TOPIC 3

Genetic Continuity

Vocabulary

asexual reproduction	egg	replicate
biotechnology	expressed	selective breeding
body cell	genes	sexual reproduction
bond	genetic engineering	sperm
chromosome	genetic recombination	subunit
clone	heredity	template
DNA	mutation	traits

Topic Overview

When two organisms reproduce, their offspring receive genetic instructions, called **genes**, from each parent. The genes determine which **traits**—or characteristics—each offspring will have. All organisms—whether they are animals, plants, or members of one of the other kingdoms—pass their genetic characteristics along in this manner. Because of this transfer of genetic information, offspring tend to resemble their parents.

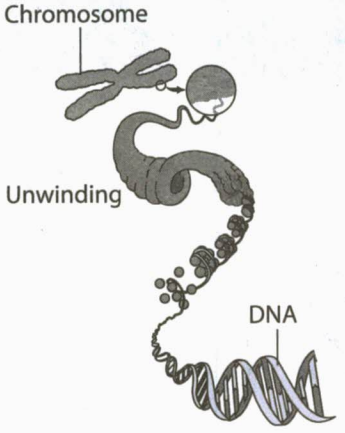


Figure 3-1. Chromosomes contain DNA: Notice that the chromosome contains one very long double strand of DNA.

Heredity and Genes

Heredity is the passing of genetic information from one generation to the next through reproduction. The hereditary information (**DNA**) is organized in the form of genes located in the **chromosomes** of each cell. Recall that chromosomes, which are found in the cell nuclei, contain the DNA molecules. (See Figure 3-1.) It is the DNA molecules that carry the genetic information of the cell.

A human cell contains many thousands of genes in its nucleus, and each gene carries a separate piece of coded information. The traits inherited by an individual can be determined by one pair of genes or by several pairs of genes. It is also true that a single gene pair can sometimes influence more than one trait. Table 3-1 shows several examples of these variations.

Table 3-1. Human Traits Inherited with Different Numbers of Genes

Trait	Number of Gene Pairs Needed to Affect Trait
Cystic fibrosis	Single gene pair
Skin color	Multiple gene pairs
Sickle cell disease	Single gene pair affecting multiple traits

Some traits that an organism inherits are readily observable. These include traits such as hair color, leaf shape, flower scent, and wing structure. The overall structure of the body is also an observable trait that is inherited from the parents. Some children, for example, inherit long, slender toes or large ear lobes.

Other traits are not so obvious. Less obvious traits may involve a defective heart, a single kidney, or

3. In an animal cell, DNA is found in the greatest concentration in the

(1) vacuole
(2) ribosome
(3) nucleus
(4) cytoplasm

4. Cystic fibrosis is a genetic disease. Examine the illustration below.

Father with cystic fibrosis
Father has two abnormal genes for the trait

Mother who does not have cystic fibrosis
Mother has ???

Child with cystic fibrosis
Child has two abnormal genes for the trait

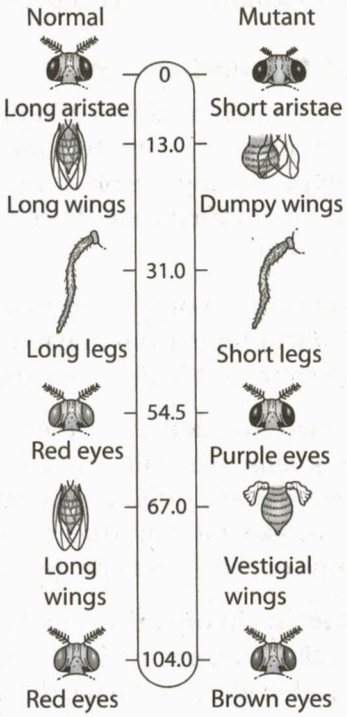
The mother's cells most likely contained

(1) a disease-causing virus
(2) one normal gene and one abnormal gene
(3) two normal genes
(4) an abnormal number of chromosomes

5. Bacteria in culture A produce slime capsules around their cell walls. A biologist removed the DNA from some of the bacteria in culture A. He then injected it into bacteria in culture B, which normally do not produce slime capsules. After the injection, bacteria with slime capsules began to appear in culture B. What conclusion could best be drawn from this investigation?

(1) The bacteria in culture A are mutations.
(2) Bacteria reproduce faster when they have slime capsules.
(3) The slime capsules of bacteria in culture B contain DNA.
(4) DNA is most likely involved in the production of slime capsules.

6. The diagram below represents the gene map of a fruit-fly chromosome.



A valid observation based on this gene map is that

(1) more than one gene may affect a single trait such as eye color
(2) each trait is influenced by genes that are identical
(3) each trait is influenced by only one pair of genes
(4) genes for traits such as eye color are always next to each other

7. Which cell structure includes all of the others?

(1) nucleus
(2) gene
(3) DNA
(4) chromosome

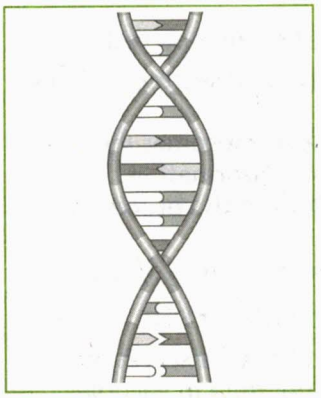


Figure 3-2. Model of a section of a DNA molecule

The Genetic Code

The inherited instructions (genes) that are passed from parent to offspring exist in the form of a chemical code. This genetic code, as the chemical code is called, is contained in the DNA molecules of all organisms. DNA molecules resemble a flexible, twisted ladder formed from many smaller repeating units, as shown in Figure 3-2.

DNA Structure

Like other large molecules of life, the DNA molecule is made of thousands of smaller sections called **subunits.** Each subunit has three chemical parts: a sugar, a phosphate, and a base. The subunits vary from one another according to the kind of bases they contain. The bases are represented by the letters A, G, C, and T. The four subunits of DNA molecules are

arranged in pairs, each subunit forming one side and half of one rung of the "twisted ladder." Base A of one subunit always pairs with the base T of another subunit. In a similar way, base G always pairs with base C. Figure 3-3 shows the details of the structure in an untwisted molecule.

Once the chemical and structural properties of DNA were discovered by scientists, it became clear how this molecule could contain a kind of message that functions as a code. Notice in Figure 3-3 that the sequence of bases on this molecule's left strand, reading from top to bottom, is ACAG. A different molecule might have a sequence in the same position reading GCAG or AACG. The specific sequence of bases in a DNA molecule forms a coded message. The message of a single gene is often a sequence of hundreds of bases. The code for an entire human is estimated to be around 3 billion base pairs!

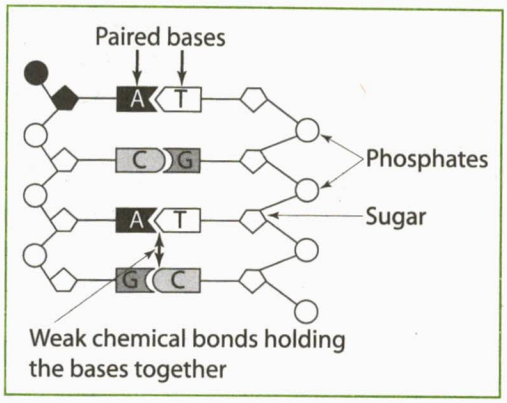


Figure 3-3. Portion of a DNA molecule: A single subunit is shown in black. The bases of the DNA molecule are arranged in pairs, represented here by letters. The base pairs form the rungs of the twisted DNA ladder. The sugar and phosphate of each subunit form the sides of the ladder and are connected by strong chemical bonds. The two sides are held together by weak chemical bonds between the paired bases. (Bonds are the links between atoms that hold molecules together.)

DNA Replication

The ability to copy the coded instructions in the DNA molecule is critical to its function. Knowing the chemical makeup and structure of DNA molecules gave scientists an immediate clue to how the molecule could be copied, or **replicated.** When scientists realized that the bases used weak chemical bonds to pair with each other, they also realized that the DNA could separate at that weak **bond** to form two single strands. Each single strand became a **template**, or pattern, for a new molecule.

The new molecule was built by attaching new subunits to each template strand, always following the base pairing rules of linking A with T and C with G. The result is the formation of two new molecules whose base pair sequences are exactly alike. See Figure 3-4.

When the structure of DNA was determined, scientists finally understood how cells could copy and transfer information to new cells each time they divide and to new offspring during reproduction. Replication produces two identical copies of the cell's genetic information, each ready to be passed from the parent cell to two offspring cells during cell division. Offspring cells are commonly called daughter cells.

Proteins and Cell Functioning

The work of the cell is carried out by the many types of molecules the cell assembles (synthesizes). Many of these molecules are proteins. Protein molecules are long chains. They are formed from various combinations of 20 kinds of amino acids arranged in a specific sequence.

The sequence of amino acids in a particular protein influences the shape of the molecule. This is because some of the amino acid parts are attracted to (and may bond with) other amino-acid parts of the chain. The connections that form between different parts of the chain cause it to fold and bend in a specific way. The final folded shape

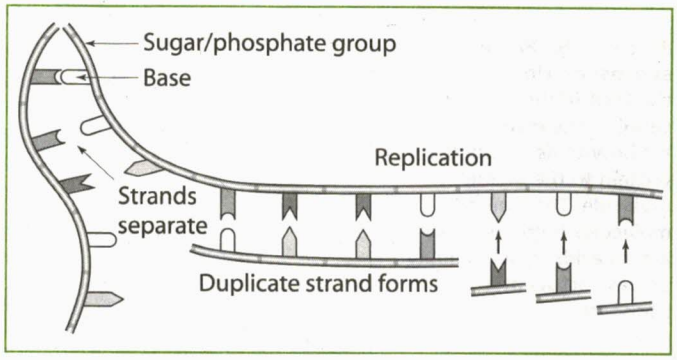


Figure 3-4. The replication of a DNA molecule: This is how cells copy their genetic information to be passed on to two offspring cells when cell division occurs. Both strands are replicated at the same time.

of the protein enables it to carry out its function in the cell. Many proteins made by a cell become enzymes that regulate chemical reactions. Remember that an enzyme can interact with a specific molecule because their shapes correspond.

Some of the proteins made in cells become parts of organelles, such as the cell membrane. Other proteins include the hormone insulin or the many antibodies that bind to antigen molecules on pathogens. The color of your eyes and skin are also the result of proteins synthesized by your body.

The DNA-Protein Connection

Cells store vast amounts of coded information in their genes. Much of this coded information is used to make the thousands of proteins that each cell requires for its functions and the structures it contains. The proteins for these structures and functions are made at the ribosomes according to the directions stored in the cell's DNA code.

Because offspring inherit genetic information from their parents, their cells make many of the same proteins. This is what causes the resemblance between some children and their parents. Making many of the same proteins causes both parent and offspring to form similar structures that give them similar features. One example of a protein-dependent trait includes hair texture (curly, straight, or kinky).

If a parent's DNA carries a code for a protein that does not function correctly, the children may also make that defective protein. For example, an albino does not produce the usual amount of eye, hair, or skin color pigment. The condition is caused by a defect in the gene that codes for the protein that produces color pigment. If albino parents pass this gene to their offspring, they, too, may not produce the normal color pigment.

Protein Synthesis The process of synthesizing a protein from DNA begins in the nucleus. There, the DNA code of a particular gene is "read" by a special enzyme and used to produce a "messenger" molecule. This messenger molecule then travels to the ribosomes in the cell's cytoplasm. With the aid of specialized transfer molecules, amino acids are moved to the ribosomes for assembly into protein. They are bonded in the order specified by the messenger molecule. In this way, the sequence of amino acids of any protein, and therefore its overall structure, is determined by the gene's DNA sequence in the nucleus. The process is shown in Figure 3-5.

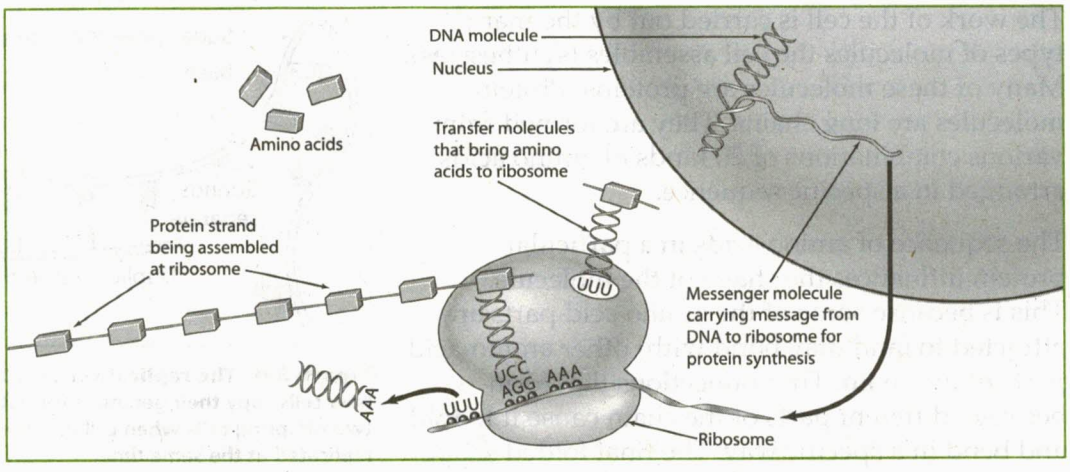


Figure 3-5. Protein synthesis: Notice that the DNA in the nucleus supplies the instructions for how to assemble the protein to the messenger molecule. The transfer molecules help assemble amino acids. The assembly process occurs at a ribosome.

8. In a DNA molecule, the letters A, T, C, and G represent

(1) bases
(2) sugars
(3) starches
(4) proteins

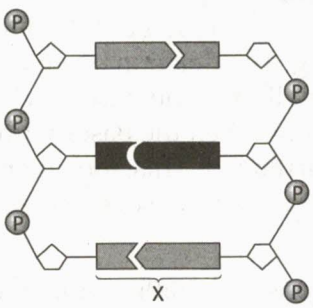
9. The individuality of an organism is determined by the organism's

(1) amino acids
(2) nitrogen bases
(3) DNA base sequence
(4) order of ribosomes

10. What would most likely happen if the ribosomes in a cell were not functioning?

(1) The cell would undergo uncontrolled mitotic cell division.
(2) The synthesis of enzymes would stop.
(3) The cell would produce antibodies.
(4) The rate of glucose transport in the cytoplasm would increase.

11. The diagram below represents a portion of a DNA molecule.



The letter X represents two bases that are

(1) identical and joined by weak bonds
(2) identical and joined by strong bonds
(3) a part of the genetic code of the organism
(4) amino acids used to build folded protein molecules

12. The kinds of genes an organism possesses are dependent on the

(1) type of proteins in the organism's nuclei
(2) sequence of bases in the organism's DNA
(3) number of ribosomes in the organism's cytoplasm
(4) size of the mitochondria in the organism's cells

13. What is the role of DNA molecules in the synthesis of proteins?

(1) They catalyze the formation of bonds between amino acids.
(2) They determine the sequence of amino acids in a protein.
(3) They transfer amino acids from the cytoplasm to the nucleus.
(4) They supply energy for protein synthesis.

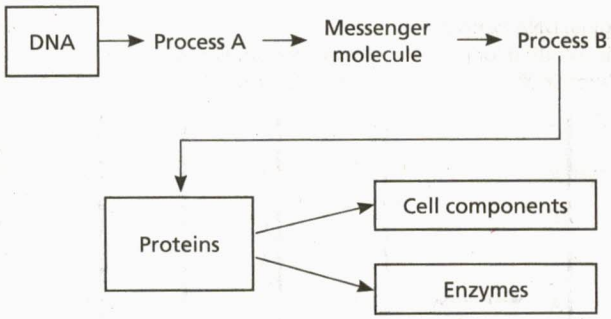
14. The diagram at the right represents a molecule of

(1) ATP
(2) protein
(3) carbohydrate
(4) DNA

15. During replication, the strands of a double-stranded DNA molecule separate when the bonds are broken between their paired bases.

Explain why, in terms of the genetic code, it is important that the molecule separate between the bases and not at some other point. [1]

Base your answers to questions 16 and 17 on the diagram below and on your knowledge of biology.



16. Within which organelle does process A occur?

(1) ribosome
(2) nucleus
(3) vacuole
(4) cell membrane

17. Within a living cell, which organelles are directly necessary for process B to occur?

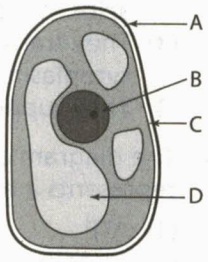
(1) ribosomes
(2) mitochondria
(3) vacuoles
(4) cell membranes

18. In all living cells, DNA controls cellular activities by

(1) determining the order of amino acids in protein molecules
(2) regulating the concentration of molecules on both sides of the cell membrane
(3) varying the rates of starch synthesis
(4) coordinating active and passive transport

19. Which cell organelle indicated in the diagram controls the synthesis of enzymes?

(1) A
(2) B
(3) C
(4) D



20. The sequence of amino acids that makes up a protein molecule is determined by the sequence of

(1) bases in DNA
(2) glucose in DNA
(3) ribosomes in the cytoplasm
(4) chloroplasts in the vacuoles

21. In DNA, the base represented by an A always pairs with the base represented by

(1) A (2) T (3) C (4) G

22. The presence of DNA is important for cellular metabolic activities because DNA

(1) directs the production of enzymes
(2) is a structural component of cell membranes
(3) directly increases the solubility of nutrients
(4) is a major component of the cytoplasm

Mutations

Genes are actually segments of DNA molecules. Any alteration of the DNA sequence is a **mutation**, which changes the normal message carried by the gene. Many mutations involve the substitution of one base for another. This often causes a different amino acid to be placed in a particular position in the growing protein chain. Some mutations involve the insertion of an additional base into an existing DNA sequence. This affects all of the code past the change, just as skipping a blank on the answer sheet for a test can cause all of the remaining answers to be shifted to the next blank, making almost all of them wrong. The deletion of a base from the normal gene sequence would also alter all the code past the change.

Some mutations occur when the bases within a gene are accidentally rearranged. This, too, alters the genetic code. Figure 3-6 shows several ways that DNA can mutate.

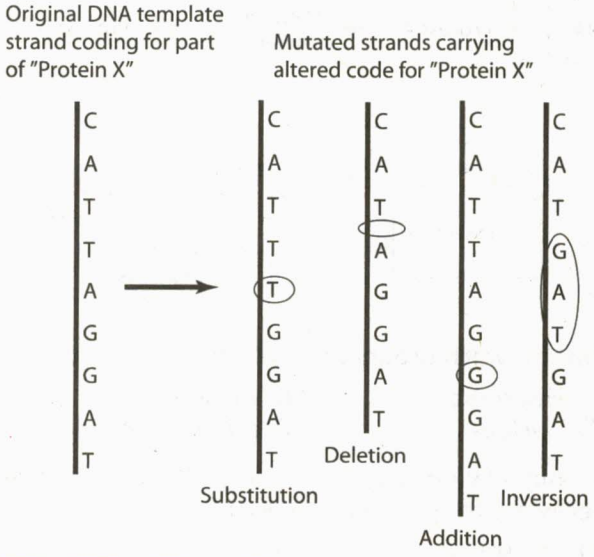


Figure 3-6. Mutation of DNA: The DNA on the left is part of the original template strand that codes for protein X. The four strands on the right show the DNA that would result from several types of mutations.

All of these alterations are totally random and can occur anywhere along the molecule, making the result of the change almost impossible to predict. However, when a DNA sequence is changed, it is quite likely that the protein it codes for may be assembled incorrectly. If some amino acids are replaced by others, or if their sequence is different, the folding of the protein may be different. Incorrect folding means that the protein's shape would not be normal. This could cause the protein to malfunction. One mutation caused by a substitution is sickle cell disease. (See Figure 3-7.)

Mutations can cause such serious changes that the cell may die. However, if a mutated cell does survive and can replicate its DNA, its changed instructions will be copied and passed on to every cell that develops from it. In sexually reproducing organisms, only mutations found in sex cells can be inherited by the offspring.

DNA and Individuality Although an individual's body cells all originally come from a single cell, the body is made up of many types of cells. Each body cell's nucleus—whether it is a nerve cell, skin cell, or bone cell—has a complete set of identical genetic instructions for that individual.

For years, scientists wondered how cells with identical genetic instructions could be so different. The answer is that each kind of cell uses only some of the genetic information it contains. It uses only the instructions it needs to operate its own kind of cell. For instance, information for building all of a person's enzymes is coded in the chromosomes of each cell, but a muscle cell uses only the specific enzymes that are needed by a muscle cell.

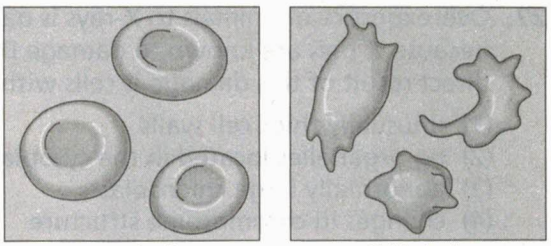


Figure 3-7. Effects of a substitution mutation: Normal red blood cells are round. The abnormal cell shapes are due to a substitution mutation that forms a defective protein which changes the cell's shape.

Both the internal and external environment of the cell can influence which genes are activated in that cell. Some of this influence may occur during development, leading to the many different types of cells that an organism needs.

The selective activation of genes in a cell may continue as conditions change throughout life. For instance, chemical signals from within the cell or from other cells may activate a particular gene. Hormones are one kind of molecule that can activate parts of a cell's DNA code, leading to the production of a particular protein.

Although genes are inherited, an organism's environment can affect the way some genes are revealed, or **expressed,** in the organism. For example, in some animals, such as the Himalayan rabbit, the outside temperature can cause the activation or inactivation of the genes for fur color. When the rabbit's body area is cold, black fur grows. If the same body area becomes warm, white fur grows instead. (See Figure 3-8.) The environment can also influence human genes. Studies of identical twins (those with identical genetic information) who were raised in different environments show that they have differences that can only be explained by the influence of the environment on gene expression.

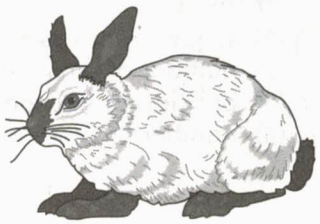


Figure 3-8. Body temperature and fur color in the Himalayan rabbit: From what you know about the activation and inactivation of the genes for fur color in this animal, why do you think the ears, feet, nose, and tail are black?

Review Questions

23. A dog breeder can determine that the sudden appearance of hairlessness in one of the puppies is a mutation if the dog

(1) is still hairless after 5 years
(2) shows no change in the hairless condition after its diet is changed
(3) develops other conspicuous differences from the parent
(4) is bred and the trait is capable of being inherited

24. Explain how a change in the sequence of nitrogen bases in a DNA molecule could result in a gene mutation. [1]

25. Which mutation could be passed on to future generations?

(1) a gene change in a liver cell
(2) cancer caused by excessive exposure to the sun
(3) a chromosomal alteration during gamete formation
(4) random breakage of a chromosome in a leaf cell of a maple tree

26. Mutations can be transmitted to the next generation if they are present in

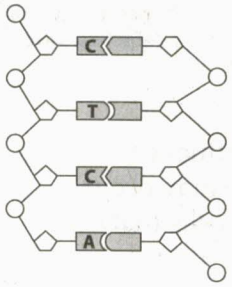
(1) brain cells
(2) sex cells
(3) body cells
(4) muscle cells

27. Overexposure of animals to X-rays is dangerous because X-rays are known to damage DNA. A direct result of this damage is cells with

(1) unusually thick cell walls
(2) no organelles located in the cytoplasm
(3) abnormally large chloroplasts
(4) changes in chromosome structure

28. The diagram below shows a portion of a DNA molecule. The base sequence of the unlabeled strand shown in the diagram is *most* likely

(1) G-A-G-T
(2) C-U-C-A
(3) T-C-T-G
(4) G-A-G-U



29. The individuality of an organism is determined by the

(1) sequence of bases in DNA
(2) number of amino acids in a cell
(3) position of ribosomes in the cytoplasm
(4) number of bases in the mitochondria

30. In which situation could a mutation be passed on to the offspring of one of the organisms listed in the data table below?

Data Table

Name of Organism	Number of Chromosomes in a Body Cell
Human	46
Fruit fly	8

(1) Ultraviolet radiation causes fruit-fly wing cells to undergo uncontrolled division, resulting in cells with 9 chromosomes.
(2) A cell in the wall of the human uterus undergoes a change, resulting in cells with 47 chromosomes.
(3) A primary sex cell in a human forms a sperm that contains 23 chromosomes.
(4) A cell in the ovary of the fruit fly undergoes a chromosomal change that results in 5 chromosomes per egg cell.

31. A change in the sequence of bases in a DNA molecule is most accurately referred to as

(1) an insertion, deletion, or substitution
(2) a chromosomal replication
(3) carbohydrate molecule synthesis
(4) selective breeding

Genetic Engineering

Genetic engineering is a new technology that humans use to alter the genetic instructions in organisms. The idea of altering organisms to have more desirable traits, however, is not new. In fact, **biotechnology**—the application of technology to biological science—has been producing useful products for thousands of years. Cheese and bread are just two examples of "biotech" products made with the use of microbes.

Throughout recorded history, humans have also used **selective breeding**—a process that produces domestic animals and new varieties of plants with traits that are particularly desirable. Many meat products, for example, come from animals that have been bred to contain less fat. In addition, many of the fruits and vegetables we consume have been selectively bred to be larger, sweeter, hardier, or even juicier.

To breed a better plant, farmers might select a bean plant that produces many pods and then crossbreed it with a bean plant that resists fungus infections. The farmers would expect to get seeds that would grow into bean plants with both features.

Gene Manipulation

In recent years, plants and animals have been genetically engineered by manipulating their DNA instructions. The result of this genetic