TOPIC 5 When Plans Change

Variation is a characteristic of life. It is an important part of ecosystems and a feature of human populations. Later in Topic 6 you will learn more about the importance of variation in adaptations. How are all of these things linked? The answer is found in the cell's nucleus. In Grade 8 Science you learned that the nucleus is the control centre of the cell and contains the genetic material. But what does the control centre do, how does it work, and what is "the genetic material"?

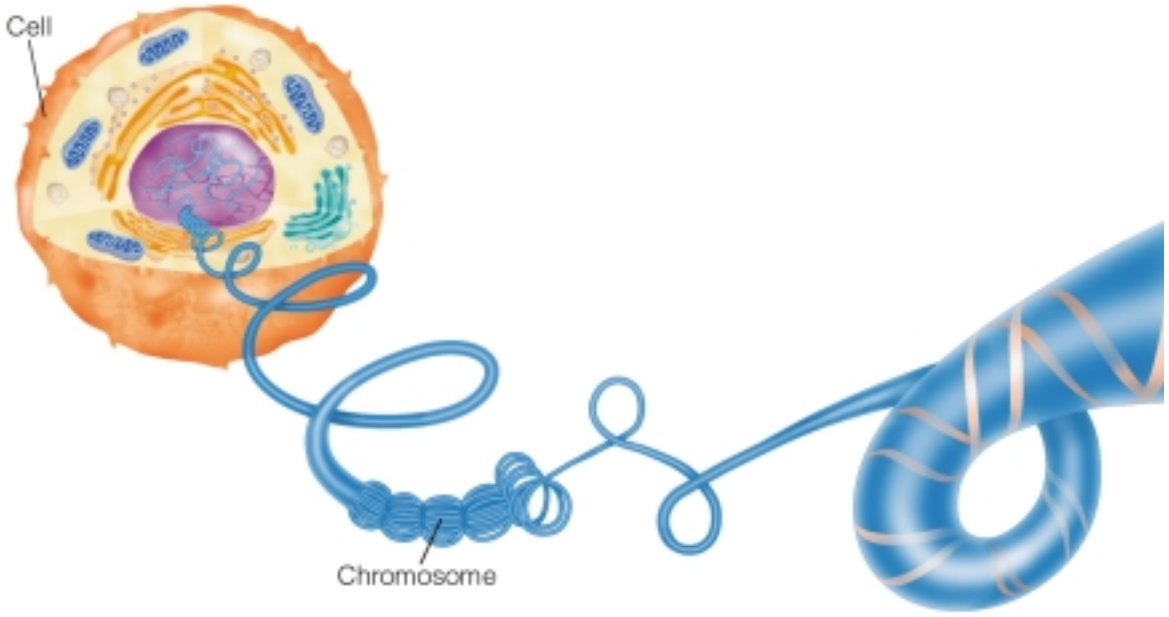


Figure 1.41 The chromosomes are found in the cell's nucleus. Chromosomes are made up of strands of DNA, the genetic material.

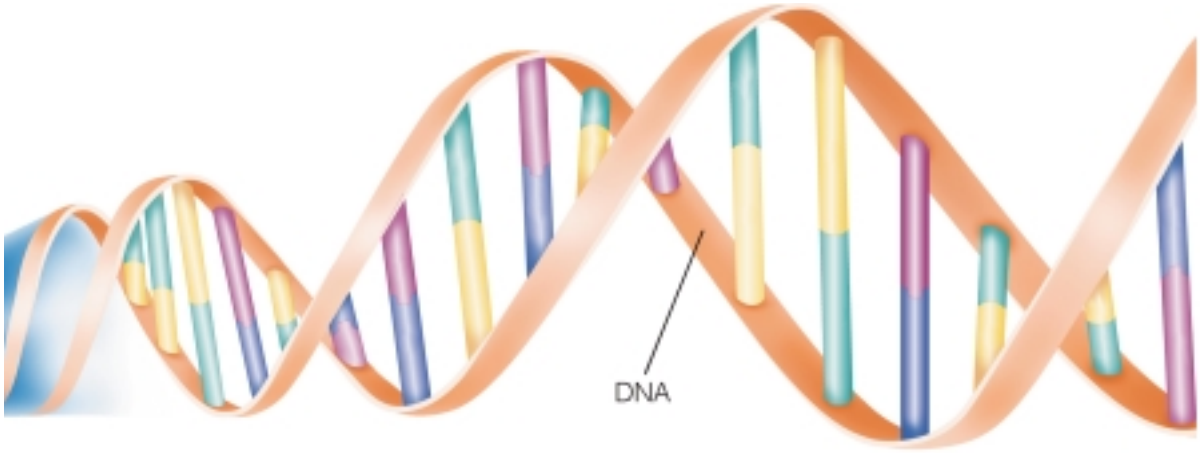
DNA: The Secret of Life

Philosophers and scientists have searched for the secret of life for thousands of years. Genetically speaking, the answer is a molecule called deoxyribonucleic acid, or **DNA**. Swedish chemist Johann Miescher collected DNA from the nuclei of certain cells in 1868. It was not until later that scientists could explain how this seemingly simple substance could carry out all of the functions of the genetic material. The genetic material had to be able to reproduce itself, move from parent to offspring, and control all the structures and functions of cells. In addition, the structure of the genetic material had to be able to explain variation within and between species.

Chromosomes, which are composed of strands of DNA, are contained in a cell's nucleus. DNA is the molecule that controls the formation of cells, the products that they release, and everything they do. DNA is also the genetic material — the plan that is passed on from one generation to another.

The Structure of DNA

Once scientists worked out the structure of DNA, they were able to explain how the molecule could do everything the genetic material had to do. Structurally a molecule of DNA has the shape of a coiled ladder. The sides of the ladder are made of alternating subunits called sugars and phosphates. The rungs of the ladder are pairs of nitrogen bases that come in four different forms: adenine (A), thymine (T), guanine (G), and cytosine (C). A forms chemical bonds with T, and C bonds to G. Figure 1.42 will help you to gain an understanding of the overall pattern of DNA.



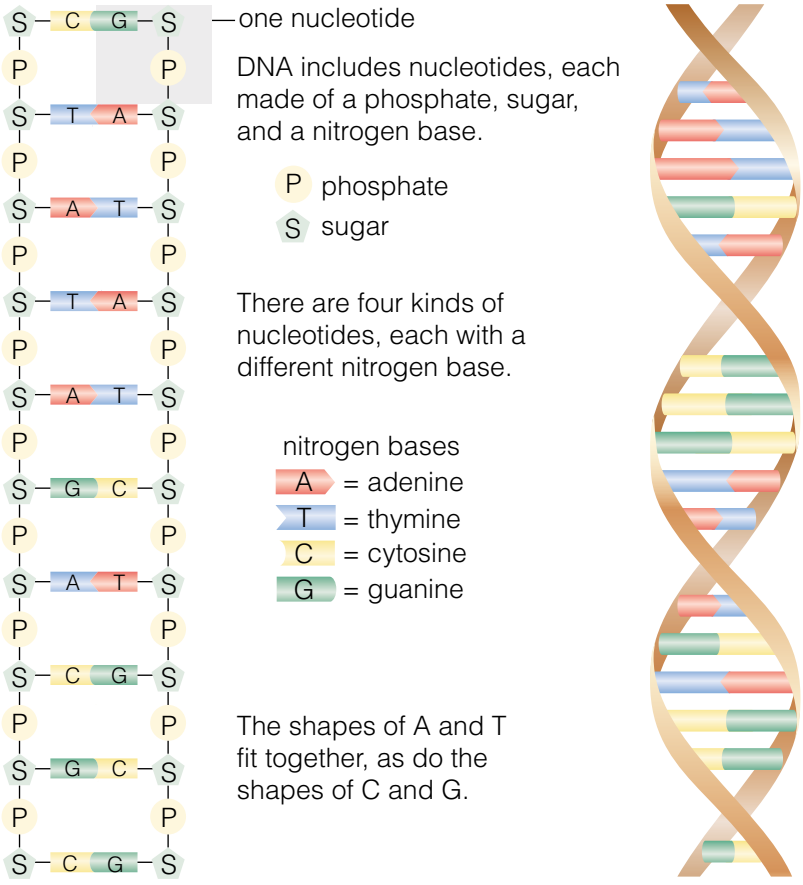


Figure 1.42 DNA is made of many thousands of nucleotides. The ladder-like structure winds like a spiral staircase.

SKILL CHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Modelling DNA

Scientists James Watson and Francis Crick worked together to figure out the structure of DNA. In 1953, they presented their findings with a model made of wire and tin, as shown in the photograph. In this investigation, you will work with a partner to design and construct a three-dimensional model of a DNA molecule.

Challenge

Construct a model of DNA in three dimensions.

Materials

Styrofoam™ chips
modelling clay
corks
jelly beans
coloured construction paper
toothpicks
clear adhesive tape
scissors

Design Specifications

A. Your model must include the six colours or objects. Each colour or object will represent one of the following parts of DNA: phosphate, sugar, four nitrogen bases (A,T,C,G).

B. The nitrogen bases must be paired according to the rule: A pairs with T, and C pairs with G.

C. Your model must show the three-dimensional shape of DNA — a twisted ladder.

Plan and Construct

1. With your partner, decide on what shapes and colours you will use to represent each of the parts of your DNA model. How long will your DNA model be?
2. Brainstorm possible designs for your model. Make a list of your ideas.
3. Choose the best idea and sketch it. Include labels in your sketch. Then list the steps of how you will construct your model. Be specific.
4. Have your plan and sketch approved by your teacher. Then build your model.

Evaluate

1. Did your DNA model include all the parts that were outlined in your plan?
2. How did your model differ from those of other groups?
3. Did you have any problems in assembling your model? If so, how did you solve them?
4. How could you improve on your design?
5. What are some advantages of working with a partner? Did you have any difficulties? If so, what were they and how did you resolve them?

Extend Your Skills

1. Why do you think models are helpful to scientists?
2. Why do you think DNA is shaped like a twisted ladder or a double helix?

STRETCH Your Mind

As you have learned, DNA can undergo mutations. In what ways do you think the structure of DNA can be altered?

The Genetic Code

The sequence of bases, or letters, in DNA forms a code. This code is like a blueprint that controls the production of proteins in the cell. Protein molecules make up much of the structure of the cells and tissues in plants and animals. In addition, various proteins control how a cell is formed and how it functions. A section of the DNA molecule that codes for a specific protein is called a **gene**.

Figure 1.43 Airlines use a three letter code on baggage tags. There is a specific code for each airport in the world.

The Dance of the Chromosomes

Chromosomes are tightly coiled strands of DNA. Generally, each human body cell has 46 chromosomes. These chromosomes are found in 23 pairs, with one copy of each chromosome coming from each parent.

It is important that each cell in the body has a complete set of chromosomes. As a result, the formation and movement of a new set of chromosomes is an important part of cell division. There are two forms of cell division. In one case, the cell divides into two identical copies. The other form of cell division results in the formation of egg and sperm cells.

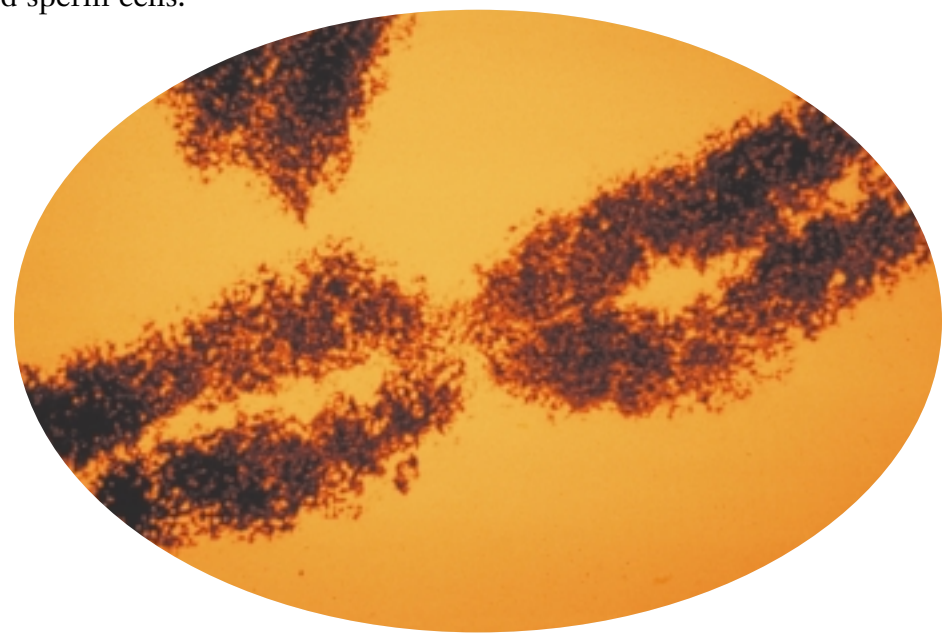


Figure 1.44 Chromosomes are formed from long strands of tightly coiled DNA.

Math CONNECT

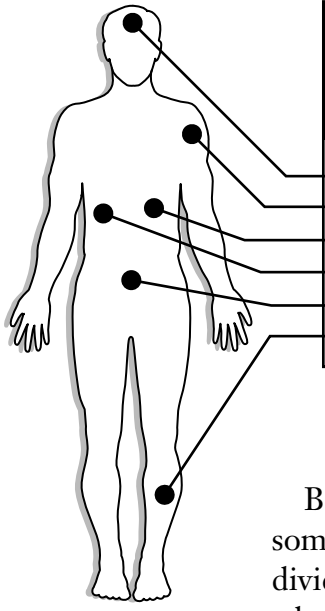
The total code for human DNA is called the human genome. The human genome contains about 3.0×10^9 pairs of bases. Humans have approximately 30 000 genes, and a typical gene has 3000 base pairs! Pretend for a moment that the genome is a railway track and each base pair is a railway tie. If each railway tie is 1 m from the next, how many kilometres does the track go? Given the information above, how much of the human genome is "junk" DNA that does not code for proteins?

DidYouKnow?

Dog cells have 78 chromosomes, and tomato cells have 24 chromosomes.

Normal Cell Replacement

Cells of multicellular organisms divide for growth of the organism and repair and replacement of tissues. The human body is incredibly complex and made up of many different kinds of body cells (**somatic cells**). No one knows how many cells are found in the body, but estimates range from 60 trillion to 100 million million. Some cells last a lifetime while others survive for only a few days.



LIFE SPANS OF DIFFERENT HUMAN BODY CELLS	
brain cells	30-50 years
red blood cells	120 days
stomach lining cells	2 days
liver cells	200 days
intestine lining cells	3 days
skin cells	20 days

Figure 1.45 Which cells live the longest? Which cells are replaced most often?

Before a cell divides, a copy of each chromosome is made. Then the chromosome copies are divided in a process called mitosis. This way, when the cell divides, each new cell ends up with a complete set of chromosomes. The two new cells are genetically identical to each other and to the original cell.

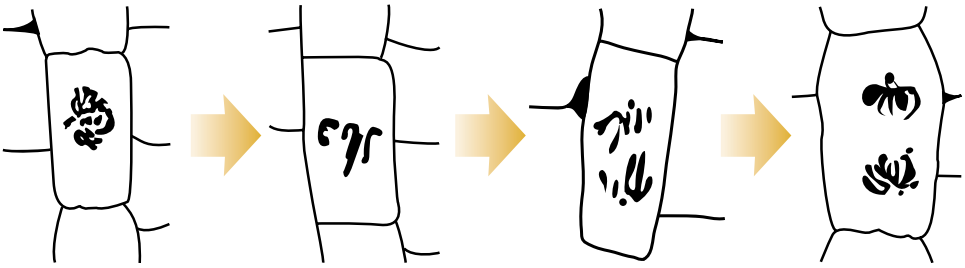


Figure 1.46 This figure shows different stages of mitosis in a cell. Before the cell divides, its chromosomes are copied. The two sets of chromosomes are then divided between the two new cells.

STRETCH Your Mind

One part of the body in which growth can easily be seen is the bones. Joy's father kept a record of her height from the time she was born until she was eight years old. When do you think cell division occurred most rapidly in Joy's skeleton? (Hint: Draw a line graph using the record of Joy's height, given below.)

Year	Height (cm)
birth	42
1	50
2	86
3	92
4	104
5	112
6	118
7	124
8	128

Pause & Reflect

Scientists are now able to grow certain body tissues outside of the human body. If researchers could create entire body organs this way, these organs could be used in people whose own organs are injured or unhealthy. Do you think it is a good idea to develop human body organs in this way? Write about the possible benefits and drawbacks of this method in your Science Log.

Sex Cells and Genetic Variation

Which type of human cell has only 23 chromosomes? These cells are the sex cells or gametes — the sperm and eggs. Only when an egg and sperm join to form a zygote does the new cell have a complete set of chromosomes. Meiosis, the process of forming the gametes, begins in the same way as the division of somatic cells. Prior to cell division, each chromosome is copied. The major difference between the two processes is that to form sex cells, cell division occurs two times. The final result is that the gametes have only half the original number of chromosomes. In humans this means that each sperm or egg has only 23 chromosomes. The process of randomly dividing 23 pairs of chromosomes in half creates the possibility of 8.4 million (2^{23}) different combinations of chromosomes! Any one of these combinations may be passed on to a gamete. In the zygote, chromosomes from two parents are combined. As a result, sexual reproduction increases variation within a species.

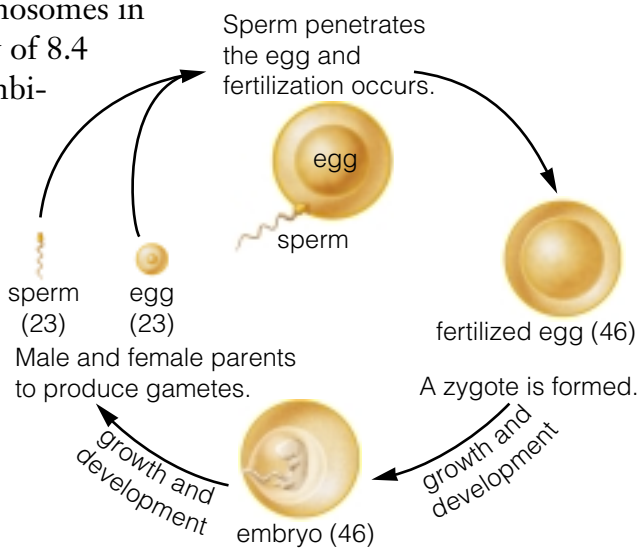
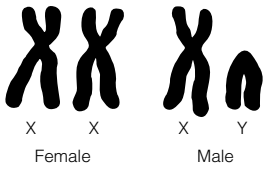


Figure 1.47 How does this cycle ensure variation in offspring?

DidYouKnow?

There are two sex chromosomes: the large X chromosome and the smaller Y chromosome. Females have two X chromosomes, while males have an X and a Y chromosome. When females form eggs, each egg will get one of the X chromosomes. However, when males form sperm, half of the sperm cells will get an X chromosome while the other half will get a Y chromosome. This means that the sex of the offspring depends on which sperm fertilizes the egg. Gender is another example of variation.



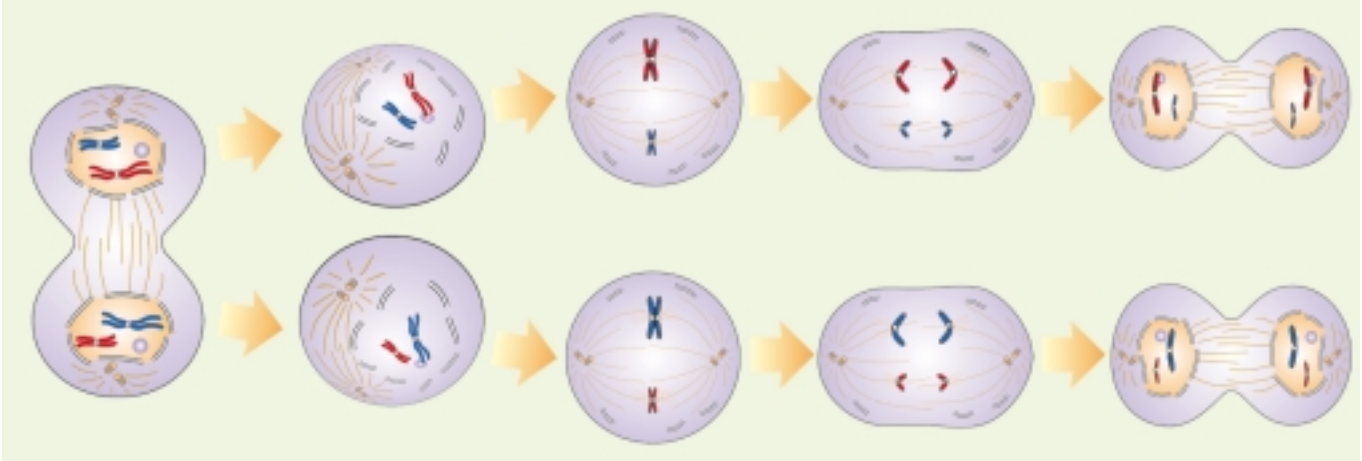


Figure 1.48 In the formation of the gametes, cell division occurs twice. Each gamete ends up with half of the original number of chromosomes.

Off the Wall

In 1991, scientists discovered that the tips of chromosomes in cells become shorter each time the cell reproduces. After about 50 replications, certain cell types stop replicating. This may be what aging really is — the inability to replace old, worn-out, or damaged cells.

The Benefits of Variation

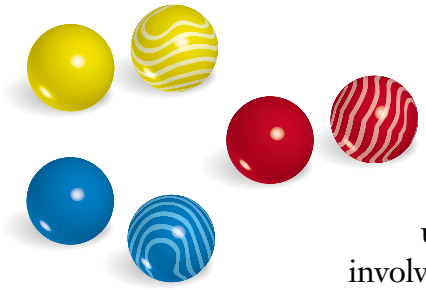


Figure 1.49 How many ways can you divide these marbles in two groups so that you have all three colours of marbles in each group? Every different combination is a form of variation — much like different combinations of chromosomes.

No individual plant or animal lives forever. Plants and animals exist today because their ancestors reproduced, either sexually or asexually. Remember that asexual reproduction requires only a single cell, such as a bacterium, to divide by binary fission. This process allows an organism to produce many offspring, usually in a short period of time. Because only one individual is involved in reproduction, the offspring are genetically the same as the parent. In contrast, in sexual reproduction, the gametes of two individuals form a zygote. Sexual reproduction requires more energy than asexual reproduction. As a result, fewer offspring are produced. However, genetic information from two parents is passed on to the offspring.

Both methods of reproduction produce more individuals of the same species, but which is better for offspring survival? The answer depends in part on an organism's environment. A change such as bad weather, disease, or inadequate food can stress organisms in a population. However, if conditions vary, even an environmental catastrophe may leave some survivors. You will see how variation in a population can be beneficial in the following activity.

Find Out ACTIVITY

Survival: The Ultimate Advantage

Aphids, a common garden pest, reproduce asexually during the summer. In late summer, they reproduce sexually and the females lay eggs, which hatch after the winter. If a species of aphid were developed that could no longer reproduce sexually, what would be the effect on the survival of this aphid species?

Materials

paper pencils

Procedure

1. Use four shapes to represent the types of individuals in the population: squares, triangles, circles, and ovals. Draw the four shapes on a piece of paper.
2. Record the outcome of each environmental change described below.
   - **(a)** The first summer provides enough food for one season of asexual reproduction. Most of the aphids survive long enough to reproduce.
   - **(b)** The second summer is unusually cold. All of the squares die before they reproduce.
   - **(c)** The third summer is mild and most of the aphids survive long enough to reproduce.
   - **(d)** A fungus in the fourth summer kills all the ovals.
3. Begin again with the original shapes. Repeat step 2, but assume the aphids can reproduce sexually. Model the potential outcome of sexual reproduction by showing the new variations each possible pairing may produce. List all possible pairings, for example, oval/oval; oval/circle.

What Did You Find Out? Analyzing and Interpreting

Consider the impact of both sexual and asexual reproduction on the population. Describe the makeup of the population after each environmental change. Does the population become more varied or less varied? Is sexual reproduction more advantageous? Why?

Technology and Variation

In the last 30 years scientists have learned how to move pieces of DNA from one cell to another, a technique called **genetic engineering**. This has allowed scientists to move genes from one organism to another and even to move desirable characteristics from one species to another. However, using these methods, also called **biotechnologies**, raises many questions. Does biotechnology "tamper with nature"? Are there unknown harms to the environment, people, or other organisms that come with specific biotechnologies? What new opportunities and ways of solving problems will advances in science bring?

Figure 1.50 This is Willow the goat, Canada's first transgenic livestock animal, born in August 1998.

Biotechnology in Medicine

One of the first uses of modern biotechnology was to move the human gene for insulin into bacteria. The introduction of the human gene allowed the bacteria to produce insulin as a waste product. This breakthrough has allowed us to produce human insulin in large quantities. This is important for diabetics who used to depend on insulin from pigs or cattle to treat their condition.

Bacterial cells cannot make large, complex proteins such as the ones listed in Table 1.1. Making these proteins requires a number of steps that can occur only in the cells of a multicellular organism. However, animals can also be given human genes. Genetically modified, or **transgenic**, animals are produced by adding human genes to the fertilized eggs of the animal. Offspring that develop from the zygote grow up with a human gene. The ability to produce human proteins can then be inherited by the offspring of the transgenic animal.

Table 1.1 Some Common Human Proteins Made Using Transgenic Animals

Product	Use	Animal
human lactoferrin	a good source of iron for babies	cow
antitrypsin	a compound used to treat an inherited form of emphysema	sheep
factor VIII and IX	blood-clotting factors used to treat hemophilia	sheep
human protein C	used to treat blood clots	pig

An advantage of using mammals is that the proteins can be collected in the mammal's milk and then purified. This means the animal does not have to be killed to obtain the proteins.

Word CONNECT

Most new discoveries are protected by agreements called *patents*. What is a patent? Why do you think patenting a newly "invented" life form, such as a bacterium that breaks down oil, or an herbicide-resistant wheat is controversial?

Pause & Reflect

Scientists have created an "EnviroPig" — a pig that produces environmentally friendly waste for manure. The pig was created by inserting bacterial genes for degrading phosphate, an unwanted chemical, into the pig's genome. What are the pros and cons of deciding to use this approach? What else could be done to produce manure that is better for the environment? Are there any ill effects – for the pig and the environment? In your Science Log, write what you would want to find out about this procedure before the EnviroPig goes to market.

Off the Wall

One problem in genetic engineering is transferring engineered DNA into a host cell. Most often viruses have been used as "transporters" or "vectors." Another method uses a "gene gun," which fires microscopic metallic particles coated with engineered DNA into a host cell.

Biotechnology in Food Production

Genetic engineering has become an important part of producing food. With the ongoing decline in natural fish stocks in oceans and lakes, fish farming or **aquaculture** is becoming an increasingly important method of fish production. Scientists have added genes for disease resistance to some varieties of fish. Growth hormone genes have also been introduced into fish eggs to increase the size and growth rate of the fish.

Researchers at Memorial University in Newfoundland have added an "antifreeze" gene into Atlantic salmon and halibut. The gene comes from a species of Arctic flatfish. It produces a protein that prevents the fish's blood from freezing, thereby allowing Canadian fish farmers to operate in winter. Some scientists are concerned that the escape of transgenic fish would adversely affect natural populations. For instance, natural populations of fish may not be able to compete with transgenic varieties. What are some other possible outcomes (positive and negative) of farming transgenic fish?

Figure 1.51 Salmon that are bioengineered to contain a gene for rapid growth can grow four to six times larger than salmon without the gene.

A Cost-Effective Crop

Crops such as wheat, corn, tomatoes, and potatoes are genetically altered for a variety of reasons. Most genetically engineered crops in Canada have been altered to be tolerant of herbicides. Since these crops are not killed by certain herbicides, farmers can use high concentrations of some herbicides, but use them less often. The results are lower costs and fewer weeds.

In the past, farmers grew plants and raised animals that survived well in local climates and soils. The result was that many different varieties of crops were used throughout the country. Now bioengineered varieties are so cost-effective that they are used across Canada. However, the widespread use of monocultures of the new varieties creates a potential problem. Even though the addition of genes to plants and animals artificially increases variation within these species, monocultures lack diversity. As a result, a single pest or disease could destroy the crops. Plant diseases that are now local problems could someday threaten the country's food supply.

Figure 1.52 Researchers experiment with putting "antifreeze" genes into salmon eggs.

DECISION-MAKING

INVESTIGATION 1-I

SKILL CHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Genetically Engineered Foods

Think About It

Tomatoes have a relatively short shelf life. The tomatoes that you buy in the supermarkets are nearly always harvested before they are ripe. Thus, they arrive in stores before they have begun to deteriorate. However, tomatoes that are harvested early do not have the same delicious taste as vine-ripened ones.

In the 1990s, scientists had genetically engineered tomatoes to have a longer shelf life. However, many people were concerned about the sale of genetically modified foods, especially those not labelled as such. Despite the controversy, scientists continue to develop different tomatoes that are slower to ripen, more nutritious, insect-resistant, and even salt-tolerant.

How Can Science Help?

A good understanding of how genes work and which genes are responsible for specific traits is needed in order to engineer a safe and desirable new food. Scientists then test new crop varieties for possible toxins and allergens (compounds that cause allergic reactions) as well as nutritional quality. In addition, scientists sometimes monitor the effect of genetically altered food crops on the environment.

Procedure

1. As a group, choose one genetically modified food to investigate. You may have to do some background reading before choosing a topic. Find out what makes this food controversial.
2. What will you need to find out in order to decide whether or not the genetically modified food should be placed or kept on the market? In your group, brainstorm a list of questions that you will need to answer. Assign the duty of writing down these questions to one member in your group.
3. Research your questions using the Internet or library. If the information to answer your questions is not available, simply make a note of this.
4. As a group, compile the information you have gathered. If your investigation led you to more questions that you think should be answered, make a note of these questions.
5. Discuss with your group whether or not you have enough information to make a decision about the genetically modified food. Discuss what else you will need to know before a final decision can be made.

Analyze

1. Were you able to answer all of the questions on your list? How many questions were left unanswered?
2. Suppose you are part of a special committee to advise Health Canada on whether or not to accept the genetically modified food into the marketplace. What would you suggest to Health Canada as the next step in the decision-making process?
3. Did the members in your group pose different questions? Did you come up with more questions to investigate as a group than you would have if you had completed the investigation on your own?

Skill FOCUS

For tips on societal decision making, turn to Skill Focus 8.

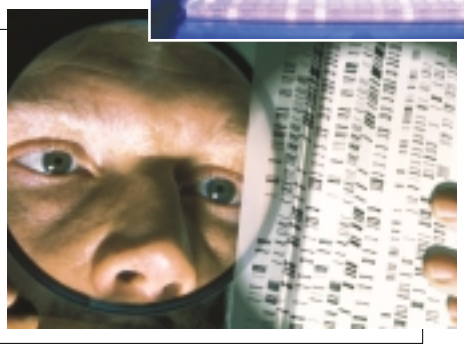
INTERNET CONNECT

www.mcgrawhill.ca/links/sciencefocus9

By understanding more about the genetic code, scientists hope to someday prevent or cure genetic diseases. To find out about the Human Genome Project, the international effort to determine the entire genetic code, go to the web site above, and click on Web Links to find out where to go next. Write a short newspaper article explaining what the Human Genome Project has achieved thus far. Also discuss at least one of the issues this project has raised.

Cool Tools

Did you know that your DNA has a distinct pattern called a DNA fingerprint? The same is true of DNA from other organisms. To view a person's DNA fingerprint, scientists must first extract DNA from human cell samples. The DNA is then cut into tiny pieces and separated on a gel. Using special stains, scientists are able to examine the pattern, or fingerprint, made by the pieces of DNA. This method can be used to identify people or recognize genes linked to certain diseases. Taxonomists use DNA fingerprints to learn about relationships between different organisms.



TOPIC 5 Review

Pause & Reflect

Imagine that you are a genetic engineer. Propose an idea for a genetically modified fruit or vegetable that most of us eat. Write a paragraph in your Science Log explaining why you think scientists should look for a gene to alter that crop. Also discuss any potential effects of the modified crop on the environment or human health.

1. In what way is DNA a code?
2. **Apply** An organism has five pairs of chromosomes. Answer the following questions.
   - **(a)** One of the organism's body cells divides. How many cells are formed? How many chromosomes does each new cell have?
   - **(b)** How many chromosomes are in each sperm cell?
3. **Thinking Critically** Explain why the body cells of all organisms that reproduce sexually have even numbers of chromosomes.
4. What is the main value of variation?
5. What form of reproduction favours variation? Explain why by referring to DNA.
6. **Thinking Critically** Is variation always an advantage? Explain.
7. **Thinking Critically** In what ways can transgenic organisms be used?
8. Biotechnology is very important in agriculture and medicine. What are some of the reasons the use of biotechnology is controversial? Explain using specific examples.

Wrap-up TOPICS 3-5

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

heritable	budding	pollen tube	dominant trait	genetic engineering
reproductive strategy	sexual reproduction	embryo	recessive trait	biotechnology
asexual reproduction	zygospore	cotyledon	mutation	transgenic
binary fission	bacterial conjugation	self-pollination	mutagen	aquaculture
spore	zygote	cross-pollination	DNA	
zoospore	pistil	genetics	chromosome	
meristem	stamen	continuous variation	gene	
clone	ovule	discrete variation	somatic cells	

Reviewing Key Terms

1. For each pair of terms below, explain what they have in common and how they differ. (3)
   (a) pistil and stamen
   (b) angiosperm and gymnosperm
   (c) seed and spore
2. What is the difference between a dominant and a recessive trait? (4)
3. Describe three methods of reproduction used by plants. (3)
4. What is a heritable trait? (3, 4)
5. What molecule controls cell function, and is it also the genetic material? (5)
6. What term is used to describe an animal whose genes have been altered using biotechnology? (5)

Understanding Key Concepts

7. Name three organisms that can reproduce asexually. How does reproduction differ in each case? (3)
8. What is produced immediately following the union of egg and sperm? What happens after that? (3)
9. **Apply** A beech tree has small green flowers. Explain why it is unlikely that beech flowers would be pollinated by insects. Suggest the most likely method of pollination. (3)


beech tree

10. What is the importance or significance of mutations? (4)
11. **Apply** State some of the advantages of internal over external fertilization in plants. (3)
12. Why are some human proteins produced by transgenic cows, sheep, or pigs rather than bacteria? (5)
13. It is estimated that every human carries between five and eight harmful genes. Why do you think that more people are not born with inherited diseases? (5)
14. **Thinking Critically** Why do you think that internal fertilization is associated with a higher success rate than external fertilization of eggs? What are some of the risks involved in fertilization? (3)