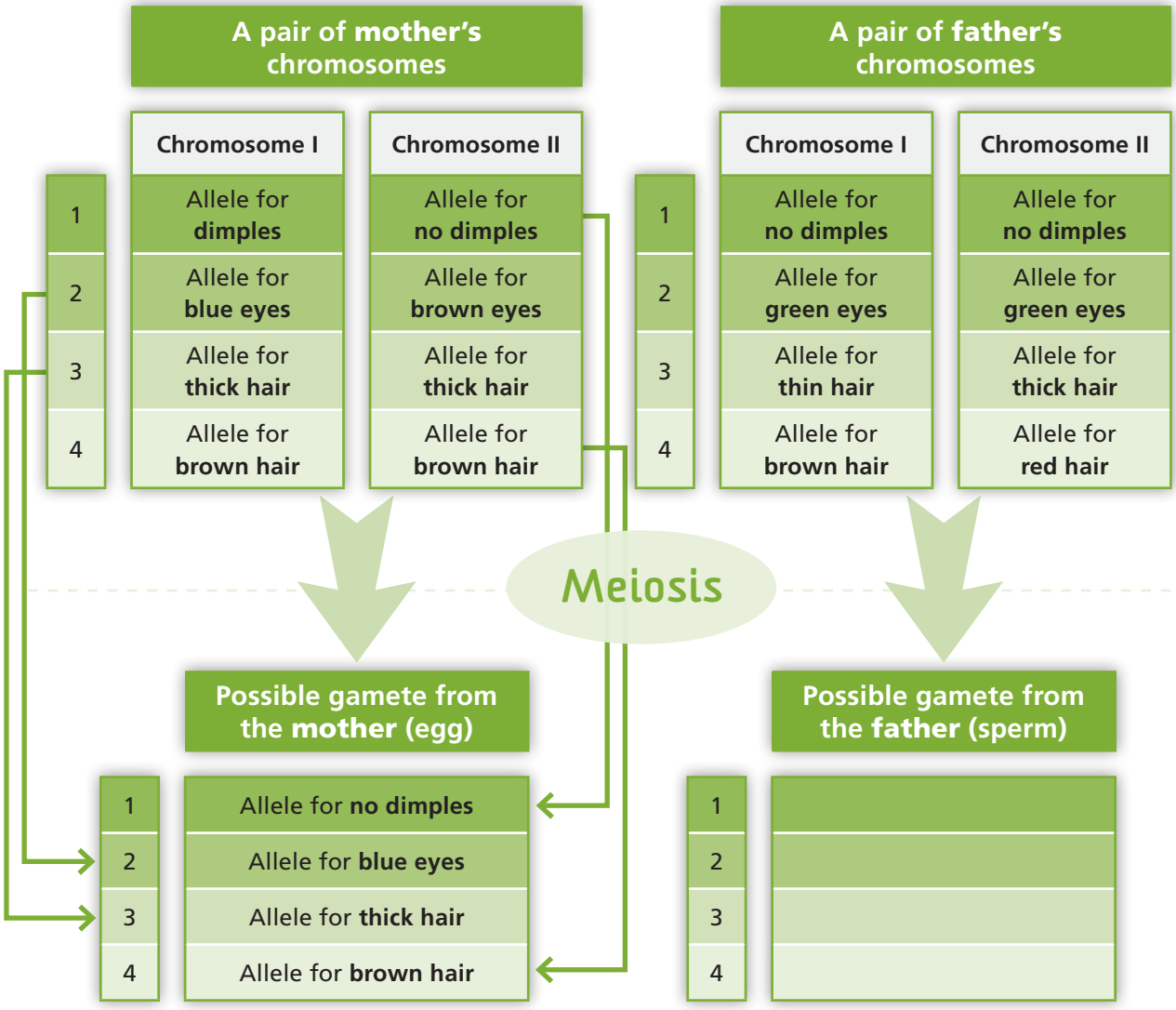
Activity 3: The Law of Independent Assortment

Mendel's Law of Independent Assortment states that different alleles are inherited independently of each other. This is called "independent assortment." The alleles (copies of a gene) that control one trait are inherited independently of the alleles (copies of a gene) controlling another trait. For example, the allele for eye color is not inherited with the allele for hair color, so if a person inherits the alleles for blue eyes, it does not mean she will inherit the alleles for blonde hair.

Below is an example of the independent inheritance (independent assortment) of alleles in a gamete from the mother.

Use the father's original pair of chromosomes to determine the alleles for the gamete from the father. Draw arrows to show which chromosome from the father's pair of chromosomes are passed to the gamete.

Mendel's Law of Independent Assortment



1. Based, on Mendel's Law of Independent Assortment, reconsider your answer to Question 3 in Activity 2: The Law of Segregation. Do you think parents pass individual alleles or entire chromosomes to their offspring? Explain your answer.

2. Describe Mendel's Law of Independent Assortment.

_____

_____

_____

Activity 4: Determine an Offspring's Genes

Mendel's Law of Segregation and Law of Independent Assortment explain why children resemble their parents and also why children are unique from their parents. In this activity, you will use both of Mendel's Laws as you model the inheritance of alleles for an offspring.

Use the penny to represent the two alleles for a gene from the mother. Use the nickel to represent the two alleles for a gene from the father. You and your partner will determine the combination of alleles an offspring inherits for each of 25 genes on chromosome I.

Humans have approximately 30,000 genes. Chromosome I, the largest chromosome, has approximately 4,220 genes. An offspring inherits one allele (copy of a gene) from the mother and one allele (copy of the gene) from the father. For chromosome I, this means that each offspring has two alleles for each of the 4,220 genes.

How many genes does a human have? _____

How many alleles does a human have for each gene? _____

1. <u>Identify the penny you will use to represent the mother's alleles and the nickel you will use to represent the father's alleles</u>.

   In this activity, the penny will represent the mother's alleles and the nickel will represent the father's alleles. For each gene, you and your partner will take turns flipping both the penny and the nickel to determine the alleles that the offspring inherits.

   The alleles that the offspring can inherit are heads (H) and tails (T).

2. <u>For each of the 25 genes, flip the penny and the nickel once</u>.

   For gene location 1, one person will flip the penny. Record "H" for heads or "T" for tails in the "Allele from Mother" column in Table 2. The same person will flip the nickel and record "H" or "T" in the "Allele from Father" column in Table 2. For example, the outcome of the toss for gene 1 might be *Allele from Mother* = H and *Allele from Father* = T.

   For gene location 2, the other person will flip the penny and record heads or tails in the "Allele from the Mother" column. The same person will flip the nickel and record "H" or "T" in the "Allele from the Father" column.

   Repeat, alternating turns, for a total of 25 genes. Record the outcome of each coin toss in the Table 2.

Table 2 - Genetic Inheritance

Gene location	Allele from mother (penny)	Allele from father (nickel)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
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23		
24		
25		

Table 2 represents the alleles that an offspring would receive from her mother and father. In reality, the combinations of alleles and the genetic information they contain are more complex. To demonstrate the concept of Mendel's Laws, you modeled the inheritance of 25 genes on chromosome I. Remember that each chromosome contains many genes, and that the chromosomes an offspring receives from her mother and father are not identical copies of the chromosomes found in the mother's and father's cells (see Activity 2: The Law of Segregation and Activity 3: The Law of Independent Assortment).

How many groups have the same combination of alleles for gene 1?

- Combination H/H: _____
- Combination H/T: _____
- Combination T/T: _____

From the other groups that had the same combination for gene 1, how many of the other 24 allele pairs were the same combinations?

_____

_____

Part IV: Conclusion questions

1. What is gene sequence? Explain how chromosomes and alleles relate to gene sequence?

2. What is Mendel's Law of Segregation? How did Activity 4: Determine an Offspring's Genes relate to Mendel's Law of Segregation?

3. What is Mendel's Law of Independent Assortment? How did Activity 4: Determine an Offspring's Genes relate to Mendel's Law of Independent Assortment?

Part V: Notes

Part I: Introduction

The History of Heredity

In the 1860's, an Austrian monk, named Gregor Mendel, studied **heredity**, the inheritance of traits from one generation to the next. While experimenting with pea plants, Mendel discovered two important principles of genetics, which are known as Mendel's Laws. Mendel was able to determine that each parent plant contained two "factors" that controlled the plants' traits. In addition, he was able to determine that each parent contributes one "factor" to the offspring. Scientists now know that the factors, or units of inheritance, that Mendel noted in his research are **genes**.

Mendel's First Law is the Law of Segregation. It states that an organism gets one copy of a gene from each parent. When a **gamete** (egg or sperm cell) forms during **meiosis**, each gamete contains only one copy of each gene. A copy of a gene is called an **allele**. Mendel's Second Law is the Law of Independent Assortment. It states that different alleles are inherited independently of each other. The alleles (copies of a gene) that control one trait are inherited independently of the alleles (copies of a gene) controlling another trait. For example, the allele for eye color is not inherited with the allele for hair color, so if a person inherits the alleles for blue eyes, it does not mean they will inherit the alleles for blonde hair.

Mendel's Laws

First Law	(The Law of Segregation)
States that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (allele).	

Second Law	(The Law of Independent Assortment)
States that different alleles (copies of a gene) are inherited independently of each other.	

Heredity and Genes

Genes are regions of the **DNA** that provide instructions for the cell. A gene contains instructions that are used to create a trait. Each person has two alleles (copies) of each gene. Genes are located at specific places on a **chromosome**. Chromosomes are tightly-coiled strands of DNA, which is an effective way to package DNA to fit into the nucleus. DNA is tightly coiled into chromosomes to effectively copy and divide the genetic information, and ensure that new cells contain the correct genetic information. For example, during meiosis chromosomes are divided so that each gamete contains 23 chromosomes with one allele for each gene. Humans have 46 chromosomes or 23 pairs.

The Importance of Heredity

Genetic inheritance is important, but it is also important that humans not be genetically identical. Genetic variation, or differences in our DNA, makes human beings collectively more resistant to disease. It is unlikely that the entire species may die from a single disease because individuals may have alleles that make them more resistant to a particular disease. Because of genetic variation, no one disease affects all people the same way. Mendel's Laws explain the reasons a child may look like her parents and have similar traits (Law of Segregation), and why a child is genetically unique from her parents (Law of Independent Assortment).

Understanding the inheritance of genes may allow scientists to improve health. For example, scientists can determine the probability of children inheriting genetic diseases from their parents. The more scientists understand about the inheritance of traits and diseases, the closer they come to finding ways to treat and cure complicated genetic problems that affect thousands of people each year.

Part II: Vocabulary

1. **Allele**: One of multiple forms of a gene (humans usually have two copies of every gene). One allele or copy comes from your mother and one allele or copy come from you father.
2. **Chromosomes**: A single molecule of DNA and its associated proteins which condense and become visible during mitosis. Chromosomes determine traits, including gender, hair color, and eye color.
3. **DNA (deoxyribonucleic acid)**: A double-stranded nucleic acid that contains the genetic information for cell growth, division, and function.
4. **Gamete**: A sex cell (egg or sperm) that has 23 chromosomes; contains only one copy of each gene.
5. **Gene**: A DNA sequence that is transcribed to produce a functional product (proteins).
6. **Heredity**: The inheritance of traits from one generation to the next.
7. **Meiosis**: A process of cell division that results in the production of sex cells (gametes) with 23 chromosomes.

Check your understanding:

A human has **23** pairs of chromosomes for a total of **46** chromosomes. One chromosome from each pair comes from the **mother** and one comes from the **father** .

A child looks like his/her parents because of inheritance of **alleles/genes/chromosomes** .

Part III: Activities

Activity 1: Gene Sequence

Humans have a total of 46 chromosomes that contain all of their genes. A person inherits 23 of her chromosomes from her mother and 23 chromosomes from her father. Therefore, a person has 23 pairs of chromosomes. The mother's 23 chromosomes contain all of the alleles for genes that the mother passes to the offspring. The father's 23 chromosomes contain all of the alleles for the genes that the father passes to the offspring (*see Table 1*). Based on **gene sequence**, each chromosome from the mother pairs with a chromosome from the father. Gene sequence is the order of genes in a chromosome.

Genes are sections of DNA that code for a particular trait. For example, everyone has a gene that codes for hair color. A person may have an allele for brown hair and an allele for red hair.

Table 1 – Inheritance of Chromosomes and Alleles

Mother	+	Father	=	Offspring
23 chromosomes		23 chromosomes		23 pairs of chromosomes 46 total chromosomes
1 allele for each gene		1 allele for each gene		2 alleles for each gene

Consider the diagram below as an example of the possible gene sequence for traits, such as dimples, eye color, hair color, and hair thickness. The diagram shows the way in which a mother and father's chromosomes pair together, based on gene sequence. The pair of chromosomes for the mother and father illustrate possible combinations of two alleles for one gene. Study the diagram below, and then answer the questions that follow to identify the gene sequence of the chromosomes shown.

Gene Sequence

	A pair of **mother's** chromosomes		A pair of **father's** chromosomes	
	Chromosome I	**Chromosome II**	**Chromosome I**	**Chromosome II**
1	Allele for **dimples**	Allele for **no dimples**	Allele for **no dimples**	Allele for **no dimples**
2	Allele for **blue eyes**	Allele for **brown eyes**	Allele for **green eyes**	Allele for **green eyes**
3	Allele for **thick hair**	Allele for **thick hair**	Allele for **thin hair**	Allele for **thick hair**
4	Allele for **brown hair**	Allele for **brown hair**	Allele for **brown hair**	Allele for **red hair**

1. Look carefully at the mother's pair of chromosomes and the father's pair of chromosomes. Can you identify the gene sequence?

   The gene that appears first codes for: **dimples/no dimples**

   The gene that appears second codes for: **eye color**

   The gene that appears third codes for: **hair thickness**

   The gene that appears fourth codes for: **hair color**

2. Can a person have two identical alleles for a gene? Provide an example to support your answer.

Yes, a person can have two identical alleles for a gene. For example, the mother has the identical alleles for gene 3: hair thickness. Both of the mother's alleles for hair thickness code for thick hair. The mother also has identical alleles for gene 3: hair color and the father has identical alleles for gene 1: dimples/no dimples and gene 2: eye color.

3. Can a person have two different alleles for one gene? Provide an example to support your answer.

Yes, a person can have two different alleles for a gene. For examples, the mother has different alleles for gene 1: dimples/no dimples. The mother has an allele that codes for dimples and an allele that codes for no dimples. The mother also has different alleles for gene 2: eye color. The father has different alleles for gene 3: hair thickness and gene 4: hair color.

4. There are five chromosomes shown below. Pair the chromosomes together, based on gene sequence. One of the chromosomes cannot be paired.

	Chromosome A	Chromosome B	Chromosome C	Chromosome D	Chromosome E
1	Allele for **no dimples**	Allele for **widow's peak**	Allele for **no dimples**	Allele for **widow's peak**	Allele for **no dimples**
2	Allele for **green eyes**	Allele for **tall height**	Allele for **black eyes**	Allele for **average height**	Allele for **thin hair**
3	Allele for **thin hair**	Allele for **long fingers**	Allele for **thick hair**	Allele for **short finger**	Allele for **blue eyes**
4	Allele for **brown hair**	Allele for **curly hair**	Allele for **blond hair**	Allele for **straight hair**	Allele for **brown hair**

a. Chromosome **A** pairs with chromosome **C**

b. Chromosome **B** pairs with chromosome **D**

c. Chromosome **E** cannot pair because:

Chromsome E contains the same genes as chromosomes A and C (dimples/no dimples, eye color, hair thickness, and hair color). However, the genes in chromosome E do not follow the same gene sequence as the genes in chromosomes A and C. In Chromosome E, the genes for eye color and hair thickness (genes 2 and 3) are out of order.

5. What are genes and alleles? How are they similar and different? Use the gene sequence diagram and your answers in question 1 to help explain your answer.

Genes are sections of DNA that code for a particular trait. For example, in the gene sequence diagram, everyone has a gene that codes for hair color, eye color, and dimples or no dimples. Alleles are the specific genes that determine variation within a population. For example, in the gene sequence diagram, the mother has an allele that codes for brown hair and the father has an allele that codes for red hair.

Activity 2: The Law of Segregation

Mendel's Law of Segregation states that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (allele). This means that the mother and father each pass only one allele for a gene to their offspring.

The top of the diagram below shows a pair of chromosomes for a mother and a pair of chromosomes for a father. The diagram shows a possible combination of alleles for genes, such as dimples, eye color, hair color, and hair thickness. The chromosomes are paired together according to gene sequence. The bottom of the diagram shows potential gametes that a mother and father may pass to an offspring.

Mendel's Law of Segregation

A pair of mother's chromosomes

	Chromosome I	Chromosome II
1	Allele for **dimples**	Allele for **no dimples**
2	Allele for **blue eyes**	Allele for **brown eyes**
3	Allele for **thick hair**	Allele for **thick hair**
4	Allele for **brown hair**	Allele for **brown hair**

A pair of father's chromosomes

	Chromosome I	Chromosome II
1	Allele for **no dimples**	Allele for **no dimples**
2	Allele for **green eyes**	Allele for **green eyes**
3	Allele for **thin hair**	Allele for **thick hair**
4	Allele for **brown hair**	Allele for **red hair**

Meiosis

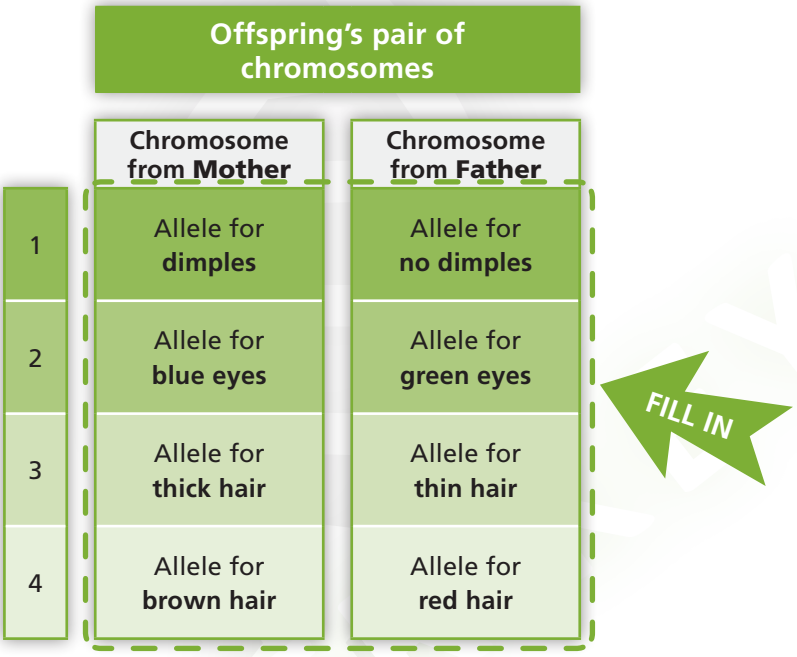
Possible gamete from the mother (egg)

1	Allele for **dimples**
2	Allele for **blue eyes**
3	Allele for **thick hair**
4	Allele for **brown hair**

Possible gamete from the father (sperm)

1	Allele for **no dimples**
2	Allele for **green eyes**
3	Allele for **thin hair**
4	Allele for **red hair**

Fill in the diagram below with the alleles the offspring would inherit from the mother and father's gametes (egg and sperm) from the bottom of the previous page. Be sure to place the alleles in the correct order, so the chromosomes can pair up.



Use Mendel's Law of Segregation to explain your answers to the following questions:

1. Could the mother's gamete (egg) have an allele for black eyes? Why or why not?

No, the mother's gamete could not have an allele for black eyes because the mother's pair of chromosomes do not include an allele for black eyes. The mother can only pass alleles from her original set of chromosomes.

2. Can the father pass on the allele for brown hair **and** the allele for red hair? Why or why not?

No, Mendel's Law of Inheritance states when a gamete forms during meiosis, it contains only one allele for each gene. Therefore, each parent can pass only one allele for a gene to the offspring. The father can pass the allele for brown hair or the allele for red hair.

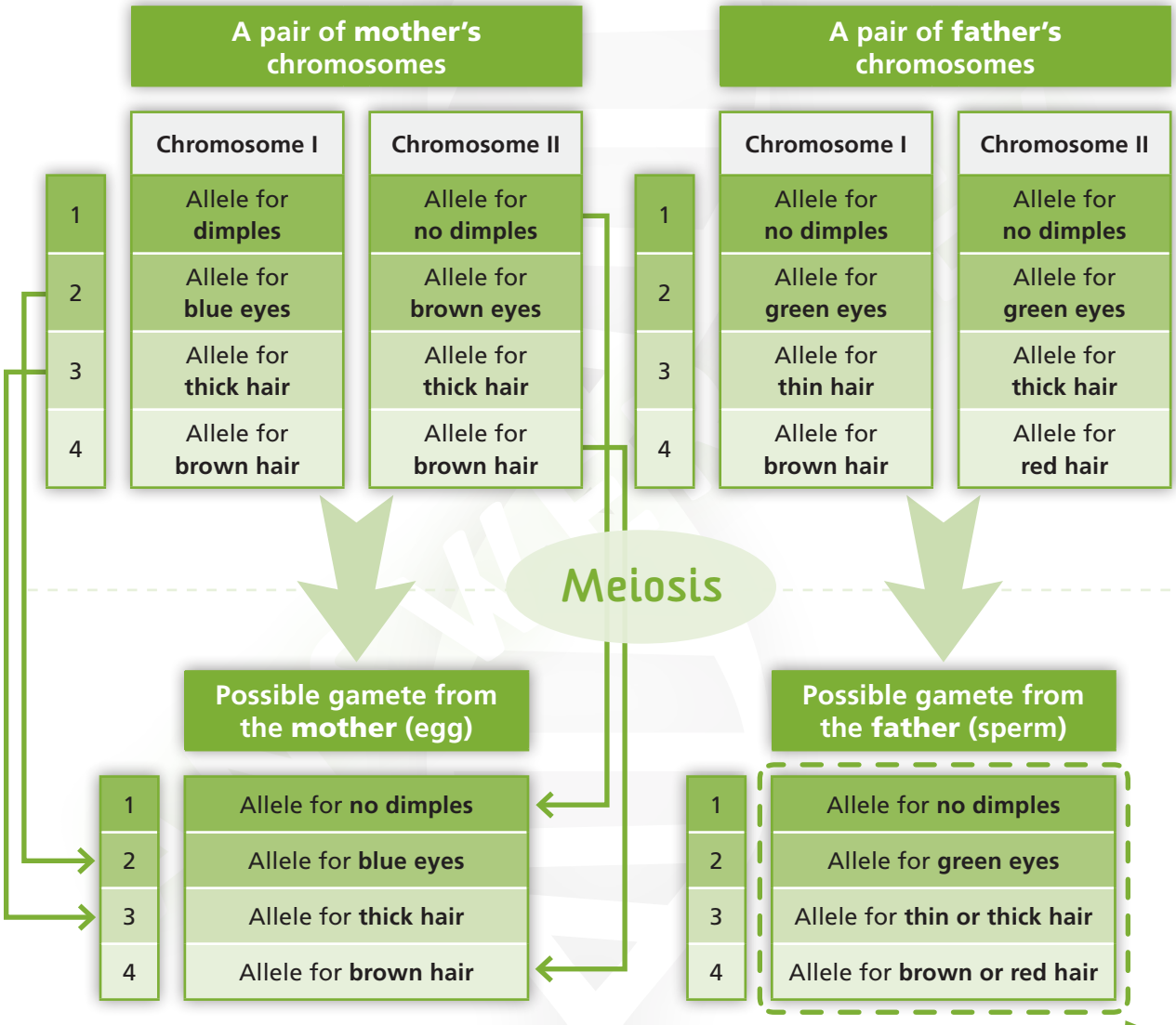
Activity 3: The Law of Independent Assortment

Mendel's Law of Independent Assortment states that different alleles are inherited independently of each other. This is called "independent assortment." The alleles (copies of a gene) that control one trait are inherited independently of the alleles (copies of a gene) controlling another trait. For example, the allele for eye color is not inherited with the allele for hair color, so if a person inherits the alleles for blue eyes, it does not mean she will inherit the alleles for blonde hair.

Below is an example of the independent inheritance (independent assortment) of alleles in a gamete from the mother.

Use the father's original pair of chromosomes to determine the alleles for the gamete from the father. Draw arrows to show which chromosome from the father's pair of chromosomes are passed to the gamete.

Mendel's Law of Independent Assortment



1. Based, on Mendel's Law of Independent Assortment, reconsider your answer to Question 3 in Activity 2: The Law of Segregation. Do you think parents pass individual alleles or entire chromosomes to their offspring? Explain your answer.

FILL IN

According to Mendel's Law of Independent Assortment, alleles are inherited independently of one another. For example, in the diagram of Mendel's Law of Independent Assortment, the father can have a gamete with alleles from chromosome I and alleles from chromosome II, as long as the gamete only includes one allele for each gene.

2. Describe Mendel's Law of Independent Assortment.

Mendel's Law of Independent Assortment states that different alleles are inherited independently of each other. For example, the allele for eye color is not inherited with the allele for hair color, so if a person inherits the alleles for blue eyes, it does not mean they will inherit the alleles for blonde hair.

Activity 4: Determine an Offspring's Genes

Mendel's Law of Segregation and Law of Independent Assortment explain why children resemble their parents and also why children are unique from their parents. In this activity, you will use both of Mendel's Laws as you model the inheritance of alleles for an offspring.

Use the penny to represent the two alleles for a gene from the mother. Use the nickel to represent the two alleles for a gene from the father. You and your partner will determine the combination of alleles an offspring inherits for each of 25 genes on chromosome I.

Humans have approximately 30,000 genes. Chromosome I, the largest chromosome, has approximately 4,220 genes. An offspring inherits one allele (copy of a gene) from the mother and one allele (copy of the gene) from the father. For chromosome I, this means that each offspring has two alleles for each of the 4,220 genes.

How many genes does a human have? **A human has about 30,000 genes**

How many alleles does a human have for each gene? **A human has 2 alleles for each gene**

1. Identify the penny you will use to represent the mother's alleles and the nickel you will use to represent the father's alleles.

   In this activity, the penny will represent the mother's alleles and the nickel will represent the father's alleles. For each gene, you and your partner will take turns flipping both the penny and the nickel to determine the alleles that the offspring inherits.

   The alleles that the offspring can inherit are heads (H) and tails (T).

2. For each of the 25 genes, flip the penny and the nickel once.

   For gene location 1, one person will flip the penny. Record "H" for heads or "T" for tails in the "Allele from Mother" column in Table 2. The same person will flip the nickel and record "H" or "T" in the "Allele from Father" column in Table 2. For example, the outcome of the toss for gene 1 might be *Allele from Mother* = H and *Allele from Father* = T.

   For gene location 2, the other person will flip the penny and record heads or tails in the "Allele from the Mother" column. The same person will flip the nickel and record "H" or "T" in the "Allele from the Father" column.

   Repeat, alternating turns, for a total of 25 genes. Record the outcome of each coin toss in the Table 2.

Table 2 - Genetic Inheritance

Gene location	Allele from mother (penny)	Allele from father (nickel)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
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23		
24		
25		

Table 2 represents the alleles that an offspring would receive from her mother and father. In reality, the combinations of alleles and the genetic information they contain are more complex. To demonstrate the concept of Mendel's Laws, you modeled the inheritance of 25 genes on chromosome I. Remember that each chromosome contains many genes, and that the chromosomes an offspring receives from her mother and father are not identical copies of the chromosomes found in the mother's and father's cells (see Activity 2: The Law of Segregation and Activity 3: The Law of Independent Assortment).

How many groups have the same combination of alleles for gene 1?

- Combination H/H: **The answer to this will vary among classes**
- Combination H/T: **The answer to this will vary among classes**
- Combination T/T: **The answer to this will vary among classes**

From the other groups that had the same combination for gene 1, how many of the other 24 allele pairs were the same combinations?

The answer to this will vary among classes

Part IV: Conclusion questions

1. What is gene sequence? Explain how chromosomes and alleles relate to gene sequence?

Gene sequence is the order in which genes appear in a chromosome. The chromosomes that an offspring inherits from its mother and father can be paired together according to gene sequence. For example, in the gene sequence diagram in today's module, the gene sequence was:

- **Gene 1: dimples/no dimples**
- **Gene 2: eye color**
- **Gene 3: hair thickness**
- **Gene 4: hair color**

Alleles are the specific genes that determine variation within a population. For example, in the gene sequence diagram, there were alleles that coded for blue eyes, brown eyes, thick hair, and thin hair.

2. What is Mendel's Law of Segregation? How did Activity 4: Determine an Offspring's Genes relate to Mendel's Law of Segregation?

Mendel's Law of Segregation states that when a gamete (egg or sperm cell) forms during meiosis, each gamete contains only one copy of a gene (allele). This means that the mother and father each pass only one allele for a gene to their offspring. In Activity 4, each parent passed only one allele for a gene to the offspring. For example, for gene 1, the mother could pass only heads or tails to the offspring. The father could also pass only heads or tails to the offspring.

3. What is Mendel's Law of Independent Assortment? How did Activity 4: Determine an Offspring's Genes relate to Mendel's Law of Independent Assortment?

Mendel's Law of Independent Assortment states that different alleles are inherited independently of each other. In Activity 4, each coin toss was done independently of the other coin tosses. Getting "tails" or "heads" for an allele for gene 1 did not predict getting "tails" or "heads" for another allele.

Part V: Notes

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Inheritance–It's the law!

Module 9