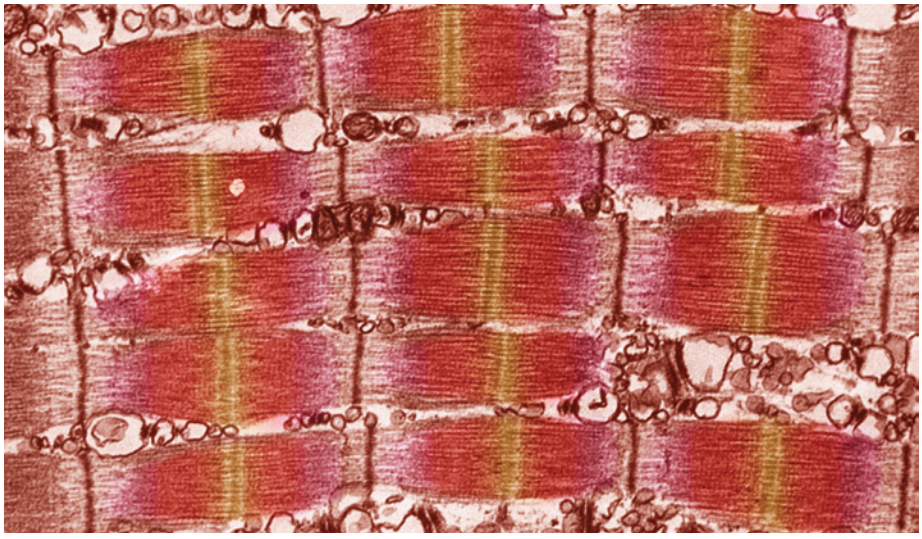
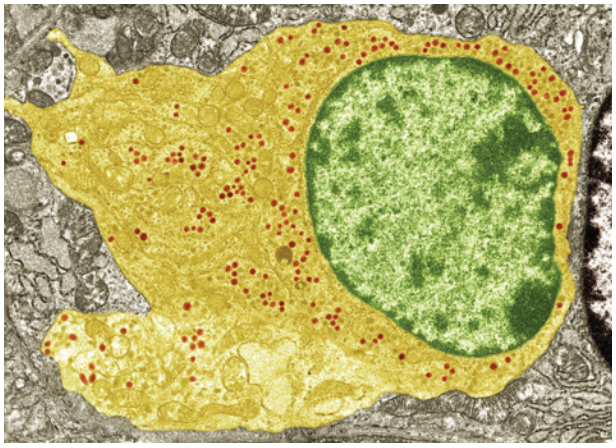
17 Cell Differentiation and Gene Expression

In most human cells, the nucleus contains a full set of 23 pairs of chromosomes, which carry 20,000–25,000 genes. These genes are identical from cell to cell. In Activity 16, "Protein Synthesis: Transcription and Translation," you learned that genes are transcribed to produce RNA, and that this RNA is in turn translated to produce proteins. If all cells in the same organism have the same genes, why don't they all make the same proteins?

Some proteins are made by almost every cell because they are needed for basic cell functions. Other proteins are made by only one type of cell or small groups of cells. Only white blood cells, for example, make antibodies, the proteins that help the body fight infections. Each of the more than 220 kinds of specialized cells in the human body makes a characteristic group of proteins.





Although the two human cells shown have the same genes in their nuclei, they are specialized to make different proteins. The skeletal muscle cells, top, are specialized for voluntary muscle movement, while the thyroid cell, left, makes large amounts of thyroid hormone.

In each cell, only some of the genes are active, or **expressed.** The activity of genes in a cell is called **gene expression.** In this activity, you will explore how some genes are turned on and off by molecules called transcription factors. These molecules control the transcription of DNA into RNA.

Challenge

How does the same set of genes direct the activities of 220 human cell types?

MATERIALS:

FOR EACH GROUP

- set of 14 Cellular Event Cards

FOR EACH PAIR OR STUDENTS

- 3 colored pencils (blue, brown, and orange)

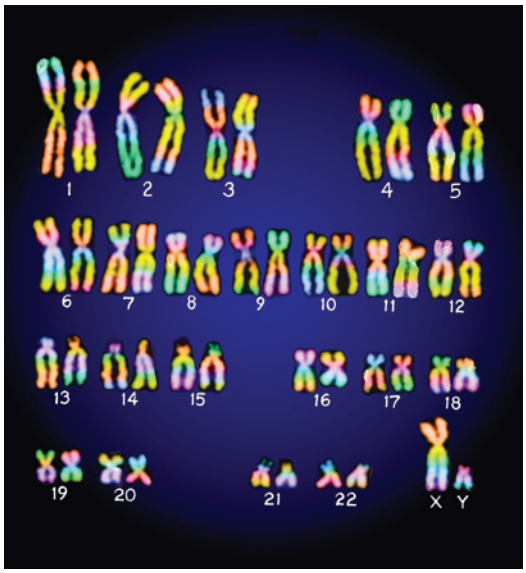
FOR EACH STUDENT

- model of human chromosome 2
- model of human chromosome 11
- 4 silver binder clips
- 7 red paper clips
- 7 green paper clips
- Student Sheet 17.1, "Chromosome Map"
- Student Sheet 2.3, "Genetics Case Study Comparison," from Activity 2
- 3 sticky notes

Procedure

Part A: Gene Expression in Differentiated Cells

1. You will look at a small number of genes on two human chromosomes: chromosome 2 and chromosome 11. Identify these chromosomes in the diagram below.



Human male karyotype

2. You will investigate the expression of only 11 of the approximately 25,000 human genes. Review the proteins these 11 genes produce and their functions in the two tables below.

Selected Genes on Human Chromosome 2	
PROTEIN PRODUCED BY THE GENE	FUNCTION
Actin, smooth muscle type	Most cells produce actin for cell movement and cell division, but muscle cells produce large amounts of specific types of actin for muscle contraction.
AGA enzyme	Breaks down fats and some toxic substances
Cellular respiration enzyme	Catalyzes reactions for aerobic respiration in the mitochondria
Lactase enzyme	Required for digestion of lactose, the sugar in milk
Protein synthesis initiator	Controls the beginning of protein synthesis
Ribosome protein S7	Needed by ribosomes, which are essential for protein synthesis

Selected Genes on Human Chromosome 11	
PROTEIN PRODUCED BY THE GENE	FUNCTION
Cell growth controller	Prevents cells from dividing unless more cells are needed, helps prevent certain cancers
DNA repair	Repairs damage to DNA and helps to prevent certain types of cancer
Fat and protein breakdown enzyme	Catalyzes one step in the breakdown of proteins and fats in the diet so they can be used for energy
Hemoglobin B	Carries oxygen to the cells throughout the body
Insulin	A hormone that regulates the metabolism of sugars and fats

3. Each member of your group will look at gene activity in one of four kinds of specialized cells shown below. With your group, decide what kind of cell each of you will investigate.

Cell Type
Beta cell in the pancreas
Red blood cell
Intestinal lining cell
Smooth muscle cell in the digestive system

4. Read the table below. It shows which of the 11 genes on chromosomes 2 and 11 are expressed in your cell.

Genes Expressed in Four Types of Human Cells

PROTEIN PRODUCED BY THE GENE	BETA CELL IN PANCREAS	DEVELOPING RED BLOOD CELL	INTESTINAL LINING CELL	SMOOTH MUSCLE CELL IN THE DIGESTIVE SYSTEM
Actin, smooth muscle type	–	–	–	+
AGA enzyme	–	–	–	–
Cell growth controller	+	+	+	+
Cellular respiration enzyme	+	+	+	+
DNA repair protein	+	+	+	+
Fat and protein breakdown enzyme	+	+	+	+
Hemoglobin B	–	+	–	–
Insulin	+	–	–	–
Lactase	–	–	+	–
Protein synthesis initiator	+	+	+	+
Ribosome protein S7	+	+	+	+

Key: + = active gene, – = repressed gene

5. Based on the information in the table above:

   a. On Student Sheet 17.1, "Chromosome Map," find the chromosomes for your cell. Draw a single, dark brown line in the position of each gene that is not expressed in your cell type. These genes are still present, but they are never expressed in your cell, and are permanently turned off, or **repressed.** Your teacher will help you with the first example.

   b. On Student Sheet 17.1, "Chromosome Map," draw a single, dark blue line in the position of any gene that is expressed *only* in your cell type. This is one of a number of genes that produce specialized proteins that help your cell perform its role in the human body.

   c. On Student Sheet 17.1, "Chromosome Map," draw a single, dark orange line in the position of any gene that is expressed in *all four* cell types. This is a gene that produces proteins that nearly all cells need if they are to function.

   d. Compare the chromosomes for your cell on Student Sheet 17.1, "Chromosome Map," with the others in your group. Copy the diagrams from their cells onto Student Sheet 17.1 to have a full set of diagrams.

6. Obtain a model of chromosomes 2 and 11. Place a silver binder clip over each gene that is permanently repressed in your cell type. This silver binder clip represents a specific **transcription factor,** a molecule that controls the transcription of DNA into RNA. This particular repressor permanently turns off genes that your cell does not need.

Part B: Differentiated Cells at Work

7. Prepare a table like the one below, in your science notebook.

Gene Expression

Cellular event	*Affected gene and result*

8. Shuffle the deck of Cellular Event Cards, and place it in the middle of your table. Put your models of chromosome 2 and chromosome 11 nearby.

9. Select one member of your group to start. That person will draw a card from the top of the deck and read it to the group.

10. Based on the information on the card, each member of the group determines which genes in their cells are activated to make proteins at this time, and which genes in their cells are repressed at this time. Follow directions on the card to place transcription factors that determine whether the genes are expressed, or temporarily repressed. These transcription factors include both activators (green paper clips) and repressors (red paper clips) that bind to portions of the DNA that regulate the gene. Place the paper clips on the appropriate gene on your model chromosomes.

    Key: Transcription activator = green paper clip
    Transcription repressor = red paper clip

11. For your cell, record the event, the affected gene, and the result in the table in your science notebook.

12. The next person, clockwise, in your group selects the next card from the top of the deck. Repeat Steps 10–11.

13. Continue selecting cards and determining which genes are affected until your teacher tells you to stop.

14. Compare your cell's chromosome 2 to those of the other members of your group. Discuss and record in your science notebook any similarities and differences you observe in the genes that are expressed and repressed.

15. Compare your cell's chromosome 11 to those of the other members of your group. Discuss and record in your science notebook any similarities and differences you observe in the genes that are expressed and repressed.

16. Discuss with your group
    a. the types of transcription factors that the paper clips represent.
    b. the types of changes in the cell or its environment that led to the need to turn the genes on and off.

Part C: Terminator Technology Case Study

17. Individually read the case study on the next pages. As you read, follow the literacy strategy, "Read, Think, and Take Note."

18. Share your thinking with your group. Place your sticky notes on the table in front of you. Look for connections between your sticky notes and the notes of others in your group.

    Hint: Were there common questions people asked? Were people unfamiliar with the same words? Did people react differently to statements in the reading?

19. Place your sticky notes in your science notebook. Below them, write a short summary of what your group discussed and any conclusions you came to.

20. Record the appropriate information from this case study on Student Sheet 2.3, "Genetics Case Study Comparison."

CASE STUDY

Terminator Technology

WITH GENETICALLY MODIFIED plants, one concern often raised is that they may spread engineered genes into plant populations that are not genetically modified. This can happen when genetically modified (GM) plants crossbreed with non-GM plants and produce hybrids, and may have unintended consequences in non-GM plant populations. For this reason, the United States Department of Agriculture and a private biotechnology company teamed up in the early 1990s to develop genetic use restriction technology, or GURT. GURT is a type of genetic modification that allows people to control gene expression in GM plants, thus earning it the nickname "terminator technology." By engineering GM plants that contain both a set of desired traits and GURT, scientists hope to develop plants that do not spread engineered genes to non-GM populations.

Two main types of GURT have been developed. The first type causes the GM plants to produce sterile seeds. It does this by activating and repressing a series of genes related to seed development. The advantage of this type of GURT is that the genetic modification cannot be passed on to other generations of plants, since the plant cannot reproduce. It is also financially advantageous for the company or group that owns the patent for the GM plant because it ensures that the seeds from one generation cannot be saved and grown again in the following years. Farmers would have to buy new seed each year.

The second type of GURT controls the phenotype of the GM plant. The genetically modified

GURT was developed to help prevent GM plants, such as the rice at left, from breeding with non-GM plants, such as the rice at right, when the GM rice is planted in fields.

plants would only express the GM gene if the plant were treated with a specific chemical. When the chemical is applied to the plants, the gene for the GM trait is activated. This approach allows seed growers and farmers to control when the GM genes are expressed. It also means that if the GM plants were to cross-breed with non-GM plants, the GM gene would not be expressed unless the chemical was reapplied.

As with any form of technology there are benefits and drawbacks. While scientists have identified genes that can be activated and repressed, field trials have shown that the control of gene expression in GURT plants has not been 100% effective. This means that the seeds will not always be sterile, or that the GM gene is expressed even though the chemical has not been applied. Scientists are also unsure of the long-term performance of terminator technology. They do not yet know what will happen several generations down the line if GURT plants crossbreed with non-GM plants.

Farmers, environmentalists, indigenous-peoples' groups, and some governments have objected to the application of terminator technology for a number of reasons. One is that the farmers who want such plants need to purchase seeds and the activating chemicals from the seed companies each year. Many farmers around the world save seed from one generation of plants to produce the next year's crops. While the terminator technology addresses the fear of gene spread, farmers might not be able to afford to pay for new seeds each year.

GURT would prevent gene spread, but would not allow farmers to save seeds from one year's crop to plant the next year's.

Because so many objections were raised, several countries, including India and Brazil, have passed laws prohibiting the planting of GURT seeds. In 2006, the United Nations Convention on Biological Diversity recommended halting all field-testing and commercial release of terminator technology, citing concerns about inadequate research on the unintended spread of the genes into non-GM populations of plants. As of mid-2010, seeds engineered to have terminator abilities were still not commercially available. However, research in the development, use, and safety of terminator technology continues. ■

Analysis

1. Compare the following in your group's four cell types:
   - **a.** Chromosomes
   - **b.** Genes
   - **c.** Expression of the genes to produce proteins
2. What kinds of genes were permanently inactivated in some cells? Why were these genes inactivated?
3. Explain why some proteins are made by nearly all cells, and give two examples.
4. What cellular mechanisms caused short-term changes in gene expression in the cell you investigated?
5. For your cell explain how gene expression related to the cell's ability to perform its function in the body.
6. How does terminator technology work?
7. **a.** What kinds of problems is GURT intended to solve?
   b. What are the pros and cons of GURT?

KEY VOCABULARY

chromosome
expressed (gene)
gene expression
repressed (gene)
transcription factor