Chapter 2

Expression and Transmission of Genetic Information

Standards:
SB1.b, SB3.c

Chapter 2 • Lesson 6

Cellular Reproduction

Key Terms • cell division • binary fission • asexual reproduction • mitosis • sexual reproduction • haploid • meiosis • gamete • crossing over • independent assortment • diploid

Getting the Idea

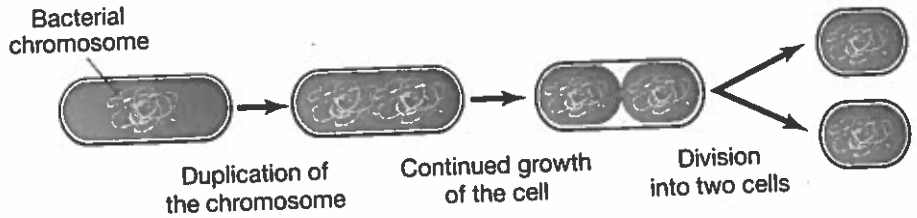
Cells reproduce, or make new cells. The single cell that makes up a unicellular organism must reproduce to produce new organisms. Multicellular eukaryotes need new cells in order to grow and to replace damaged cells. They also need specialized cells to produce new organisms like themselves. In all kinds of cellular reproduction, genetic information is copied and passed on to the new cells that are formed.

Binary Fission

Cells reproduce by **cell division**, a process by which a cell divides to form two or more new cells. Recall that genetic information is stored in DNA, which is copied as part of reproduction. After the genetic information is copied, how the cell divides will depend on the type of cell involved. In prokaryotes, cell division is relatively simple. In one such process, known as **binary fission**, a cell divides into two parts. Each part receives one copy of the DNA. As a result, each new cell is identical to the parent cell.

Bacteria reproduce through binary fission, as shown in the diagram below.

Binary Fission



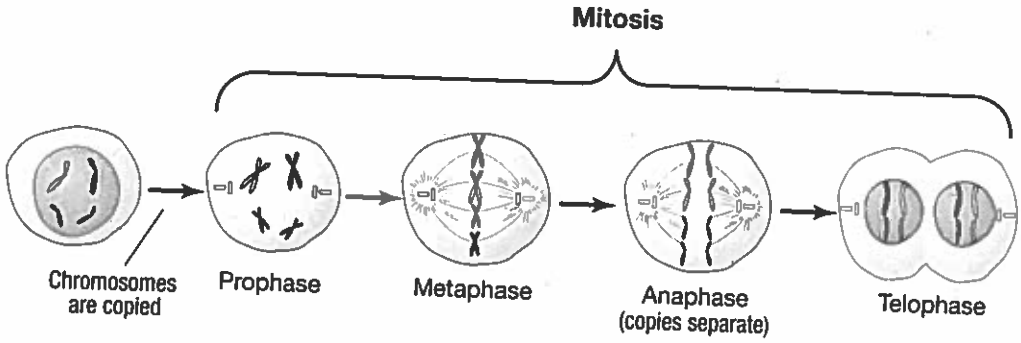
Binary fission is a form of asexual reproduction. **Asexual reproduction** is the production of offspring by a single parent. The offspring produced through asexual reproduction are genetically identical to the parent.

Mitosis

Growth and repair in eukaryotes take place by a more complex form of cell division. Recall that in eukaryotes, DNA is bundled into structures called chromosomes, which are located in the nucleus. An organism has a characteristic number of chromosomes in each cell.

Before a cell can reproduce, recall that its DNA must first make a copy of itself in a process called DNA replication. The cell makes an exact copy of its chromosomes to pass on to each new cell. The original cell is called the parent cell. Each new cell that forms from the parent cell is called a daughter cell. In a continuous cycle, individual cells grow, make copies of their chromosomes, and then divide to form daughter cells.

Mitosis is a process of nuclear division in which DNA is divided equally between two new nuclei. Each nucleus contains a complete set of chromosomes. Mitosis is a continuous process, but biologists have divided it into four phases—prophase, metaphase, anaphase, and telophase. The diagram below shows the phases of mitosis in a typical animal cell.



Between cell divisions, the chromosomes are invisible because they are uncoiled and spread out through the nucleus. During prophase, a substance called chromatin condenses to form visible chromosomes. Sister chromatids—paired strands of a duplicated chromosome—are attached at regions called centromeres. The nuclear membrane breaks down, and organelles called centrioles travel to opposite poles of the cell. Fanlike structures called spindles form around the centrioles.

During metaphase, the sister chromatids line up at the cell's center. The centromere of each chromatid is attached to a spindle fiber.

Anaphase begins as the spindle fibers pull the sister chromatids apart at their centromeres. Each chromatid is an exact duplicate of its parent chromosome. The spindle fibers pull the sister chromatids of each pair toward opposite ends of the cell.

During telophase, the chromosomes reach opposite poles of the cell and begin to uncoil. The spindle breaks down. Nuclear membranes form around the chromosomes at each pole. The cell now has two identical nuclei, each with a complete set of chromosomes. All that remains in cell division is the division of the cytoplasm (cytokinesis) and organelles. This process begins during telophase. Completion of the process results in two separate daughter cells, each with the same genetic information as the parent cell.

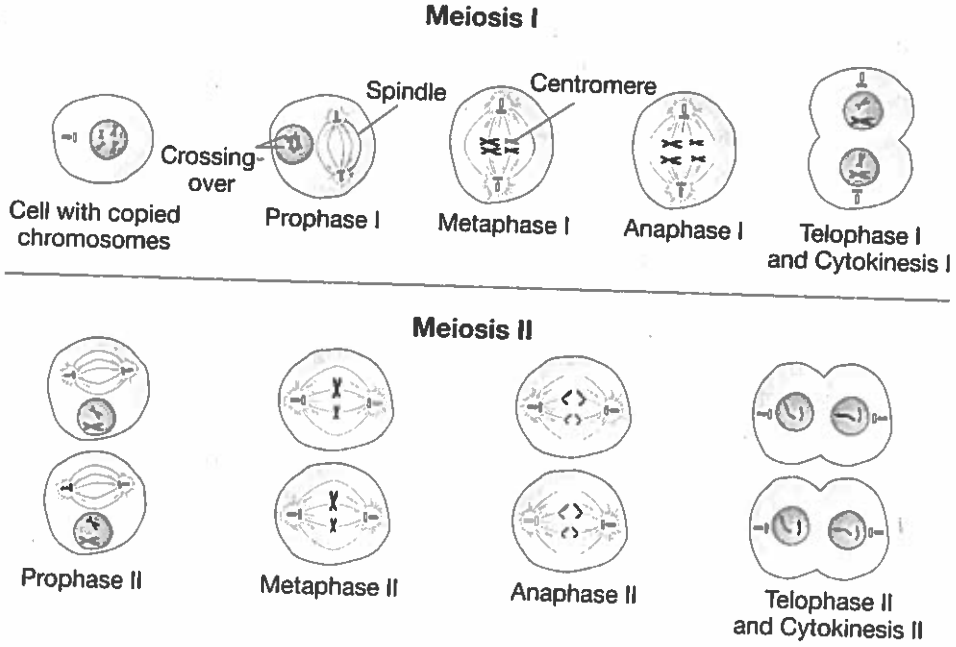
A scientific model is a representation of an object, process, or system. One way scientists use models is to study and explain things that are difficult or impossible to observe directly. For example, scientists use models to study atoms because they are so small. Scientists also use models to study the universe because it is so large. Processes that occur within a cell can be studied using models. A diagram is one type of scientific model.

Mitosis is a process that can be modeled. Refer to the diagram on the preceding page showing the steps of mitosis. In the space below, draw a parent cell with six chromosomes. Make each chromosome a different color. Then, using that color coding, draw the cell undergoing the steps of mitosis. (You may arrange the steps in more than one row if you wish.) Your completed, color-coded diagram should show how genetic information is passed from the parent cell to the daughter cells.

Meiosis

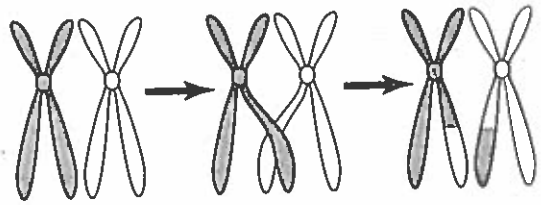
Most multicellular organisms reproduce sexually. **Sexual reproduction** is a form of reproduction in which cells from two parents join to form a new individual. Offspring produced through sexual reproduction are genetically different from either parent. If two ordinary cells joined together, the resulting cell would have twice as many chromosomes as it should. This does not happen because sexual reproduction involves specialized sex cells. Sperm are sex cells produced by males. Eggs are sex cells produced by females. Sex cells are **haploid;** that is, they have half the number of chromosomes present in other cells of the organism. Sex cells are formed through meiosis.

Meiosis is a process of two nuclear divisions that produces sex cells, or **gametes**. When sex cells form, the chromosomes are copied once. The nucleus then divides twice. The four cells that result have half as many chromosomes as a normal body cell. The steps of meiosis are shown in the following diagram. The two divisions are called meiosis I and meiosis II. Before meiosis begins, the cell's chromosomes are copied, just as for mitosis.



Each organism that reproduces sexually has a characteristic number of chromosomes in its cells. For example, human body cells, such as skin cells, each contain 46 chromosomes. Homologous chromosomes are paired chromosomes that are similar in size, shape, and genetic material. A human skin cell has 23 pairs of homologous chromosomes. One chromosome in each pair is from the mother, and one is from the father.

The first stage of meiosis is called prophase I. During this phase, crossing over occurs. **Crossing over** is a process in which chromosome segments that code for the same sets of traits break off and are exchanged between homologous chromosomes. This process ensures that the daughter cells will be genetically distinct from the original cell. The diagram below shows crossing over. The centrioles move to opposite ends of the cell and produce spindle fibers.



In the next stage, metaphase I, the homologous pairs line up along the center of the cell in a random fashion called **independent assortment.** Like crossing over, independent assortment leads to genetic variation. When the cell divides, each daughter cell will receive a mix of chromosomes that differs from that of the original cell. The exact mix will depend on how the chromosomes line up during metaphase I.

In anaphase I, spindle fibers separate the paired homologous chromosomes and pull them toward opposite ends of the cell. During telophase I, the cell divides to produce two daughter cells, each with a complete set of chromosomes.

At the end of meiosis I, meiosis II begins. In meiosis II, the two daughter cells divide again to form four haploid cells. Each haploid cell has a unique set of chromosomes.

Two sex cells combine through fertilization. The resulting cell has a complete set of chromosomes—half from each haploid sex cell. The offspring are **diploid,** which means they have two copies of each chromosome.

Comparing Modes of Reproduction

Asexual reproduction and sexual reproduction each have advantages and disadvantages. One advantage of asexual reproduction is that it can produce many offspring quickly. Also, organisms that cannot move around, or cannot readily find others of their species to mate with, can reproduce this way. For example, many colonizers of new environments reproduce asexually.

Asexual reproduction is an advantage in a stable environment to which the parent is well suited. However, asexual reproduction can be a disadvantage in a changing environment. Because all the offspring from asexual reproduction are genetically identical, they are vulnerable to the same threats. For example, a disease that kills one organism could kill the whole population.

Sexual reproduction is slower than asexual reproduction because the organisms must form gametes and then mate. Sexual reproduction also generally produces fewer offspring than asexual reproduction. However, because these offspring are diverse, they may be able to survive in more different conditions than organisms produced asexually. For example, suppose a disease strikes a type of crop plant. Variations arising from sexual reproduction may have given some individuals in the population genes that make them resistant to the disease. Although many individuals will die, some resistant plants will survive and reproduce. They will pass their beneficial genes to future generations.

The genetic variation that results from sexual reproduction is often an advantage in rapidly changing environments. In addition, new gene combinations may produce traits that let organisms move into new and slightly different environments.

Some organisms can reproduce both sexually and asexually. Which method they use may depend on the environmental conditions. This ability lets these organisms benefit from the advantages of both sexual and asexual reproduction. For example, grasses use sexual reproduction to produce seeds. They also reproduce asexually, using mitosis to grow runners. A single grass plant can produce some offspring just like itself and some that are different from it. Other organisms capable of both kinds of reproduction include some termites and algae.

Scientific arguments are supported by careful reasoning and evidence. Select one of the scenarios below. Make a claim as to which mode of reproduction would be most advantageous in that scenario. Then construct an argument, including evidence, to support your claim.

- A wetland is located near an area being developed as housing and roadways. The change in land use has caused a change in the amount of sunlight in the wetland, the amount of dissolved oxygen in the water, and the water's pH.
- A tropical rain forest has been protected by its remote location. Although the rain forest undergoes continual small changes, the overall conditions are stable.

Claim:

Argument:

Lesson Review

1. Which statement correctly describes cells produced through asexual reproduction?

   A. They are genetically identical to their parents.

   B. They do not grow and divide.

   C. They do not contain genetic material.

   D. They have a unique set of genetic instructions, unlike their parents'.

2. In which phase of mitosis is division of the nucleus completed?

   A. metaphase

   B. telophase

   C. prophase

   D. anaphase

3. Which process can be a source of genetic variation?

   A. copying of chromosomes

   B. binary fission

   C. mitosis

   D. crossing over

4. Which statement describes the products of meiosis I and meiosis II?

   A. Meiosis I produces two haploid cells, and meiosis II produces four haploid cells.

   B. Meiosis I produces four diploid cells, and meiosis II produces four haploid cells.

   C. Meiosis I produces two diploid cells, and meiosis II produces four haploid cells.

   D. Meiosis I produces two diploid cells, and meiosis II produces two haploid cells.

Standard:
SB2.b

Chapter 2 • Lesson 7

Inheritable Genetic Variations

Key Terms • mutation • substitution mutation • insertion mutation • deletion mutation • frame shift • genetic variation • crossing over • nondisjunction • mutagen

Getting the Idea

Recall that chromosomes are made up of DNA, the macromolecule that stores and transmits genetic information. That information can be changed in several ways, and the changes can be passed to offspring. Some changes result in variations in the traits of offspring.

Gene Mutations

Recall that a gene is a sequence of DNA that codes for a particular trait. Any change to an organism's genetic material is called a **mutation**. A gene mutation is a change in the sequence of DNA that makes up a single gene. Gene mutations can be compared to an error in a sentence. These changes include substitutions, insertions, and deletions.

In a **substitution mutation**, a base pair is changed in a DNA sequence. Recall that a codon is a sequence of three nitrogenous bases that codes for a particular amino acid. Also recall that amino acids are the building blocks of proteins, the organic molecules that give cells their structure and control chemical reactions. You can compare each codon to a three-letter word.

Consider the sentence below:

THE CAT ATE THE RAT

Imagine that each word (codon) in the example above represents a different amino acid. Observe what can happen if one letter is changed. Consider the sentence below:

THE CAT ATE THE BAT

In this case, only one word has changed, but the sentence still makes sense. However, the meaning of the sentence has changed.

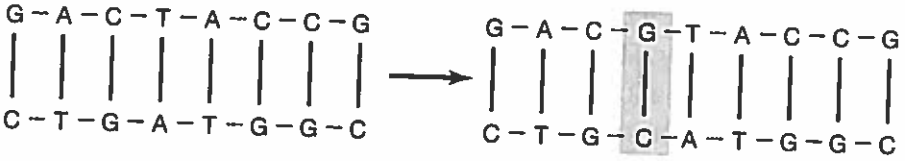
A base-pair substitution is like changing one letter in a sentence. Sometimes the effects of these mutations are minimal. However, some can have serious impacts on an organism. Suppose the *A* in "ATE" is replaced with another *T*, to produce "TTE." This new combination of letters does not form a word, so the sentence no longer makes sense.

Recall that more than one codon can produce the same amino acid during translation. Suppose you said, "Please hand me my hat," but your friend heard, "Please hand me my cap." Your friend would probably understand what you meant and give you your hat. In the same way, two different sequences of bases can sometimes produce the same amino acid sequence. The protein the amino acid becomes part of is not affected, so this type of mutation does not affect an organism's functioning.

Other base-pair substitution mutations can seriously affect protein production and harm the organism. In some cases, the substitution of one base for another turns a codon for one amino acid into a codon for a functionally different amino acid. This can result in a nonfunctioning protein. Another type of base-pair substitution changes a codon for an amino acid into a stop codon. For example, a mutation in the third base of a codon for tyrosine can make it a stop codon instead. This results in a shortened protein that is unlikely to function properly in the organism.

Other mutations involve adding or removing nucleotides. In a base **insertion mutation**, a base pair is inserted in a DNA sequence. In a base **deletion mutation**, a base pair is removed. Inserting or deleting a nucleotide causes a **frame shift**, in which all the codons that follow the mutation are changed. It results in an amino acid sequence that is completely different from what would be normal.

Consider two codons next to each other in a sequence: GAC and UAC. GAC codes for aspartic acid, and UAC codes for tyrosine. However, if a G is inserted between the two original codons, the new codon sequence will be GAC GUA. Because GUA codes for valine, valine rather than tyrosine will be inserted into the amino acid chain. This frameshift will alter the rest of the chain because the C will be attached to the next codon and so on. The diagram below shows a base-pair insertion in DNA that would change the RNA codon UAC to GUA. All the following codons would change as well.



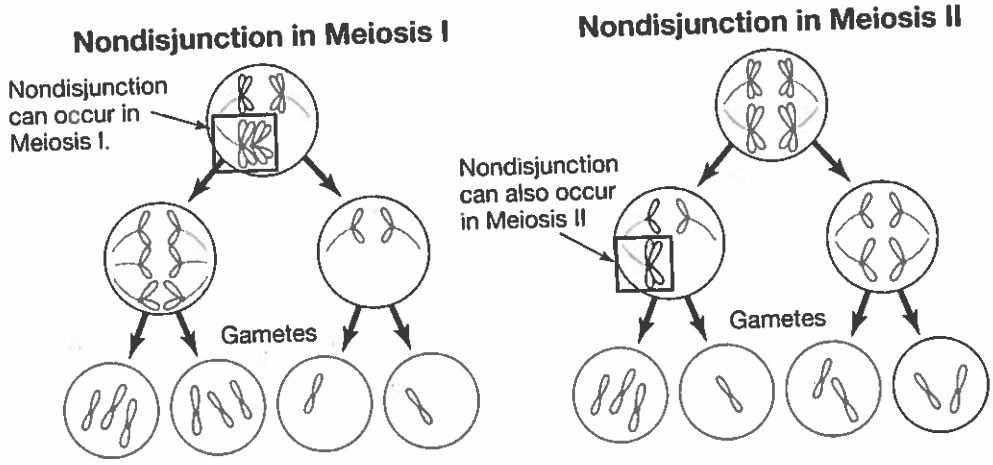
New Genetic Combinations through Meiosis

Recall that meiosis is the process by which gametes form in organisms that reproduce sexually. Changes that occur during meiosis are a source of **genetic variation**, the range of possibilities for a trait that can be passed to offspring. Changes that occur during meiosis include crossing over and nondisjunction.

Recall that **crossing over** is a process in which chromosome segments that code for the same sets of traits break off and are exchanged between homologous chromosomes.

The failure of chromosomes to separate correctly during the production of gametes is called **nondisjunction**. Nondisjunction can lead to abnormalities in offspring because an offspring receives an extra copy of a chromosome or no chromosome at all. Down syndrome is an example of a human disorder caused by a chromosomal mutation. In Down syndrome, an individual has an extra copy of chromosome 21, for a total of three copies of this chromosome instead of two.

The following diagram shows nondisjunction during meiosis. Notice the different numbers of chromosomes in the gametes.



The cell that forms when two gametes unite is called a *zygote*. In most cases, a nondisjunction mutation that results in a zygote with a missing chromosome is fatal.

Effects and Causes of Mutations

The consequences of mutations depend on the type of cell in which the mutation occurs. Mutations can occur either in somatic cells (body cells) or in gametes (eggs and sperm). These two kinds of cells form in slightly different ways. Recall that body cells form through mitosis, which usually produces two genetically identical cells. Gametes form through meiosis, which produces cells that are not genetically identical and that have only half as many chromosomes as other cells of the organism.

In an organism that reproduces sexually, a mutation in a body cell can affect the organism. However, the mutation will not be passed on to offspring. In contrast, a mutation in a gamete will be passed on to offspring and will be part of each of the offspring's body cells. As you have read, these mutations may be harmless, but some can be harmful or even fatal.

Although some mutations have no apparent cause, many are caused by factors in the environment. These factors include radiation, viruses, and harmful substances, such as those in tobacco products and some other chemical compounds. An agent that causes a genetic mutation is called a **mutagen.**

Mutations in genes in body cells often lead to cancers. Cancers are diseases that occur when cells reproduce uncontrollably. Recall that information in genes directs most cell activities. Most mutations linked to cancer allow cells to reproduce without limit. Cancer cells also do not respond to body signals that kill damaged cells. Offspring do not inherit cancer-causing mutations in genes in body cells. However, some mutations in gametes make organisms more likely to develop certain cancers. Offspring do inherit such mutations.

Sometimes mutations have favorable effects, by giving individuals traits that help them survive. For example, a beneficial mutation may help an organism survive in a changing environment. Like sexual reproduction, mutations increase genetic variation.

Recall that a scientific argument must be supported by evidence. Scientists gather evidence through observations, investigation, measurements, and experimentation. Evidence includes facts but not personal opinions or beliefs.

Sickle cell anemia is a disorder of the blood protein hemoglobin. Do research in online or print sources to learn about the cause of sickle cell anemia. Be sure to use reliable sources, such as university or government websites. Gather specific evidence about the cause of this disorder. Then use your evidence to construct an argument that genetic variation can result from errors during DNA replication.

Lesson Review

1. What is a mutation?

   A. a change in the genetic material of a cell

   B. the specific sequence of bases in a molecule of DNA

   C. the process by which a molecule of DNA makes a copy of itself

   D. the perfect replication of a DNA molecule

2. Consider this DNA nucleotide sequence:

   ACG GTT CTA GAC

   Which mutation will result in a frame shift?

   A. substitution of T for the first A in the sequence

   B. deletion of GTT from the sequence

   C. insertion of C at the start of the sequence

   D. substitution of ATA for ACG in the sequence

3. Which event results in a change in the number of chromosomes in a cell?

   A. crossing over

   B. deletion

   C. insertion

   D. nondisjunction

4. Researchers studying rice plants are using radiation to cause random mutations. Which statement **best** describes the goal of the researchers?

   A. to destroy viral diseases that infect rice plants

   B. to create beneficial traits that can be passed on to offspring

   C. to reduce the amount of fertilizer that the rice plants will need

   D. to eliminate the rate of insect infestation among the rice plants

Chapter 2 • Lesson 8

Standards:
SB3.a, b

Patterns of Inheritance

Key Terms • alleles • dominant • recessive • homozygous • heterozygous • genotype • phenotype • monohybrid cross • dihybrid cross • law of dominance • law of segregation • law of independent assortment • incomplete dominance • codominance

Getting the Idea

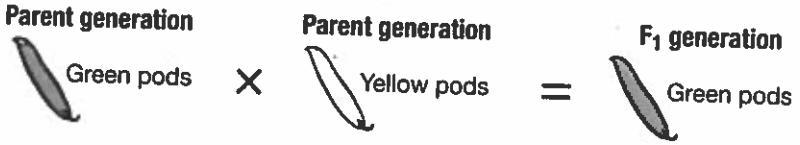
All living things have traits, or characteristics. Many of these traits are passed from one generation to the next. The patterns of inheritance of traits can be predicted and explained.

Mendel's Experiments with Pea Plants

In the mid-1800s, an Austrian monk named Gregor Mendel made a discovery that paved the way for today's understanding of genetics. Using pea plants, Mendel studied how characteristics are passed from one generation to the next. Although his work was largely ignored until 1900, Mendel's ideas formed the foundation for the basic principles of heredity. These ideas are now known as Mendelian genetics.

Mendel developed true-breeding pea plants to use in his experiments. A true-breeding plant can self-pollinate to produce offspring that are identical with their parent. Then Mendel began to cross, or interbreed, different true-breeding strains of peas. In one experiment, Mendel crossed green-pod plants with yellow-pod plants. All offspring (first generation, or F_1) resulting from the cross had green pods, as shown below. This result was unexpected.

Mendel's Pea Plants



From this experiment and others, Mendel concluded that an organism has two factors for each trait and receives one factor from each parent. Today we know that these factors are genes. The genes from each parent may be the same, or they may code for different forms of a trait, such as green or yellow pods. The different forms of a gene for a specific trait are called **alleles**.

Each of Mendel's true-breeding pea plants had two identical alleles for pod color. The plants with green pods had two alleles for green pods, and the plants with yellow pods had two alleles for yellow pods. When the plants were crossed, each parent contributed one allele to each offspring. Therefore, all the offspring had two different alleles for pod color, one for green pods and one for yellow pods. If each offspring had both alleles, why were all the pods green (like one parent plant) instead of yellow (or some other combination, such as greenish yellow)?

Dominant and Recessive Traits

An organism exhibits a characteristic when it has two matching alleles for that trait (e.g., green and green or yellow and yellow). However, if an offspring receives two different alleles, only the **dominant** allele is expressed. The organism does not exhibit the trait coded for by the other, recessive, allele. **Recessive** alleles are expressed only when no dominant alleles are present. For this to occur, the organism must have two matching recessive alleles. An organism with two matching (dominant or recessive) alleles for a trait is **homozygous**. An organism is **heterozygous** if it has two different alleles for a trait.

In Mendel's experiment, the parent plants (P generation) were homozygous. In the P generation, the green-pod pea plants had two alleles for green color, and the yellow-pod plants had two alleles for yellow color. When the two types of plants were interbred, each parent contributed one allele to the offspring (first generation, or F_1). The results were heterozygous offspring, each of which had two different alleles for pod color.

Mendel had similar results when he crossed true-breeding short pea plants with true-breeding tall pea plants. All the offspring were heterozygous, and all the offspring were tall, the dominant trait.

Tall Short All tall

Genotype and Phenotype

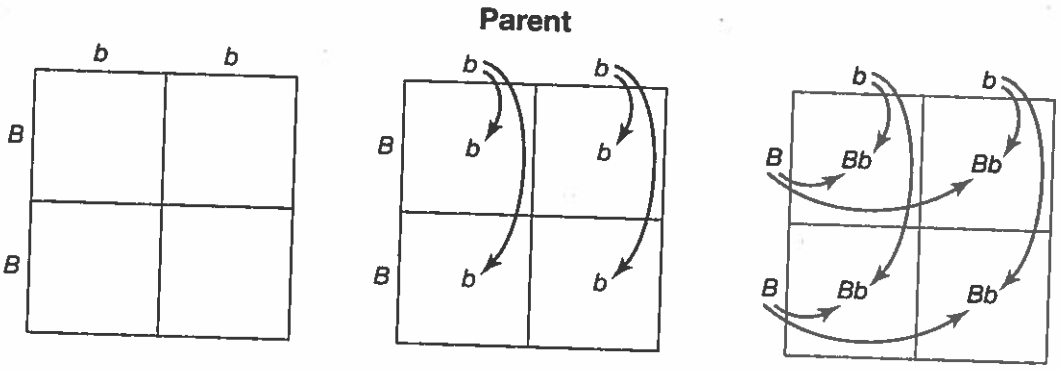
When describing the genetic makeup of an organism, scientists represent dominant alleles with uppercase letters. Recessive alleles are represented by lowercase letters. For example, black fur (*B*) is dominant over brown fur (*b*) in some rabbits. A rabbit could be *BB* (two dominant alleles), *Bb* (one dominant and one recessive allele), or *bb* (two recessive alleles). The alleles an organism inherits from its parents make up its genotype. An organism's **genotype** is all or part of its genetic composition. The possible genotypes for the fur color of the rabbits just discussed are *BB*, *Bb*, and *bb*.

Although these rabbits can have three different genotypes, they can have only two colors of fur—black or brown. One or more traits that an organism displays is its **phenotype**. Black fur and brown fur are phenotypes. The recessive trait, in this case brown fur, appears only when no dominant alleles are present. So a rabbit will have black fur if it is *BB* or *Bb*. It will have brown fur only if it is *bb*.

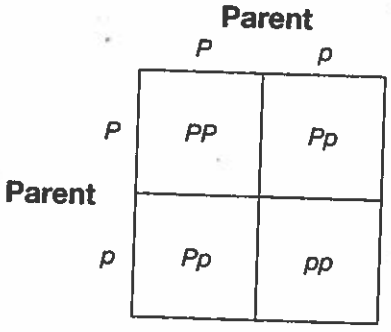
Punnett Squares

Scientists can predict outcomes of genetic crosses using the laws of probability. Scientists sometimes use Punnett squares to help with these predictions. A Punnett square is a diagram used to identify possible combinations of dominant and recessive alleles in offspring based on the genotypes of the parents.

To create a Punnett square, divide a square into four sections. Write the genotype of one parent across the top of the square, placing one allele at the top of each column. Write the genotype of the other parent down the side, placing one allele per row. To complete the square, combine the alleles of one parent with the alleles of the parent in each box. The Punnett square below shows a cross between a rabbit with brown fur (*bb*) and a rabbit with black fur (*BB*). Follow the arrows in the example to see how to combine the alleles in each box. Note that the dominant allele is always written first when it is present.



A Punnett square does not give exact information about the offspring. Instead, it shows probability, which is the mathematical chance that a certain event will occur. The Punnett square below shows a cross between two heterozygous pea plants with purple flowers. In this cross, *P* stands for the dominant allele, for purple flowers, and *p* stands for the recessive allele, for white flowers.



Notice that the probability that an offspring will have the genotype *PP* is 1 out of 4, or 25 percent.

A one-fourth, or 25 percent, probability does not mean that exactly 25 out of 100 offspring will have the *PP* genotype. It means you can predict that about 25 offspring out of every 100 will have this genotype. The more offspring, the closer the actual percentages are likely to be to the predicted percentages.

You can also use a Punnett square to analyze possible phenotypes. In the previous square, there are two phenotypes—purple flowers and white flowers. A plant will have purple flowers if it has at least one dominant allele. Because three of the four boxes contain a dominant allele (*P*), three-fourths, or 75 percent, of the offspring are likely to have purple flowers.

Recall that Mendel crossed pea plants that were homozygous for green pods (*GG*) and homozygous for yellow pods (*gg*). The Punnett square to the right shows the results of this cross.

Parent

Parent	*G*	*G*
g	*Gg* Green	*Gg* Green
g	*Gg* Green	*Gg* Green

According to this Punnett square, the offspring can have only one combination of alleles, or genotype—*Gg*. The genotypic ratio is 4:0 (100 percent *Gg*). The only possible phenotype of the offspring is green, producing a phenotypic ratio of 4:0 (100 percent green). What would the genotypic and phenotypic ratios be if we crossed two of the offspring from Mendel's F_1 generation? The Punnett square below shows this outcome.

F_1 Cross

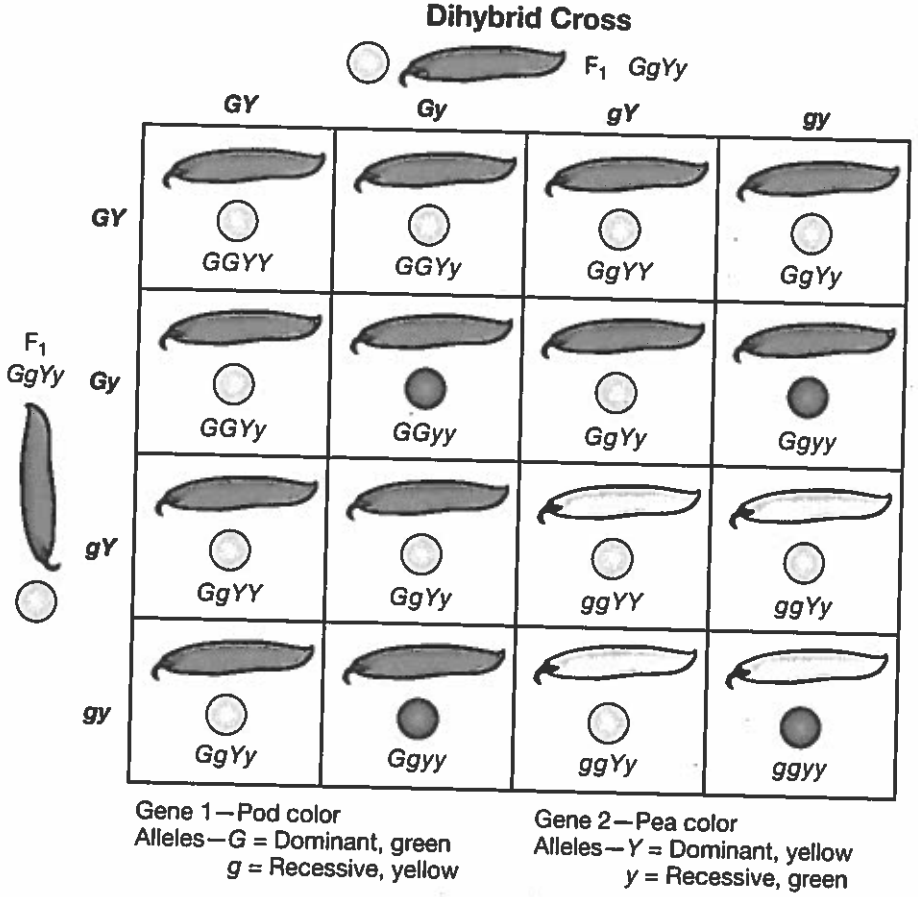
	G	*g*
G	*GG* Green	*Gg* Green
g	*Gg* Green	*gg* Yellow

In this cross, both parents are heterozygous for green pods. Each has one allele for each color. The result in the second, or F_2, generation is a variety of offspring. The possible genotypes are *GG*, *Gg*, and *gg*. The genotypic ratio of 1:2:1 (25 percent *GG*, 50 percent *Gg*, 25 percent *gg*). The two possible phenotypes are green (in plants that have either one or two dominant alleles) and yellow (in plants with two recessive alleles). So the phenotypic ratio is 3:1 (75 percent green, 25 percent yellow).

Types of Crosses

The Punnett squares shown in the lesson so far represent monohybrid crosses. A **monohybrid cross** is a cross in which only one trait is studied. A **dihybrid cross** can be used to study two traits at once.

This Punnett square shows a dihybrid cross between two plants with green pods and yellow peas.



Mendel's Laws

Mendel made several discoveries that are important to our current understanding of DNA and its role in genetics. His findings can be summarized in three scientific laws: the law of dominance, the law of segregation, and the law of independent assortment.

- The **law of dominance** states that the dominant allele will prevent the recessive allele from being expressed. The recessive allele is expressed only when paired with another recessive allele in the offspring.
- The **law of segregation** states that gene pairs separate when gametes are formed by the process of meiosis, so each gamete contains only one allele from each pair.
- The **law of independent assortment** states that different pairs of genes separate independently of each other during meiosis. Recall that homologous pairs line up along the center of the cell randomly during meiosis in a process called independent assortment. Dihybrid crosses helped Mendel discover this law.

Scientists develop explanations of natural phenomena by asking questions and looking for answers. You can use this process to help clarify the role of meiosis in genetic variation.

How does Mendel's law of segregation explain how a parent with the genotype *Aa* can have an offspring with the genotype *aa*?

Now write a question about the law of independent assortment that, when answered, helps further explain the role that meiosis plays in genetic variation. Use the dihybrid cross shown on the preceding page to develop your question.

Discuss your question and possible responses with a partner. Then record your answer.

Summarize how segregation and independent assortment during meiosis increase genetic variation.

Intermediate Traits

Mendel's experiments with pea plants involved simple traits, each determined by one pair of alleles. The pea plants had either the dominant or the recessive form of the trait. However, the genetics of most traits is more complicated.

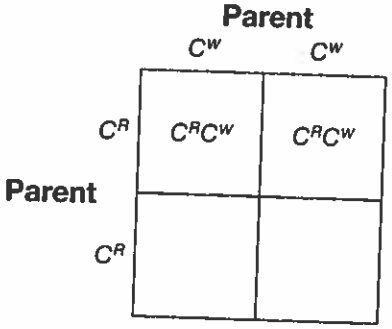
For some traits, neither allele is dominant over the other. In this pattern, known as **incomplete dominance**, the result is a blend of the two forms of the trait. Snapdragon plants are an example of incomplete dominance. A cross between a snapdragon with red flowers and a snapdragon with white flowers produces offspring with pink flowers. Only capital letters are used to represent these traits: *RR* (red), *WW* (white), and *RW* (pink). Often a letter, in this case *C* for color, is used with a superscript: C^R (red), C^W (white), and C^RC^W (pink).

Other organisms exhibit **codominance**, a pattern in which both alleles are expressed in the same organism. Some chickens exhibit codominance with regard to feather color. Mendel would have expected the heterozygous offspring of a black-feathered rooster and a white-feathered hen to be either black or white. The offspring actually have some black feathers and some white feathers. In codominance, both alleles are expressed equally.

Some traits are determined by multiple alleles. Although each organism has only two alleles for the trait, more than two possible alleles exist in the population. Human blood types are an example of such a trait. A person's blood type may be A, B, AB, or O. Although each person can have at most two alleles for blood type, there are three alleles for blood type in the human population. Two of these alleles, A and B, are codominant.

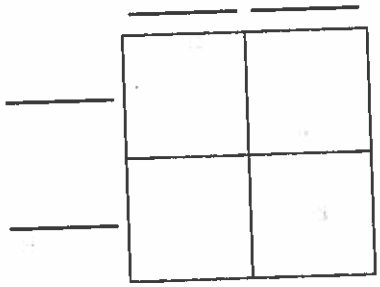
In cattle, the allele for a white coat and the allele for a red coat are codominant. When both alleles are present, the blend of colors is called roan. Roan cattle have coats made up of white and red hairs in equal proportions.

The Punnett square below shows a cross between a red cow and a white cow. The genotype of red cows is written as C^RC^R, and the genotype for a white cow is written C^WC^W. A roan offspring has the genotype C^RC^W. This is shown in the partially completed Punnett square below.



Complete the Punnett square on the previous page to show the genotypes of the remaining offspring. What phenotypes would these offspring show?

Fill in the Punnett square below to predict the results of a cross between two roan cattle.



What is the ratio of phenotypes in the offspring? _____

Lesson Review

1. Which word describes an organism that has two different alleles for a trait?

   A. dominant

   B. heterozygous

   C. homozygous

   D. recessive

2. Which combination of alleles represents the same phenotype but different genotypes?

   A. *Aa* and *AA*

   B. *Aa* and *aa*

   C. *AA* and *aa*

   D. *Aa* and *Aa*

3. Which statement summarizes the law of independent assortment?

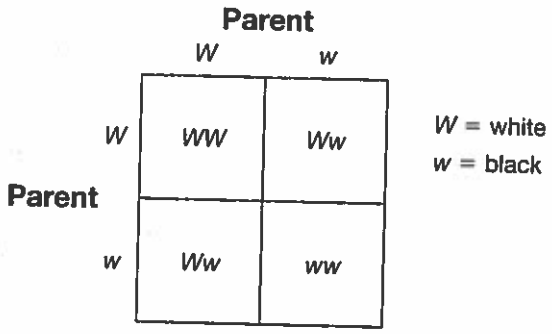
   A. A parent can pass on only one allele of each gene to any one offspring.

   B. A recessive trait will only be expressed if two recessive alleles are present.

   C. The chance of inheriting an allele is not affected by inheriting any other allele.

   D. The probability of offspring inheriting either allele from a parent is 50 percent.

4. This Punnett square shows a cross between two organisms that are heterozygous for a particular fur color.



Based on this cross, what percentage of the offspring are likely to show the recessive phenotype?

A. 0 percent

B. 25 percent

C. 50 percent

D. 100 percent

Standard:
SB2.c

Chapter 2 • Lesson 9

Biotechnology

Key Terms • selective breeding • biotechnology • genetic engineering • genetically modified organism (GMO) • recombinant DNA • gene therapy • cloning • DNA fingerprinting • forensics

Getting the Idea

You might have watched a show about solving crimes using DNA evidence or read about foods being produced with ingredients that have been genetically modified. These are just two examples of the many areas to which the science of genetics has been applied. These include medicine, industry, agriculture, and crime solving.

Selective Breeding

Agriculture is the practice of growing crops and raising livestock for food and other products. Early in the history of agriculture, long before anyone knew about DNA or genes, humans began modifying organisms. They did this by **selective breeding**—the intentional mating of organisms to produce offspring with specific traits. Almost all domestic animals and food plants are at least partly the result of selective breeding. For example, dairy breeders have selected for cows that give more milk. Breeders of apple trees have selected for fruit size, taste, and color.

In selective breeding, organisms with desired traits are mated. Their grown offspring who display the desired traits are also mated. This process is repeated over many generations until offspring consistently show the desired trait. The process is slow. When people began to practice selective breeding, they did not know that traits are controlled by genes. Today, breeders can use their knowledge of genetics to produce organisms with desired traits more quickly.

Genetic Engineering

Scientists have used their knowledge of genes and DNA to develop organisms with traits that are useful to humans. This is one aspect of the field of biotechnology. **Biotechnology** is the use of organisms or biological systems to develop useful products or processes. Biotechnology has a wide range of economic and social impacts.

Genetic engineering is the direct manipulation of a cell's genetic material to produce organisms with useful traits. Genes or pieces of DNA from an organism of one species may be transferred to an organism of a different species. An organism whose genes have been altered through genetic engineering is called a **genetically modified organism (GMO)**. Selective breeding relies on natural processes. In contrast, GMOs cannot occur in nature.

Genetic engineers have altered the genes of bacteria and yeasts to produce medicines used to treat human diseases. They have modified lab animals to make it easier to study cancer and other diseases. They have improved some crops to make them more nourishing. They have modified other plants to be more resistant to damage from frost, insect pests, diseases, and herbicides.

Asking questions and gathering information can lead to a deeper understanding of a topic. When developing a question, consider how it could be used to guide research. Specific questions lead to more focused research.

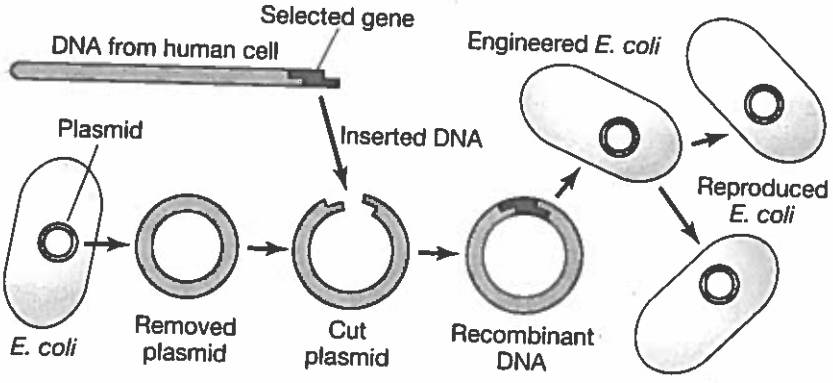
Ask a question that you have about biotechnology:

Carry out research to gather information related to your question. As you gather information, be sure to evaluate the reliability of the sources. Always check for bias. Keep in mind that scientific journals are peer-reviewed but that information from other sources may not have undergone careful review.

On a separate sheet of paper, write a paragraph that summarizes the information you find.

Recombinant DNA

When DNA from one organism is inserted into the DNA of another organism, the new DNA that results is called **recombinant DNA**. The laboratory process in which recombinant DNA is produced is called *gene splicing*. Recombinant DNA often is formed by transferring a portion of DNA from a complex organism into a simpler organism. For example, scientists may insert a human gene into a bacterium. The following diagram shows the production of recombinant DNA in a common bacterium called *E. coli*. Refer to it as you read the next two paragraphs.



Recall that some of the DNA in a bacterial cell is in the form of a ring called a *plasmid*. To form recombinant DNA, biotechnologists remove the plasmid from a bacterium, use enzymes to cut the plasmid, and then insert a human gene into the plasmid. Once the gene is inserted, the plasmid returns to its ring shape. The modified plasmid is then put back inside the bacterium. Recall that bacteria reproduce asexually through a type of cell division called binary fission. Binary fission is similar to cell division by mitosis, except that the DNA is not in a nucleus. Before reproducing, a bacterium makes a copy of its DNA, including the plasmid. If the plasmid contains recombinant DNA, the offspring will also contain the recombinant DNA.

This technique has been used to produce bacteria that make human insulin. Many people with diabetes must receive insulin because their bodies cannot produce insulin.

Scientists have also used recombinant DNA to modify bacteria for industrial and environmental uses. For example, genetically altered bacteria are used to help clean up oil spills. The bacteria break down the oil, producing water and carbon dioxide as byproducts. Other genetically engineered bacteria are used to process minerals and make chemicals. Genetically engineered bacteria have many useful applications. However, the potential consequences of releasing genetically modified bacteria into the environment are an important consideration. Scientists must consider how genetically modified bacteria will affect and interact with the populations of living things in the ecosystems to which they are introduced.

Recombinant DNA has also been used to change the traits of animals and plants. For example, goats have been modified to produce milk containing a certain protein. The protein can be extracted to treat people whose blood clots too easily. Some genetically modified sheep produce a protein that is used to treat emphysema, a respiratory disease. An example of a genetically engineered plant is Bt corn. This corn has a gene from a bacterium (*Bacillus thuringiensis*) that produces a natural pesticide. Bt corn makes the same pesticide, which protects the plant from an insect called the corn borer. Scientists have used a similar technique to modify cotton plants. The genetically altered plants are resistant to worms that attack cotton buds. This resistance increases the cotton yield and enables farmers to use fewer chemical pesticides.

Gene Therapy

Gene therapy is the alteration, insertion, or deletion of a gene in an individual's cells in order to treat a disease. Many genetic disorders involve missing or incorrect genes for making certain proteins. For example, children who are born with Tay-Sachs disease do not produce a specific enzyme necessary to digest lipids. The resulting buildup of lipids causes severe neurological problems. Scientists are looking for a way to use gene therapy to repair the DNA that codes for this enzyme.

Gene therapy is still an experimental treatment. So far, it has had limited success, but many scientists think it holds promise for the future.

Risks of Genetic Engineering

Like other forms of technology, genetic engineering has potential risks as well as benefits. For example, genetic engineering is used to create plants that make their own pesticides. If these crops are planted too widely or in the wrong place, they could harm beneficial insects. Other genetically engineered crops are resistant to weed killers. This is useful to farmers, but people worry that pollen from those crops could fertilize wild plants. This could result in larger populations of weeds that are difficult to kill.

A less obvious risk is that genetically engineered crops can reduce genetic variation. A genetically diverse population is often better able to resist disease and other threats. In the past, farmers in different places have grown many different regional varieties of corn, wheat, and other food crops. In some countries, a dozen or more varieties may be grown in the same small area. The scientists who are genetically engineering crops often create a single variety with the desired trait. If all the farmers in an area plant the same variety of seed, they may grow more wheat or more nourishing rice; however, they may also increase their risk of losing an area's entire crop to a disease to which a different variety of wheat or rice would be resistant.

Consider the following situation:

> A company develops a genetically modified crop that is now inedible to an insect species that formerly fed on the crop. When a farmer plants and raises this variety of crop, its seeds float in the wind to several neighboring farms.

Work with a small group. Within your group, assign roles, such as farmer, seed company representative, legislator, local conservationist, and neighboring farmer, that are related to the information in the scenario. From the perspective of the role you are assigned, think about ethical considerations and economic impacts of the use of this biotechnology. Use the space below to record the main points you want to share with others. Then have a group discussion in which you communicate information about the use of this form of biotechnology.

Assigned role:

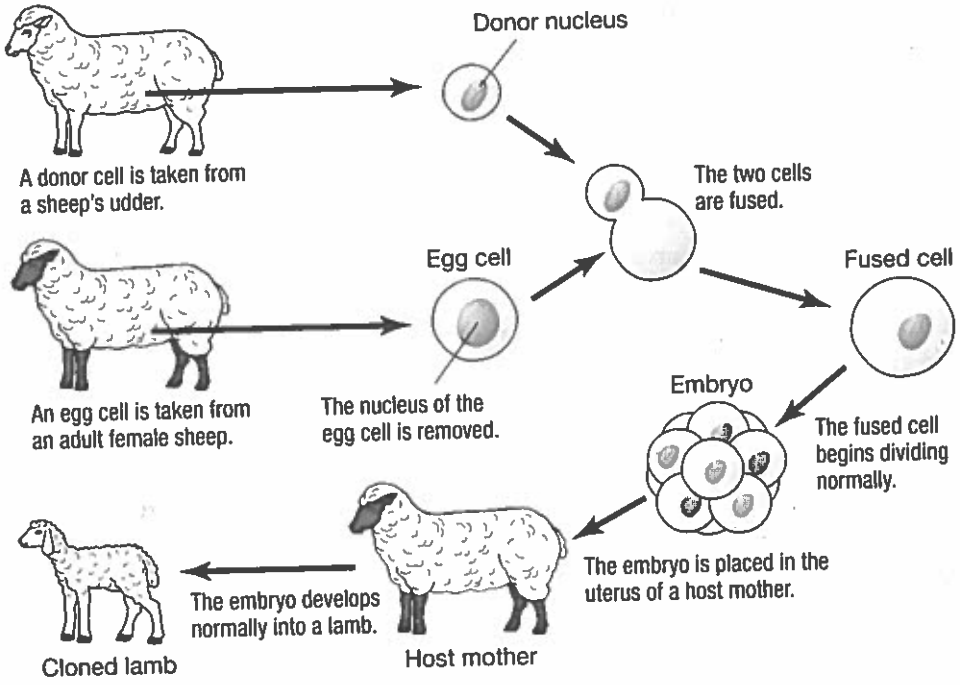
Main ideas to communicate:

Cloning

Cloning is another form of biotechnology. **Cloning** is the artificial production of a DNA fragment, cell, or organism that is genetically identical to the original DNA fragment, cell, or organism. In some cases, scientists can use a single cell from an adult organism to grow an entire new individual that is genetically identical to the donor.

Cloning is not difficult when it involves making a DNA fragment, because DNA normally replicates to form an exact copy of itself. It is also fairly simple to clone a single cell or a single-celled organism because each cell normally produces a daughter cell that is genetically identical to the parent cell. However, cloning in animals is a complex and difficult process.

To clone an animal, scientists remove and discard the nucleus from a female gamete (egg cell). Next, they inject the nucleus of a body cell from another adult into that egg. The two partial cells fuse and begin to divide. After a few divisions, the cell has become an embryo and is placed inside a host mother. The embryo develops into an offspring that is genetically identical to the animal that donated the nucleus. This process is illustrated in the diagram.



Some researchers hope to use cloning to increase the populations of endangered species. Cloning might also be used together with recombinant DNA to produce medically or commercially valuable substances. For example, recombinant DNA could be used to produce goats whose milk contains valuable proteins. The goats could then be cloned to produce a new population of goats that would produce milk containing those proteins.

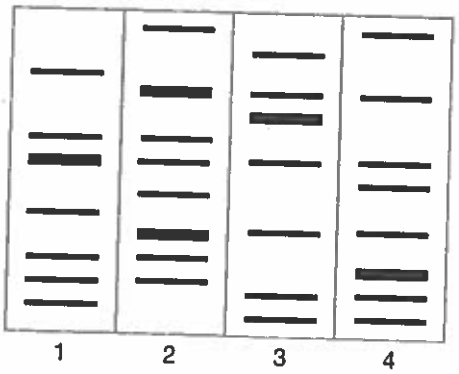
Animal cloning raises some ethical concerns. A major concern is that being able to clone animals could lead to someone trying to clone a human. Many people, including many scientists, believe that cloning a human would be morally wrong. There is also a risk of producing an infant with serious birth defects.

DNA Fingerprinting

No two people's fingerprints are the same. Similarly, with the exception of identical twins, no two people have the same DNA. (Even identical twins may develop small differences in their DNA during their lives.) The same is true of other animals. This knowledge has led to a technology known as DNA fingerprinting. **DNA fingerprinting** compares images of DNA fragments to determine relationships among individuals.

Enzymes are used to cut a DNA molecule into smaller pieces, and the fragments are placed in a gel. Then an electric current is passed through the gel. This technique is called gel electrophoresis. The fragments move through the gel at different rates based on their size. The resulting pattern of lines is called a DNA fingerprint.

DNA Fingerprints of Four Individuals



DNA fingerprinting technology has several uses. For example, DNA fingerprints can be used to determine how closely related various organisms are to one another. The more similar the patterns in two DNA fingerprints, the closer the relationship of the organisms. Biologists sometimes use this technique to identify related species and to identify and catalog endangered species. DNA fingerprinting can also be used to identify a child's mother or father.

Forensics is the use of science and technology to investigate crimes and answer legal questions. Police departments and criminal lawyers use DNA fingerprinting as one form of forensic data. For example, technicians may collect blood, skin, or other samples from a crime scene and make DNA fingerprints from those samples. Investigators can then compare the DNA fingerprints with the DNA fingerprint of someone suspected of the crime.

Lesson Review

1. Which form of biotechnology is **most likely** to be used in forensics?

   A. animal cloning
   B. DNA fingerprinting
   C. genetic engineering
   D. selective breeding

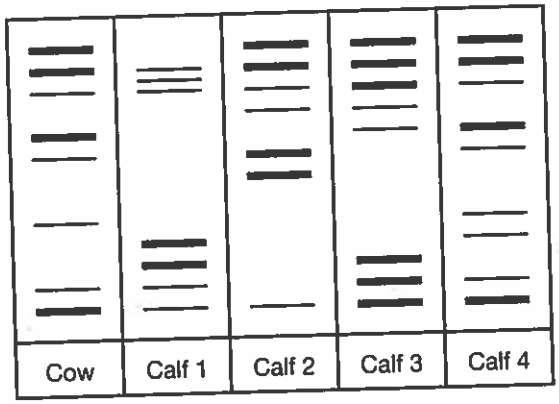
2. Which is a theoretical benefit of cloning?

   A. The variation in a species could be increased.
   B. Organisms with new traits could be produced.
   C. Genetic diseases in humans could be cured.
   D. Populations of endangered species could be increased.

3. A gene for human growth hormone (HGH) production is taken from human DNA and inserted into a bacterial plasmid. Which statement explains why bacteria are used as host organisms for creating recombinant DNA in this example?

   A. They replicate quickly, with each cell producing HGH.
   B. They can be injected directly into patients to produce HGH.
   C. They digest the gene and metabolize the nucleotides into HGH.
   D. They provide the HGH production gene that can be inserted into a human cell.

4. The first panel of the diagram shows a segment of DNA from a cow. The next four panels show DNA segments from four calves.

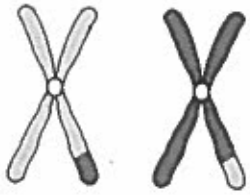


   Which calf is **most likely** the offspring of the cow?

   A. Calf 1
   B. Calf 2
   C. Calf 3
   D. Calf 4

Chapter 2 Review

1. Genetic variation can arise in different ways. The diagram shows an example that occurs during meiosis.



Which term describes this source of genetic variation?

(a) crossing over
(b) nondisjunction
(c) substitution mutation
(d) insertion mutation

2. Which statement BEST explains why DNA fingerprinting is useful in law enforcement?

(a) Each individual's DNA is unique.
(b) DNA samples are easy to gather and analyze.
(c) DNA fingerprinting uses fast-reproducing bacteria.
(d) DNA fingerprinting can pinpoint when a crime occurred.

3. The ability to taste a bitter chemical called PTC is a dominant trait in humans. The Punnett square below shows a cross between two parents who are heterozygous for the ability to taste this chemical.

		Parent: T	Parent: t
Parent: T		TT	Tt
Parent: t		Tt	tt

T = ability to taste PTC
t = inability to taste PTC

Based on the information provided, what is the probability that these parents will produce an offspring who cannot taste PTC?

(a) 25 percent
(b) 50 percent
(c) 75 percent
(d) 100 percent

4. Almost all commercial banana plants are genetically identical. Customers like the fact that bananas sold in grocery stores are seedless and are consistent in size, color, and taste. Yet scientists have recently discovered a problem facing the banana plants. Which statement describes the MOST LIKELY risk to genetically identical banana plants?

   (a) The plants grow more slowly than wild bananas.

   (b) The fruits ripen too soon after they are harvested.

   (c) The plants are susceptible to a new disease-causing fungus.

   (d) The bananas have less nutritional value with each generation.

5. Which cells form as a result of the second division of meiosis?

   (a) two diploid cells

   (b) two haploid cells

   (c) four diploid cells

   (d) four haploid cells

6. A student gathered information about a specific type of biotechnology and used the following table to record what she learned.

Considerations
• Could result in disease-resistant pests • Reduces genetic variation • Can harm environment in some circumstances

   Based on the information in the table, which question did the student ask to guide her research?

   (a) What are some uses of biotechnology?

   (b) What are some economic advantages of GMO crops?

   (c) What are some possible risks of genetic engineering?

   (d) What are some ethical considerations involved in cloning?

7. Meiosis plays a role in the variability of offspring produced by sexual reproduction. The answer to which question would BEST help explain this relationship?

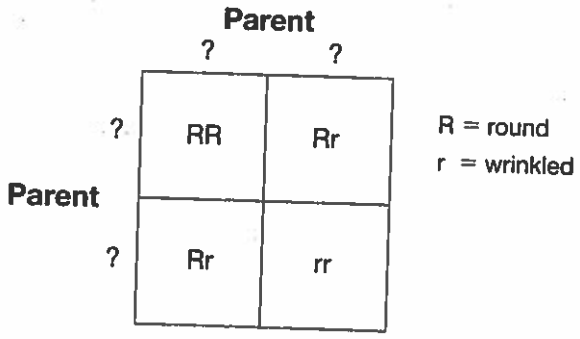
   (a) What happens to gene pairs as gametes form?

   (b) What happens when two genes are codominant?

   (c) How do mutations occur during DNA replication?

   (d) How can Punnett squares be used to find phenotype ratios?

8. The Punnett square below shows the genotypic results of a cross between two pea plants. *R* represents the dominant gene for round seeds, and *r* represents the recessive gene for wrinkled seeds.



Part A

Which phrase describes the parents' genotypes for this trait?

(a) both heterozygous

(b) one homozygous recessive and one heterozygous

(c) one homozygous dominant and one heterozygous

(d) one homozygous recessive and one homozygous dominant

Part B

What is the ratio of phenotypes in the offspring?

(a) 1 round : 3 wrinkled

(b) 2 round : 2 wrinkled

(c) 3 round : 1 wrinkled

(d) 4 round : 0 wrinkled

9. A body cell in an organism develops a DNA mutation. This beneficial mutation causes production of a more efficient enzyme for digestion. Where will the mutation be found over time?

(a) in the organism only

(b) in the organism's immediate offspring only

(c) in the organism and its immediate offspring only

(d) in the organism, its offspring, and all its direct descendants

10. A trait for petal color in snapdragon flowers has two alleles, white and red, that demonstrate incomplete dominance. If one white and one red individual are crossed, what percentage of their offspring is LIKELY to have pink petals?

(a) 25 percent

(b) 50 percent

(c) 75 percent

(d) 100 percent

11. A gardening company grows Plant Species X, which has white flowers. Over time, the company also develops a new variety of Plant X that has blue flowers. The company would like to sell the blue-flowering variety to the public. What is the best way to avoid genetic recombination from one generation to the next and ensure that customers will receive only blue-flowering plants?

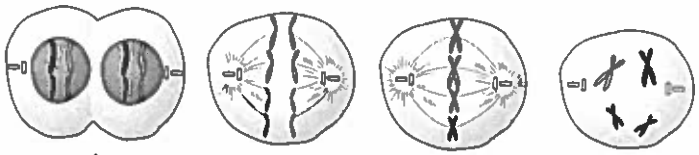
(a) Make new plants to sell by allowing the old plants to form runners.

(b) Sell seeds to customers so they can grow as many plants as they wish.

(c) Raise plants in different environmental conditions to find the best plants.

(d) Grow plants from seed to quickly produce large numbers of plants for sale.

12. The diagrams show four stages of mitosis, identified by numbers.



A student wants to develop a model to explain how genetic continuity is maintained by mitosis. In which order should the diagrams be placed?

(a) 1, 2, 3, 4

(b) 1, 3, 2, 4

(c) 4, 2, 3, 1

(d) 4, 3, 2, 1

13. Which statement would BEST support an argument that sexual reproduction provides an advantage over asexual reproduction in a changing environment?

(a) Sexual reproduction provides greater variation.

(b) Sexual reproduction takes less energy and time.

(c) Sexual reproduction produces genetically identical offspring.

(d) Sexual reproduction produces fewer offspring.