Connect to the Big Idea

Have students look at the photograph and read the caption. Call on a volunteer to describe how the two tigers differ. (One has orange and black fur, and the other has white and brown fur.) Help students connect this observation with the Big Idea of Information and Heredity. Explain that genes carry the information needed by cells to produce proteins, and proteins determine traits such as fur color. Remind students that genes are contained within the nucleus. Add that proteins are made, or synthesized, in the cytoplasm. Then, have students anticipate the answer to the question, How does information flow from DNA to RNA to direct the synthesis of proteins?

Have students read over the Chapter Mystery. Remind them that DNA is the universal code for life and that it helps determine an organism’s characteristics. Stress the universality of the code to help students understand how a mouse gene inserted into a fruit fly could lead to a fruit fly with many eyes. Then, discuss with the class why scientists would want to transplant a mouse gene into a fruit fly. Challenge students to predict what scientists might learn by doing this.

Have students preview the chapter vocabulary using the Flash Cards.

Understanding by Design

Chapter 13 provides knowledge that is fundamental to the Unit 4 Enduring Understanding: DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics. As shown in the graphic organizer at the right, the chapter explains how information encoded in DNA flows from the nucleus to the cytoplasm, where it directs protein synthesis.

PERFORMANCE GOALS

Students will analyze data, interpret diagrams, and use analogies to develop an understanding of how the information in DNA is used to direct protein synthesis and influence an organism’s characteristics. At the end of the chapter, they will write a story about gene regulation and develop a research proposal about how RNA interference affects gene expression.
MOUSE-EYED FLY

It was definitely not a science fiction movie. The animal in the laboratory was real. Besides having two forward-looking eyes, it also had eyes on its knees and eyes on its hind legs. It even had eyes in the back of its head! Yet as strange as it looked, this animal was not a monster. It was simply a fruit fly with eyes in very strange places. These eyes looked like the fly's normal compound eyes, but a mouse gene transplanted into the fly's DNA had produced them. How could a mouse gene produce extra eyes in a fly?

As you read this chapter, look for clues to explain how a gene that normally controls the growth of eyes in mice could possibly cause a fly to grow extra eyes in unusual places. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the solution to the mouse-eyed fly is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.
The Role of RNA

When Watson and Crick solved the double-helix structure of DNA, they understood right away how DNA could be copied. All a cell had to do was to separate the two strands and then use base pairing to make a new complementary strand for each. But the structure of DNA by itself did not explain how a gene actually works. That question required a great deal more research. The answer came from the discovery that another nucleic acid—ribonucleic acid, or RNA—was involved in putting the genetic code into action.

RNA, like DNA, is a nucleic acid that consists of a long chain of nucleotides. In a general way, genes contain coded DNA instructions that tell cells how to build proteins. The first step in decoding these genetic instructions is to copy part of the base sequence from DNA into RNA. RNA then uses these instructions to direct the production of proteins, which help to determine an organism's characteristics.

Comparing RNA and DNA

Remember that each nucleotide in DNA is made up of a 5-carbon sugar, a phosphate group, and a nitrogenous base. This is true for RNA as well. But there are three important differences between RNA and DNA: (1) the sugar in RNA is ribose instead of deoxyribose, (2) RNA is generally single-stranded and not double-stranded, and (3) RNA contains uracil in place of thymine. These chemical differences make it easy for enzymes in the cell to tell DNA and RNA apart.

You can compare the different roles played by DNA and RNA molecules in directing the production of proteins to the two types of plans builders use. A master plan has all the information needed to construct a building. But builders never bring a valuable master plan to the job site, where it might be damaged or lost. Instead, as Figure 13–1 shows, they work from blueprints, inexpensive, disposable copies of the master plan.

THINK ABOUT IT

We know that DNA is the genetic material, and we know that the sequence of nucleotide bases in its strands must carry some sort of code. For that code to work, the cell must be able to understand it. What exactly do those bases code for? Where is the cell's decoding system?
Functions of RNA

You can think of an RNA molecule as a disposable copy of a segment of DNA, a working facsimile of a single gene. RNA has many functions, but most RNA molecules are involved in just one job—protein synthesis. RNA controls the assembly of amino acids into proteins. Like workers in a factory, each type of RNA molecule specializes in a different aspect of this job. Figure 13–2 shows the three main types of RNA: messenger RNA, ribosomal RNA, and transfer RNA.

- **Messenger RNA**  Most genes contain instructions for assembling amino acids into proteins. The RNA molecules that carry copies of these instructions are known as messenger RNA (mRNA). They carry information from DNA to other parts of the cell.

- **Ribosomal RNA**  Proteins are assembled on ribosomes, small organelles composed of two subunits. These subunits are made up of several ribosomal RNA (rRNA) molecules and as many as 80 different proteins.

- **Transfer RNA**  When a protein is built, a third type of RNA molecule transfers each amino acid to the ribosome as it is specified by the coded messages in mRNA. These molecules are known as transfer RNA (tRNA).

### Biology In-Depth

**SNURPS AND SPLICEOSOMES**

In addition to the three types of RNA described above, a fourth type of RNA is also at work in cells. This type of RNA, called small nuclear RNA (snRNA) is involved in the important role of editing mRNA before it leaves the nucleus. snRNA is only found in the nucleus in combination with certain proteins, called small ribonucleoproteins, or snRNP (snurps). Snurp-snRNA complexes are given the name spliceosomes. They have a role that is somewhat analogous to ribosomes in the cytoplasm. As ribosomes join together amino acids to form chains of polypeptides, spliceosomes splice together exons to form edited strands of mRNA.

### Teach

**VISUAL ANALOGY**

**MASTER PLANS AND BLUEPRINTS**

*Figure 13–1* The different roles of DNA and RNA molecules in directing protein synthesis can be compared to the two types of plans used by builders: master plans and blueprints.

- **Master Plans**
  - **DNA**
    - *Carries instructions for polypeptide synthesis in the cytoplasm.*
  - **rRNA**
    - *Forms an important part of both subunits of the ribosome.*
  - **Amino acid**
    - *Carries amino acids to the ribosome and matches them to the coded mRNA message.*

- **Blueprints**
  - **mRNA**
    - *Carries instructions for polypeptide synthesis from nucleus to ribosomes in the cytoplasm.*
  - **tRNA**
    - *Carries氨基酸 acids to the ribosome.*

### Address Misconceptions

**Importance of RNA**  Students often fail to appreciate the importance of other genetic material besides DNA. Make sure they are aware that DNA is the inherited genetic material but RNA is the genetic material that carries out the instructions encoded in DNA. Without RNA, the instructions in DNA could not be used by cells.
How does the cell make RNA?

Cells invest large amounts of raw material and energy into making RNA molecules. Understanding how cells do this is essential to understanding how genes work.

Transcription

Most of the work of making RNA takes place during transcription. In transcription, segments of DNA serve as templates to produce complementary RNA molecules. The base sequences of the transcribed RNA complement the base sequences of the template DNA.

In prokaryotes, RNA synthesis and protein synthesis take place in the cytoplasm. In eukaryotes, RNA is produced in the cell’s nucleus and then moves to the cytoplasm to play a role in the production of protein. Our focus here is on transcription in eukaryotic cells.

Transcription requires an enzyme, known as RNA polymerase, that is similar to DNA polymerase. RNA polymerase binds to DNA during transcription and separates the DNA strands. It then uses one strand of DNA as a template from which to assemble nucleotides into a complementary strand of RNA, as shown in Figure 13–3.

The ability to copy a single DNA sequence into RNA makes it possible for a single gene to produce hundreds or even thousands of RNA molecules.

Figure 13–3: Transcribing DNA into RNA

During transcription, the enzyme RNA polymerase uses one strand of DNA as a template to assemble complementary nucleotides into a strand of RNA.

LESSON 13.1

Teach continued

Use Visuals

Make color copies of Figure 13–3, and give a copy to each student. As you discuss the process of transcription with the class, have students record their class notes on the diagram. Discuss the role of RNA polymerase in “unzipping” the two strands of DNA. Explain that RNA polymerase binds to DNA only at sites called promoters, which have specific base sequences. The promoters “tell” the enzyme where to start transcribing DNA. Point out how bases in the DNA strand are bound to complementary bases that will form the RNA strand. Ask students to label the bases in some of the base pairs with the letters A, C, G, T, or U. Remind them that uracil in RNA is complementary to adenine in DNA. State that transcription is just the first stage of RNA synthesis.

Ask: What is the second stage of RNA synthesis? (RNA editing)

DIFFERENTIATED INSTRUCTION

Less Proficient Readers

Some students may be confused by the multiple steps of RNA synthesis. Suggest that they make a Flowchart showing the sequence of steps in the process. Their flowchart should include the steps of both DNA transcription and RNA editing. Encourage them to add simple sketches to the steps of their flowchart.


Focus on ELL: Extend Language

BEGINNING AND INTERMEDIATE SPEAKERS

Have students divide a sheet of paper into four equal parts. In the upper left square, have them write the word transcription. In the upper right square, ask them to sketch the transcription process, using Figure 13–3 as a guide. In the lower left square, ask them to write a definition of transcription, in their own words, based on the diagram. Then, tell them to write an original sentence about transcription in the lower right square. Give students a chance to share their work with other students.

Check for Understanding

VISUAL REPRESENTATION

Ask students to make a Concept Map about RNA, with the term RNA in the center of the map. The concept map should include information about the general structure of RNA and the specific functions of the three main types of RNA.

Study Wkbks A/B, Appendix S21, Concept Map. Transparencies, GO4.

ADJUST INSTRUCTION

If students struggle to complete their concept maps, have them exchange their maps with a partner. Have partners discuss the concepts and relationships represented in the maps and revise them as necessary.
RNA polymerase, regions of DNA that have specific base sequences. Promoters are signals in the DNA molecule that show RNA polymerase exactly where to begin making RNA. Similar signals in DNA cause transcription to stop when a new RNA molecule is completed.

RNA Editing  Like a writer’s first draft, RNA molecules sometimes require a bit of editing before they are ready to be read. These pre-mRNA molecules have bits and pieces cut out of them before they can go into action. The portions that are cut out and discarded are called introns. In eukaryotes, introns are taken out of pre-mRNA molecules while they are still in the nucleus. The remaining pieces, known as exons, are then spliced back together to form the final mRNA, as shown in Figure 13–4.

Why do cells use energy to make a large RNA molecule and then throw parts of that molecule away? That’s a good question, and biologists still don’t have a complete answer. Some pre-mRNA molecules may be cut and spliced in different ways in different tissues, making it possible for a single gene to produce several different forms of RNA. Introns and exons may also play a role in evolution, making it possible for very small changes in DNA sequences to have dramatic effects on how genes affect cellular function.

13.1 Assessment

Review Key Concepts

1. a. Review  Describe three main differences between RNA and DNA.
b. Explain  List the three main types of RNA, and explain what they do.
c. Infer  Why is it important for a single gene to be able to produce hundreds or thousands of the same RNA molecules?
2. a. Review  Describe what happens during transcription.
b. Predict  What do you think would happen if introns were not removed from pre-mRNA?

Creative Writing

3. An RNA molecule is looking for a job in a protein synthesis factory. It asks you to write its résumé. This RNA molecule is not yet specialized and could, with some structural changes, function as mRNA, rRNA, or tRNA. Write a résumé for this molecule that reflects the capabilities of each type of RNA.

Assessment Answers

1a. RNA contains the sugar ribose instead of deoxyribose, is generally single-stranded rather than double-stranded, and contains uracil instead of thymine.

1b. Messenger RNA carries instructions for polypeptide synthesis from DNA in the nucleus to ribosomes in the cytoplasm. Ribosomal RNA forms an important part of both subunits of a ribosome, where proteins are assembled. Transfer RNA carries amino acids to a ribosome and matches them to the coded mRNA message.

1c. Sample answer: Proteins must be continuously synthesized in the cell, so the instructions coded in genes must be used over and over again. Therefore, a single gene must be able to produce hundreds or thousands of the same RNA molecules for protein synthesis.

2a. During transcription, the enzyme RNA polymerase binds to DNA and separates the DNA strands. It then uses one strand of DNA as a template to assemble nucleotides into a complementary strand of RNA.

2b. Sample answer: If introns were not removed, the instructions carried by mRNA for assembling amino acids into a protein might be incorrect, and the resulting protein might not function properly.

3. Answers will vary but should show that students understand the different functions of mRNA, rRNA, and tRNA in protein synthesis.
Getting Started

Objectives
13.2.1 Identify the genetic code and explain how it is read.
13.2.2 Summarize the process of translation.
13.2.3 Describe the “central dogma” of molecular biology.

Student Resources
Study Workbooks A and B, 13.2 Worksheets
Spanish Study Workbook, 13.2 Worksheets

Build Background
Introduce the genetic code by giving the class an encoded message to translate. On the board, write:

9 3-1-14 18-5-1-4 20-8-9-19 3-15-4-5

Tell students that each number represents a letter (a = 1, b = 2, c = 3, and so on). After students have deciphered the message (I can read this code), explain that RNA also contains a code.

Answers
FIGURE 13–5 AUG, AAC, and UCU

THINK ABOUT IT
How would you build a system to read the messages that are coded in genes and transcribed into RNA? Would you read the bases one at a time, as if the code were a language with just four words—one word per base? Perhaps you would read them as we do in English, as individual letters that can be combined to spell longer words.

The Genetic Code
What is the genetic code, and how is it read?

The first step in decoding genetic messages is to transcribe a nucleotide base sequence from DNA to RNA. This transcribed information contains a code for making proteins. You learned in Chapter 2 that proteins are made by joining amino acids together into long chains, called polypeptides. As many as 20 different amino acids are commonly found in polypeptides.

The specific amino acids in a polypeptide, and the order in which they are joined, determine the properties of different proteins. The sequence of amino acids influences the shape of the protein, which in turn determines its function. How is the order of bases in DNA and RNA molecules translated into a particular order of amino acids in a polypeptide?

As you know from Lesson 13.1, RNA contains four different bases: adenine, cytosine, guanine, and uracil. In effect, these bases form a “language” with just four “letters”: A, C, G, and U. We call this language the genetic code. How can a code with just four letters carry instructions for 20 different amino acids?

The genetic code is read three “letters” at a time, so that each “word” is three bases long and corresponds to a single amino acid. Each three-letter “word” in mRNA is known as a codon. As shown in Figure 13–5, a codon consists of three consecutive bases that specify a single amino acid to be added to the polypeptide chain.

FIGURE 13–5 Codons A codon is a group of three nucleotide bases in messenger RNA that specifies a particular amino acid.

Observe What are the three-letter groups of the codons shown here?
**How to Read Codons**  Because there are four different bases in RNA, there are 64 possible three-base codons (4 x 4 x 4 = 64) in the genetic code. **Figure 13–6** shows these possible combinations. Most amino acids can be specified by more than one codon. For example, six different codons—UUA, UUG, CUU, CUC, CUA, and CUG—specify leucine. But only one codon—UGG—specifies the amino acid tryptophan.

Decoding codons is a task made simple by use of a genetic code table. Just start at the middle of the circle with the first letter of the codon, and move outward. Next, move out to the second ring to find the second letter of the codon. Find the third and final letter among the smallest set of letters in the third ring. Then read the amino acid in that sector.

**Start and Stop Codons**  Any message, whether in a written language or the genetic code, needs punctuation marks. In English, punctuation tells us where to pause, when to sound excited, and where to start and stop a sentence. The genetic code has punctuation marks, too. The methionine codon AUG, for example, also serves as the initiation, or “start,” codon for protein synthesis. Following the start codon, mRNA is read, three bases at a time, until it reaches one of three different “stop” codons, which end translation. At that point, the polypeptide is complete.

![Genetic Code Table](https://example.com/genetic-code-table.png)

**FIGURE 13–6 Reading Codons**  This circular table shows the amino acid to which each of the 64 codons corresponds. To read a codon, start at the middle of the circle and move outward.

1. **To decode the codon CAC, find the first letter in the set of bases at the center of the circle.**
2. **Find the second letter of the codon A, in the “C” quarter of the next ring.**
3. **Find the third letter, C, in the next ring, in the “C.A” grouping.**
4. **Read the name of the amino acid in that sector—in this case histidine.**

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**Quick Lab**

**How Does a Cell Interpret Codons?**

1. A certain gene has the following base sequence: GACAAGTCCACAAAC
   - Write this sequence on a separate sheet of paper.
2. From left to right, write the sequence of the mRNA molecule transcribed from this gene.
3. Using **Figure 13–6**, read the mRNA codons from left to right. Then write the amino acid sequence of the polypeptide.

**Analyze and Conclude**

1. **Apply Concepts**  Why did steps 3 and 4 produce different polypeptides?
2. **Infer** Do cells usually decode nucleotides in one direction only or in either direction?

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**Teach**

**Use Visuals**

Explain how to use **Figure 13–6** to identify the amino acid that corresponds to a particular codon. Then, write several codons on the board, and call on students to name the amino acid each one represents. Reverse the process by writing the names of several amino acids and having students identify the codons that represent them. Finally, guide students in drawing conclusions about the genetic code.

**Ask**  How many amino acids does each codon represent? (one)

**Ask**  How many codons can code for a single amino acid? (from one to six)

**Ask**  What else may codons represent? (stop and start)

Point out that the methionine codon, AUG, also means “start.” Call on a volunteer to explain how the stop and start codons are interpreted during protein synthesis.

**Differentiated Instruction**

**Special Needs**  Some students may find it difficult to understand and use Figure 13–6. Pair these students with students who have a good understanding of the material, and have partners work together to make index cards to represent the genetic code. Let students use the index cards instead of Figure 13–6 when they answer questions about the genetic code.

**Struggling Students**  Help students access genetic code content by presenting and discussing a visual representation of the code that differs from the diagram in Figure 13–6. For example, show students a rectangular matrix of the code. Have them take notes on the discussion and then use the notes to explain the alternative code representation to another student.
**TEACH**

**LESSON 13.2**

**Teach continued**

**VISUAL SUMMARY**

As students examine Figure 13–7, ask volunteers to briefly describe transcription and the structure and function of ribosomes. Describe how a ribosome moves along an mRNA strand, like a bead sliding along a string, translating the strand of mRNA as it moves.

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Instruct students to complete an ELL Frayer Model for the term translation. Tell them to define the term and to sketch the translation process, using Figure 13–7 as a guide. For their example, they can write a sequence of codons and their matching anticodons and amino acids. Then, have students write a definition of the term translation into their own language, if possible.

**Study Wkbks A/B,** Appendix S26, ELL Frayer Model. Transparencies, GO10.

**LPR** Less Proficient Readers Use Cloze Prompts to help students focus on the most important points as they read about translation in the text. Copy important sentences from the passage, leaving a term out of each one. Then, have students fill in the blanks as they read.

**Study Wkbks A/B,** Appendix S2, Cloze Prompts.

In InterActive Art: Transcription and Translation, students can explore translation with an interactive version of Figure 13–7. To help students understand how the products of translation—proteins—relate to phenotype, have them view Tutor Tube: Why Are Proteins So Important?

**Address Misconceptions**

**Products of Translation** Students frequently misidentify the products of translation as mRNA or amino acids. Stress that mRNA is the product of transcription, not translation, and that amino acids are already available in the cell—they just need to be joined together in the correct sequence to make a polypeptide.

**Translation**

What role does the ribosome play in assembling proteins?

The sequence of nucleotide bases in an mRNA molecule is a set of instructions that gives the order in which amino acids should be joined to produce a polypeptide. Once the polypeptide is complete, it then folds into its final shape or joins with other polypeptides to become a functional protein.

If you’ve ever tried to assemble a complex toy, you know that instructions alone don’t do the job. You need to read them and then put the parts together. In the cell, a tiny factory—the ribosome—carries out both these tasks. **Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains.** The decoding of an mRNA message into a protein is a process known as translation.

**Steps in Translation** Transcription isn’t part of the translation process, but it is critical to it. Transcribed mRNA directs that process. In a eukaryotic cell, transcription goes on in the cell’s nucleus; translation is carried out by ribosomes after the transcribed mRNA enters the cell’s cytoplasm. Refer to Figure 13–7 as you read about translation.

Translation begins when a ribosome attaches to an mRNA molecule in the cytoplasm. As each codon passes through the ribosome, tRNAs bring the proper amino acids into the ribosome. One at a time, the ribosome then attaches these amino acids to the growing chain.

**Check for Understanding**

**ORAL QUESTIONING**

Call on students to answer the following questions about the genetic code and translation:

- How is a codon similar to a word? How is it different from a word?
- What are general characteristics of the genetic code?
- Describe the process of translation.

**ADJUST INSTRUCTION**

Discuss any questions that students answer incorrectly or incompletely. Then, ask if anyone still has questions. Call on volunteers to address any additional questions that students raise.
Each tRNA molecule carries just one kind of amino acid. In addition, each tRNA molecule has three unpaired bases, collectively called the **anticodon**. Each tRNA anticodon is complementary to one mRNA codon.

In the case of the tRNA molecule for methionine, the anticodon is UAC, which pairs with the methionine codon, AUG. The ribosome has a second binding site for a tRNA molecule for the next codon. If that next codon is UUC, a tRNA molecule with an AAG anticodon fits against the mRNA molecule held in the ribosome. That second tRNA molecule brings the amino acid phenylalanine into the ribosome.

Like an assembly-line worker who attaches one part to another, the ribosome helps form a peptide bond between the first and second amino acids—methionine and phenylalanine. At the same time, the bond holding the first tRNA molecule to its amino acid is broken. That tRNA then moves into a third binding site, from which it exits the ribosome. The ribosome then moves to the third codon, where tRNA brings it the amino acid specified by the third codon.

The polypeptide chain continues to grow until the ribosome reaches a "stop" codon on the mRNA molecule. When the ribosome reaches a stop codon, it releases both the newly formed polypeptide and the mRNA molecule, completing the process of translation.

**FIGURE 13–8 Molecular Model of a Ribosome** This model shows ribosomal RNA and associated proteins as colored ribbons. The large subunit is blue, green, and purple. The small subunit is shown in yellow and orange. The three solid elements in the center are tRNA molecules.

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**Quick Facts**

**ANTICODONS AND TRANSFER RNA**

Individual transfer RNA anticodons sometimes recognize more than one mRNA codon. These are generally codons that differ only in their third base. This is because the binding attraction is relatively weak between the third base of a tRNA anticodon and the third base of an mRNA codon. This can result in mistakes in translation. For example, the tRNA anticodon GCC might bind to CGA instead of CGG. However, in this case, the same amino acid would still be inserted in the polypeptide, because CGA and CGG both code for arginine. In fact, because there are multiple codons for each amino acid, most of which differ only in their third base, such mistakes in translation often have no effect on the polypeptide.

**Use Models**

Ask groups of students to use materials of their choice to make a three-dimensional model representing the process of translation. Suitable materials might include modeling clay, craft sticks, various beads, dried pasta in different shapes and colors, chenille stems, string, or yarn. Remind students to include in their model a strand of mRNA, a ribosome, a few molecules of tRNA, and a short polypeptide. Give groups a chance to share their models with the class.

**DIFFERENTIATED INSTRUCTION**

**L1 Special Needs** Support special needs students by modeling the processes of transcription and translation as a class. Sit at your desk, and tell the class that you represent DNA in the nucleus of a cell and the classroom represents the cytoplasm of the cell. Assign a student to represent a ribosome, and place a handful of multicolored paper clip “amino acids” next to him or her. On a piece of paper, write the message, “Clip a yellow and white paper clip together.” Ask another student to come to your desk, copy the message on a scrap of paper, and carry the copy to the “ribosome.” After the “ribosome” student follows the instructions in the note, explain how the exercise models the way information encoded in DNA is carried from the nucleus to the cytoplasm and acted upon at a ribosome. Ask students if they know what the messenger student represents. (mRNA)

**LPR Less Proficient Readers** Use a more familiar meaning of the term translation as an analogy to help students understand the process of mRNA translation. On the board, write specific examples showing how words of one language can be translated into another language (e.g., madre to street to rue). Ask English language learners or students who have studied a foreign language to translate a few words, as well. Then, explain that translation in genetics is a similar process. The codons of mRNA are like words of one language, and they are translated into amino acids, which are like words of another language.

**Answers**

**IN YOUR NOTEBOOK** The ribosome positions the start codon of mRNA to attract its anticodon, which is part of a tRNA molecule. The ribosome also binds the next codon and attracts its anticodon. Then, the ribosome joins the first two amino acids and breaks the bond between the first amino acid and its tRNA. The ribosome moves along the mRNA strand, repeating this process until the ribosome reaches a stop codon. Then, it releases the newly formed polypeptide and the mRNA strand.
The central dogma of molecular biology was first postulated by Francis Crick in 1958. Over most of the next 50 years, it was the cornerstone of the field, focusing research on DNA segments that code for proteins. However, research shows that the central dogma is too simple and may be pointing researchers in the wrong direction. It now seems that RNA may play at least as important a role in genetics and evolution as DNA. For example, researchers have found that a single RNA molecule is probably responsible for many of the differences between human and chimpanzee brains. Other researchers, studying the human genome, have shown that so-called junk DNA that doesn’t code for proteins may actually be transcribed into RNA and play important roles in cells, although most of these roles are still unknown.
Assessment Answers

1a. The genetic code is read one codon, or three bases at a time; each codon, except the stop codon, codes for an amino acid.

1b. Codons are three-letter “words” in mRNA that specify amino acids. Anticodons are three unpaired bases in tRNA, complementary to mRNA codons.

1c. Tryptophan, lysine, cysteine

2a. During translation, a ribosome uses the sequence of codons in mRNA to assemble amino acids into a polypeptide chain. The correct amino acids are brought to the ribosome by tRNA.

2b. Check that students’ responses identify differences between protein synthesis and DNA replication.

3a. In all organisms the code is read three bases at a time and in the same direction. In most organisms the same amino acids are assigned to particular codons.

3b. It refers to the way in which DNA, RNA, and proteins are involved in putting genetic information into action in living cells.

3c. Proteins build or operate components of cells, so they play a key role in producing an organism’s characteristics. For example, enzymes catalyze and regulate chemical reactions in cells, and other proteins regulate growth patterns or embryonic development.

4. Questions should pertain to a single component or step in translation, and one of the questions should be restated as a testable hypothesis. Sample answer: Question: What happens to mRNA after it has been translated by a ribosome? Hypothesis: After mRNA has been translated, it is released from the ribosome.
What are mutations? Now and then cells make mistakes in copying their own DNA, inserting the wrong base or even skipping a base as a strand is put together. These variations are called mutations, from the Latin word *mutare*, meaning “to change.” Mutations are heritable changes in genetic information. Mutations come in many different forms. The sequence of bases in DNA are like the letters of a coded message, as we’ve just seen. But what would happen if a few of those letters changed accidentally, altering the message? Could the cell still understand its meaning? Think about what might happen if someone changed at random a few lines of code in a computer program that you rely on. Knowing what you already do about the genetic code, what effects would you predict such changes to have on genes and the polypeptides for which they code?

Types of Mutations

**What are mutations?**

Now and then cells make mistakes in copying their own DNA, inserting the wrong base or even skipping a base as a strand is put together. These variations are called *mutations*, from the Latin word *mutare*, meaning “to change.” Mutations are heritable changes in genetic information.

Mutations come in many different forms. Figure 13–10 shows two of the countless examples. But all mutations fall into two basic categories: Those that produce changes in a single gene are known as gene mutations. Those that produce changes in whole chromosomes are known as chromosomal mutations.

**Key Questions**

- **What are mutations?**
- **How do mutations affect genes?**

**Vocabulary**

- mutation
- point mutation
- frameshift mutation
- mutagen
- polyploidy

**Taking Notes**

**Preview Visuals** Before you read, look at Figures 13–11 and 13–12. As you read, note the changes produced by various gene and chromosomal mutations.

**THINK ABOUT IT**

The sequence of bases in DNA are like the letters of a coded message, as we’ve just seen. But what would happen if a few of those letters changed accidentally, altering the message? Could the cell still understand its meaning? Think about what might happen if someone changed at random a few lines of code in a computer program that you rely on. Knowing what you already do about the genetic code, what effects would you predict such changes to have on genes and the polypeptides for which they code?
You read about the different forms of point mutations. Different types of gene mutations include substitutions, insertions, and deletions. They generally occur during replication. If a gene in one cell is altered, the alteration can be passed on to every cell that develops from the original one. Refer to Figure 13–11 as you read about the different forms of point mutations.

**Substitutions** In a substitution, one base is changed to a different base. Substitutions usually affect no more than a single amino acid, and sometimes they have no effect at all. For example, if a mutation changed one codon of mRNA from CCC to CCA, the codon would still specify the amino acid proline. But a change in the first base of the codon—changing CCC to ACC—would replace proline with the amino acid threonine.

**Insertions and Deletions** Insertions and deletions are point mutations in which one base is inserted or removed from the DNA sequence. The effects of these changes can be dramatic. Remember that the genetic code is read three bases at a time. If a nucleotide is added or deleted, the bases are still read in groups of three, but now those groupings shift in every codon that follows the mutation. Insertions and deletions are also called frameshift mutations because they shift the “reading frame” of the genetic message. By shifting the reading frame, frameshift mutations can change every amino acid that follows the point of the mutation. They can alter a protein so much that it is unable to perform its normal functions.

**Quick Facts**

**Timing and Frequency of Mutations**

Mutations may occur at different times in the life cycle of an individual. Mutations that occur in gametes or just after fertilization affect all the cells of the organism. Mutations that occur during the embryonic stage, when cells and tissues are differentiating, cause mosaicism, in which only some cells of the organism have the mutation. Mutations that occur after an organism is fully formed affect only the cells in which they occur and their daughter cells. If these mutations occur in sex cells, they may be inherited by the organism’s offspring. On the contrary, if mutations occur in somatic (body) cells, the mutations will leave the gene pool when the organism dies. At the population level, some mutations are fairly common. They are called polymorphisms if they have allele frequencies greater than 1 percent. Polymorphisms contribute to normal human genetic variation.
**LESSON 13.3**

### Expand Vocabulary

On the board, write the verbs delete, duplicate, and invert. Call on students to define each verb. (Sample answers: Delete means “to erase,” duplicate means “to copy,” and invert means “to reverse.”) Have students look at the deletion, duplication, and inversion mutation examples shown in Figure 13–12. Call on volunteers to explain how the meanings of the verbs relate to the manner in which the mutations occur. Then, write the term translocation on the board, and divide it into its parts. Ask students if they know what the parts mean. (Trans- means “across,” and location means “place.”) Call on a volunteer to explain how the meaning of the term relates to what happens when a translocation mutation occurs.

### Differentiated Instruction

**Special Needs** Have students model chromosomal mutations with strips of paper representing segments of chromosomes. Give them six strips of paper of the same length. On five of the strips, ask them to write the sequence of letters A B C D E F. Tell them to glue one of these strips across the top of a sheet of paper. Then, have them cut the remaining labeled strips into sections and rearrange them to illustrate each of the chromosomal mutations shown in Figure 13–12. Tell them to use the blank strip to make any extra parts they need for the mutations. Have students glue the rearranged strips below the original strip and label the type of mutation each rearrangement represents.

### Models

**Chromosomal Mutations**  Chromosomal mutations involve changes in the number or structure of chromosomes. These mutations can change the location of genes on chromosomes and can even change the number of copies of some genes. Figure 13–12 shows four types of chromosomal mutations: deletion, duplication, inversion, and translocation. Deletion involves the loss of all or part of a chromosome; duplication produces an extra copy of all or part of a chromosome; and inversion reverses the direction of parts of a chromosome. Translocation occurs when part of one chromosome breaks off and attaches to another.

### Effects of Mutations

**How do mutations affect genes?** Genetic material can be altered by natural events or by artificial means. The resulting mutations may or may not affect an organism. And some mutations that affect individual organisms can also affect a species or even an entire ecosystem.

Many mutations are produced by errors in genetic processes. For example, some point mutations are caused by errors during DNA replication. The cellular machinery that replicates DNA inserts an incorrect base roughly once in every 10 million bases. But small changes in genes can gradually accumulate over time.

### Quick Lab

**Modeling Mutations** Small mutations in DNA can cause huge changes in the proteins that are synthesized. Similarly, small changes in a word can dramatically alter its meaning. Look at the following sequence of words:

- milk
- mile
- wile
- wise
- wisp
- wasp

Notice that each word differs from the previous word by just one letter and that none of the words is meaningless. Think of these changes as “point mutations” that affect word meaning.

### ANALYZE AND CONCLUDE

1. **Sample answer:** gene → gone → tone
2. **Answers will vary but should show that students understand that a frameshift mutation occurs when a base is inserted or deleted, which shifts the “reading frame.” For example, they could write a sentence and then delete or insert a single letter so that the reading frame shifts and the letters no longer spell out recognizable words.
3. **Sample answer:** Changing words to works models a substitution mutation.

### Answers

**FIGURE 13–12** An inversion mutation reverses the direction of part of one chromosome. A translocation mutation attaches part of one chromosome to another chromosome.
Stressful environmental conditions may cause some bacteria to increase mutation rates. This can actually be helpful to the organism, since mutations may sometimes give such bacteria new traits, such as the ability to consume a new food source or to resist a poison in the environment.

**Mutagens** Some mutations arise from mutagens, chemical or physical agents in the environment. Chemical mutagens include certain pesticides, a few natural plant alkaloids, tobacco smoke, and environmental pollutants. Physical mutagens include some forms of electromagnetic radiation, such as X-rays and ultraviolet light. If these agents interact with DNA, they can produce mutations at high rates. Cells can sometimes repair the damage; but when they cannot, the DNA base sequence changes permanently. Some compounds interfere with base-pairing, increasing the error rate of DNA replication. Others weaken the DNA strand, causing breaks and inversions that produce chromosomal mutations.

**Harmful and Helpful Mutations** As you’ve already seen, some mutations don’t even change the amino acid specified by a codon, while others may alter a complete protein or even an entire chromosome. The effects of mutations on genes vary widely. Some have little or no effect; and some produce beneficial variations. Some negatively disrupt gene function. Many if not most mutations are neutral; they have little or no effect on the expression of genes or the function of the proteins for which they code. Whether a mutation is negative or beneficial depends on how its DNA changes relative to the organism’s situation. Mutations are often thought of as negative, since they can disrupt the normal function of genes. However, without mutations, organisms could not evolve, because mutations are the source of genetic variability in a species.

**Harmful Effects** Some of the most harmful mutations are those that dramatically change protein structure or gene activity. The defective proteins produced by these mutations can disrupt normal biological activities, and result in genetic disorders. Some cancers, for example, are the product of mutations that cause the uncontrolled growth of cells. Sickle cell disease is a disorder associated with changes in the shape of red blood cells. You can see its effects in Figure 13–13. It is caused by a point mutation in one of the polypeptides found in hemoglobin, the blood’s principal oxygen-carrying protein. Among the symptoms of the disease are anemia, severe pain, frequent infections, and stunted growth.

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**Check for Understanding**

**ANALOGY PROMPT**

Ask students to complete the following analogy prompt:

A mutation is like ________ because ___________________. (Sample answer: A mutation is like a typo because both are mistakes in “words” that may or may not change how messages are read.)

**ADJUST INSTRUCTION**

Call on several students to read their analogies to the class. Discuss the merits of each analogy.

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**Connect to Health**

Elaborate on sickle cell disease to illustrate how the effects of a mutation may depend on the environment. Explain that sickle cell disease occurs only in heterozygotes for the sickle cell allele. Heterozygotes—those who have one sickle cell allele and one normal allele—do not have sickle cell disease, but may notice harmful effects at high altitudes. Both homozygotes and heterozygotes are resistant to the parasite that causes malaria. In areas like tropical Africa, where malaria is endemic, heterozygotes are more fit than people who are homozygous for the normal allele. This explains why the sickle cell allele is fairly common in some populations (including African and African-American populations), and why people in these populations have a relatively high risk of inheriting two copies of the mutant gene. Tell students they will learn more about sickle cell disease in Chapter 14.

**DIFFERENTIATED INSTRUCTION**

**LEP Less Proficient Readers** Suggest that students make a Cluster Diagram to organize the information about the effects of mutations. They should write Effects of Mutations in the center circle of the diagram. In the major surrounding circles they should write Neutral Effects, Harmful Effects, and Helpful Effects. Additional circles should be used to add information as students read the text.

**Study Wkbks A/B, Appendix S19, Cluster Diagram, Transparencies, GO2.**

Because they have not yet read about homeobox genes, students might assume that a major chromosomal mutation would be required to cause more eyes than normal to appear on a fly. Students can go online to Biology.com to gather their evidence.
LESSON 13.3

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Give each student seven index cards. Tell students to write or draw an example of one type of gene or chromosomal mutation on the front of each card and its name on the back. Ask students to exchange cards with a partner and try to identify the types of mutations from the examples. Then, have students complete the 13.3 Assessment.

REMEDICATION SUGGESTION

ELL English Language Learners If students have trouble with Question 2b, explain that the term significance means “importance.” Then, suggest that students reread the paragraphs about harmful and helpful mutations. As they do, they should look for information on how mutations are important to organisms and species.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Answers

IN YOUR NOTEBOOK Check that students have listed five examples of mutations and identified each as neutral, harmful, or helpful. For example, students may list a mutation that increases bone strength and density as a helpful mutation.

Assessment Answers

1a. Gene mutations involve changes in one or a few nucleotides. Chromosomal mutations involve changes in the number or structure of chromosomes.

1b. A frameshift mutation is an insertion or deletion that shifts the “reading frame” of the genetic message. An example is the insertion of an extra U in AUGCUC to make AUGUCUC. Following AUG, the “reading frame” is shifted by one base.

1c. Sample answer: To identify a gene mutation, a biologist might compare DNA base sequences among members of the species. To identify a chromosomal mutation, the biologist might examine some karyotypes.

2a. Effects of mutations on genes can be harmful, beneficial, or they can have little or no effect at all.

2b. Mutations are a source of genetic variation for living things. Sometimes, variation can help organisms adapt to different or changing environments. Mutations are also necessary for species to evolve.

2c. Sample answer: To determine whether a mutation has occurred and, if so, what type of mutation it is.

3. Students’ tables should contain much of the following information: Gene mutations involve changes in one or a few nucleotides. They include substitutions, insertions, and deletions. Insertions and deletions are called frameshift mutations because they change the “reading frame” of the genetic message. Gene mutations may or may not have major effects on an organism. Chromosomal mutations involve changes in the number or structure of chromosomes. They include deletions, duplications, inversions, and translocations. They can change the location of genes on chromosomes, and even the number of copies of genes. Chromosomal mutations generally have major effects on an organism.
THINK ABOUT IT Think of a library filled with how-to books. Would you ever need to use all of those books at the same time? Of course not. If you wanted to know how to fix a leaky faucet, you'd open a book about plumbing but would ignore the one on carpentry. Now picture a tiny bacterium like E. coli, which contains more than 4000 genes. Most of its genes code for proteins that do everything from building cell walls to breaking down food. Do you think E. coli uses all 4000-plus volumes in its genetic library at the same time?

Prokaryotic Gene Regulation

How are prokaryotic genes regulated?

As it turns out, bacteria and other prokaryotes do not need to transcribe all of their genes at the same time. To conserve energy and resources, prokaryotes regulate their activities, using only those genes necessary for the cell to function. For example, it would be wasteful for a bacterium to produce enzymes that are needed to make a molecule that is readily available from its environment. By regulating gene expression, bacteria can respond to changes in their environment—the presence or absence of nutrients, for example. How? DNA-binding proteins in prokaryotes regulate genes by controlling transcription. Some of these regulatory proteins help switch genes on, while others turn genes off.

How does an organism know when to turn a gene on or off? One of the keys to gene transcription in bacteria is the organization of genes into operons. An operon is a group of genes that are regulated together. The genes in an operon usually have related functions. E. coli, shown in Figure 13–15, provides us with a clear example. The 4288 genes that code for proteins in E. coli include a cluster of 3 genes that must be turned on together before the bacterium can use the sugar lactose as a food. These three lactose genes in E. coli are called the lac operon.

FIGURE 13–15 Small Cell, Many Genes

The common bacterium E. coli has more than 4000 genes.

Teach for Understanding

ENDURING UNDERSTANDING DNA is the universal code of life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How do cells regulate gene expression?

EVIDENCE OF UNDERSTANDING After completing the lesson, assign students the following assessment to show they understand how eukaryotic cells regulate gene expression. Ask students to use presentation software to create and present a series of slides showing how gene expression in eukaryotic cells is regulated by transcription factors and RNA interference. Their slides should include both text and visuals.

Getting Started

Objectives

13.4.1 Describe gene regulation in prokaryotes.
13.4.2 Explain how most eukaryotic genes are regulated.
13.4.3 Relate gene regulation to development in multicellular organisms.

Student Resources

Study Workbooks A and B, 13.4 Worksheets
Spanish Study Workbook, 13.4 Worksheets
Lab Manual B, 13.4 Data Analysis Worksheet

For corresponding lesson in the Foundation Edition, see pages 320–325.

Activate Prior Knowledge

Have students recall from Lesson 13.1 what happens to mRNA after it is transcribed. (The mRNA is edited; introns are cut out and exons are spliced together.) Next, call on a student to define gene expression, which was introduced in Lesson 13.2. (the way that DNA, RNA, and proteins put genetic information into action in living cells) Then, ask a volunteer to infer how mRNA editing affects gene expression. (Sections of mRNA are cut out and not translated into proteins.) Tell students they will read in this lesson about other ways gene expression is controlled.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES

I, II, IV, V

CONTENT

B.3, C.1.d, C.1.f, C.3.c, E.2, G.1

INQUIRY

A.1.a, A.2.a, A.2.b, A.2.c
LESSON 13.4


In the Data Analysis: A Complicated Operon, students analyze results of growing bacteria with lac operon mutations to identify which genes contain the mutations.

Answers

FIGURE 13–16 Sample answer: Cold air causes a furnace to turn on. When the air is no longer cold, the warmer temperature causes the furnace to turn off. Lactose works in a similar way. The presence of lactose causes lac genes to turn on. When lactose is no longer present, the absence of lactose causes lac genes to turn off.

How Science Works

DISCOVERY OF THE LAC OPERON

The three French scientists who discovered the lac operon won the 1965 Nobel Prize in Physiology or Medicine for their work. Why was it considered such an important discovery? The lac operon is the first system of gene regulation ever discovered. It showed for the first time that structural genes, which code for proteins, are regulated by other genes. The existence of regulatory genes was unknown until then. The lac operon also provided a mechanism to explain how living cells could respond to environmental stimuli by controlling the expression of genes and thereby the enzymes and other proteins they code for.
Eukaryotic Gene Regulation

How are genes regulated in eukaryotic cells?
The general principles of gene regulation in prokaryotes also apply to eukaryotes, although there are differences. Most eukaryotic genes are controlled individually and have more complex regulatory sequences than those of the lac repressor system.

Figure 13–17 shows several features of a typical eukaryotic gene. One of the most interesting is the TATA box, a short region of DNA, about 25 or 30 base pairs before the start of a gene, containing the sequence TATATA or TATAAA. The TATA box binds a protein that helps position RNA polymerase by marking a point just before the beginning of a gene.

**Transcription Factors** Gene expression in eukaryotic cells can be regulated at a number of levels. One of the most critical is the level of transcription, by means of DNA-binding proteins known as transcription factors. By binding DNA sequences in the regulatory regions of eukaryotic genes, transcription factors control the expression of those genes. Some transcription factors enhance transcription by opening up tightly packed chromatin. Others help attract RNA polymerase. Still others block access to certain genes, much like prokaryotic repressor proteins. In most cases, multiple transcription factors must bind before RNA polymerase is able to attach to the promoter region and start transcription.

Promoters have multiple binding sites for transcription factors, each of which can influence transcription. Certain factors activate scores of genes at once, dramatically changing patterns of gene expression in the cell. Other factors form only in response to chemical signals. Steroid hormones, for example, are chemical messengers that enter cells and bind to receptor proteins. These “receptor complexes” then act as transcription factors that bind to DNA, allowing a single chemical signal to activate multiple genes. Eukaryotic gene expression can also be regulated by many other factors, including the exit of mRNA molecules from the nucleus, the stability of mRNA, and even the breakdown of a gene’s protein products.

In Your Notebook Compare gene regulation in single-cell organisms and multicellular organisms.

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**Build Science Skills**

Tell students that transcription promotion, which is shown in Figure 13–17, is just one way that eukaryotic genes can be regulated. They can also be regulated by transcription repression. Create a class diagram on the board that shows how repressor proteins could control transcription in eukaryotes. (The diagram should resemble the part of Figure 13–16 that shows transcription repression in prokaryotes.)

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Have students begin a **KWL Chart** about eukaryotic gene regulation before they start reading about it in the lesson. Ask them to make predictions about eukaryotic gene regulation based on what they already know about gene regulation in prokaryotes. Tell them to list their predictions in column K. In column W, they should write questions they would like to have answered. Have them try to find answers to the questions as they read and record their answers in column L.

**Study Wkbks A/B,** Appendix S27, KWL Chart, Transparencies, GO11.

**Mystery Clue** Sample answer: The researchers attached a new promoter sequence to the mouse eye gene so that RNA polymerase would have a point to start transcription of the gene. Students can go online to Biology.com to gather their evidence.

**Address Misconceptions**

**Control of Gene Expression** Students often fail to understand the importance of regulatory genes in gene expression. Address this lack of understanding by pointing out that genes coding for repressor proteins and other regulatory proteins are an important part of the genome of even single-celled organisms such as bacteria. The lac operon is just one, well-studied example. Stress how the specialized cells of multicellular eukaryotes make gene regulation even more important.

**Answers**

**IN YOUR NOTEBOOK** In a single-celled organism, if a gene is turned on, it is turned on in the entire organism. In single-celled organisms, genes are usually regulated by repressor proteins that bind to operons or other substrates and prevent or allow the transcription of groups of genes. In a multicellular organism, cells are specialized. Each cell can have a unique set of genes that are turned on at any given moment.
Cell Specialization  Why is gene regulation in eukaryotes more complex than in prokaryotes? Think for a moment about the way in which genes are expressed in a multicellular organism. The genes that code for liver enzymes, for example, are not expressed in nerve cells. Keratin, an important protein in skin cells, is not produced in blood cells. Cell specialization requires genetic specialization, yet all of the cells in a multicellular organism carry the same genetic code in their nucleus. Complex gene regulation in eukaryotes is what makes specialization possible.

RNA Interference  For years biologists wondered why cells contain lots of small RNA molecules, only a few dozen bases long, that don’t belong to any of the major groups of RNA (mRNA, tRNA, or rRNA). In the last decade, a series of important discoveries has shown that these small RNA molecules play a powerful role in regulating gene expression. And they do so by interfering with mRNA.

As Figure 13–18 shows, after they are produced by transcription, the small interfering RNA molecules fold into double-stranded hairpin loops. An enzyme called the “Dicer” enzyme cuts, or dices, these double-stranded loops into microRNA (miRNA), each about 20 base pairs in length. The two strands of the loops then separate. Next, one of the miRNA pieces attaches to a cluster of proteins to form what is known as a silencing complex. The silencing complex binds to and destroys any mRNA containing a sequence that is complementary to the miRNA. In effect, miRNA sticks to certain mRNA molecules and stops them from passing on their protein-making instructions.

The silencing complex effectively shuts down the expression of the gene whose mRNA it destroys. Blocking gene expression by means of an miRNA silencing complex is known as **RNA interference**. At first, RNA interference (RNAi) seemed to be a rare event, found only in a few plants and other species. It’s now clear that RNA interference is found throughout the living world and that it even plays a role in human growth and development.

**Biology In-Depth**

**TREATING DISEASE USING RNA INTERFERENCE**

Soon after RNA interference was discovered, scientists began exploring ways that it might be used to treat or cure diseases. The aim was to develop artificial miRNA molecules that could turn off the expression of disease-causing genes. One of the first diseases to be studied was macular degeneration, which is the primary cause of adult blindness in the U.S. The disease occurs when a protein stimulates overgrowth of capillaries in the eye. An RNAi drug was developed that shuts down the expression of the gene coding for this protein. The drug can be injected directly into the eye. This is important because a drug injected into the blood might prevent the expression of this gene in parts of the body where it is needed. Researchers are also trying to find RNAi treatments for cancer, AIDS, hepatitis C, and Huntington’s disease.
The Discovery of RNA Interference

In 1998, Andrew Fire and Craig Mello carried out an experiment that helped explain the mechanism of RNA interference. They used RNA from a large gene called unc-22, which codes for a protein found in muscle cells. They prepared short mRNA fragments corresponding to two exons regions of the gene and injected them into egg cells of the worm *Caenorhabditis elegans*. Some of their results are shown in the table.

1. **Draw Conclusions** How did the adult worms’ responses differ to injections of single-stranded mRNA (the “sense” strand), its complementary strand (“antisense”), and double-stranded RNA (“sense + antisense")?

<table>
<thead>
<tr>
<th>Portion of Gene Used to Produce mRNA</th>
<th>Strand Injected</th>
<th>Result in Adult Worm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unc-22</strong> (exon 21–22)</td>
<td>Sense</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Antisense</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>Sense + Antisense</td>
<td>Twitching</td>
</tr>
</tbody>
</table>

2. **Form a Hypothesis** Twitching results from the failure of muscle cells to control their contractions. What does this suggest about the unc-22 protein in some of the worms? How would you test your hypothesis?

3. **Infer** The injected fragments came from two different places in the gene and were only a few hundred bases long. The unc-22 mRNA is thousands of bases long. What does this suggest about the mechanism of RNA interference?

The Promise of RNAi Technology

The discovery of RNAi has made it possible for researchers to switch genes on and off at will, simply by inserting double-stranded RNA into cells. The Dicer enzyme then cuts this RNA into miRNA, which activates silencing complexes. These complexes block the expression of genes producing miRNA complementary to the miRNA. Naturally this technology is a powerful way to study gene expression in the laboratory. However, RNAi technology also holds the promise of allowing medical scientists to turn off the expression of genes from viruses and cancer cells, and it may provide new ways to treat and perhaps even cure diseases.

Genetic Control of Development

What controls the development of cells and tissues in multicellular organisms?

Regulating gene expression is especially important in shaping the way a multicellular organism, like the mouse embryo in Figure 13–19, develops. Each of the specialized cell types found in the adult originates from the same fertilized egg cell. Cells don’t just grow and divide during embryonic development. As the embryo develops, different sets of genes are regulated by transcription factors and repressors. Gene regulation helps cells undergo differentiation, becoming specialized in structure and function. The study of genes that control development and differentiation is one of the most exciting areas in biology today.

**FIGURE 13–19 Differentiation**

This scanning electron micrograph shows a mouse embryo undergoing cell differentiation 13.5 days after conception.

Connect to Health

After students read about the promise of RNA interference technology, challenge them to explain how the technology could be used to treat a specific genetic disease. Explain that Huntington’s disease is caused by a single autosomal dominant mutant gene. The gene produces a protein that causes brain abnormalities, which in turn interfere with coordination, speech, and mental abilities.

**Ask** How might RNA interference technology be used to treat Huntington’s disease? (An miRNA molecule complementary to the mutant gene that causes Huntington’s disease might be injected into a person with the gene. The miRNA would prevent the expression of the gene so that its protein could not be produced. This would prevent the disease from developing.)

DIFERENTIATED INSTRUCTION

**Struggling Students** Use a Quick Write strategy to check students’ understanding of the difficult topics of RNA interference and RNA interference technology. Give them one or two minutes to write down everything they know about the topics. Then, read their responses and identify anything they don’t understand. Clarify these issues before moving on to the next topic.

**Advanced Students** Assign one of the following diseases to each of five students: macular degeneration, cancer, AIDS, hepatitis C, or Huntington’s disease. Tell them to find reports of research investigating the use of RNA interference to treat their assigned disease. Ask them to make a list of the most student-friendly research reports to share with the class.

PURPOSE Students will analyze data to infer how RNA interference works.

**PLANNING** Make sure students understand the role of double-stranded RNA in RNA interference by reviewing Figure 13–18.

**ANSWERS**

1. For both portions of the gene, injection of single-stranded mRNA produced adult worms with normal responses, whereas injection of double-stranded mRNA produced adult worms with twitching responses.

2. Sample answer: In worms with the twitching response, the unc-22 protein that controls muscle contractions was not produced. I would test this hypothesis by determining whether the protein was present in the worms with the twitching response.

3. Sample answer: RNA interference may prevent a gene from being expressed by interfering with just a small percentage of its bases.
LESSON 13.4

Use Models

Use a simple model to help students understand how homeobox genes control development. Stand about 20 dominoes on end in a long row. The dominoes should be spaced so that knocking over the first domino will cause a cascade effect that knocks over the rest of the dominoes. Say that the first five dominoes represent a homeobox gene and the other dominoes represent genes that control the development of an organ. Have students observe what happens to the other dominoes when you knock over the first domino. Explain how this models the effects of a homeobox gene on genes that control development. Set up the dominoes again, and then remove the second through fifth dominoes from the row. Say that this represents a mutation in the homeobox gene. Demonstrate how knocking over the first domino no longer causes the cascade effect. Ask students to infer how a mutation in a homeobox gene might affect an organism’s development.

DIFFERENTIATED INSTRUCTION

Less Proficient Readers On the board, write the term differentiation and separate it into its parts (different and -ation). Explain that -ation means “process of.”

Ask What do you think differentiation means? (process of making things different)

Ask What does cell differentiation mean? (process of making cells different)

Describe concrete examples of differentiated cells, such as skin and blood cells. Point out specific ways they differ. Then, explain how gene regulation is involved in the differentiation of cells.

Students are likely to infer that homeobox genes control the growth and development of eyes in flies and mice. Students can go online to Biology.com to gather their evidence.

Answers

FIGURE 13–20 the back of the body (posterior portion of the abdomen of the fruit fly and rump of the mouse)

How Science Works

DISCOVERY OF HOMEOBOX GENES

The discovery of homeobox genes by Edward B. Lewis provided an explanation for something scientists had observed 200 years before but had never been able to explain: the similarity in basic body plans of animals as diverse as insects and humans. In the early 1800s, French zoologist Étienne Geoffroy Saint-Hilaire noted that vertebrates are basically arthropods turned upside down. Around the same time, German embryologist Karl Ernst von Baer demonstrated that vertebrate embryos were all virtually identical. When Lewis identified homeobox genes in fruit flies in the mid-1900s, these observations suddenly made sense. The evolution of gene sequencing technologies over the next few decades allowed scientists to sequence the homeobox genes. Since then, nearly identical homeobox genes have been found in many vertebrates, including humans. This discovery has had a profound influence on the study of evolution.
Environmental Influences You’ve seen how cell differentiation is controlled at least in part by the regulation of gene expression. Conditions in an organism’s environment play a role too. In prokaryotes and eukaryotes, environmental factors like temperature, salinity, and nutrient availability can influence gene expression. One example: The lac operon in E. coli is switched on only when lactose is the only food source in the bacteria’s environment.

Metamorphosis is another well-studied example of how organisms can modify gene expression in response to change in their environment. Metamorphosis involves a series of transformations from one life stage to another. It is typically regulated by a number of external (environmental) and internal (hormonal) factors. As organisms move from larval to adult stages, their body cells differentiate to form new organs. At the same time, old organs are lost through cell death.

Consider the metamorphosis of a tadpole into a bullfrog, as shown in Figure 13–21. Under less than ideal conditions—a drying pond, a high density of predators, low amounts of food—tadpoles may speed up their metamorphosis. In other words, the speed of metamorphosis is determined by various environmental changes that are translated into hormonal changes, with the hormones functioning at the molecular level. Other environmental influences include temperature and population size.

Assess and RemEDIATE

EVALUATE UNDERSTANDING

Ask students to write a list of steps that occur in eukaryote gene regulation. Have them compare lists with a partner and discuss any discrepancies. Then, have students complete the 13.4 Assessment.

REMEDIATION SUGGESTION

Struggling Students If students have trouble with Question 4, review the role of repressors and transcription factors in gene regulation. Remind students that repressors, transcription factors, and hormones are proteins.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.
Pre-Lab
Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab
Tell students they will perform the chapter lab From DNA to Protein Synthesis described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 326.

Pre-Lab Answers

BACKGROUND QUESTIONS
a. mRNA, because the sequence contains uracil instead of thymine.
b. Sample answer: During both transcription and translation, large molecules are synthesized from smaller units. During transcription, nucleotides are assembled into complementary mRNA molecules. During translation, amino acids are assembled into proteins.
c. DNA, mRNA, tRNA, amino acid

PRE-LAB QUESTIONS
1. Transcribe the DNA to mRNA; translate the mRNA to amino acids, find the single-letter abbreviation for each amino acid.
2. In protein synthesis, a stop codon is used to mark the end of a protein synthesis. In the coded messages, stop codons are used to represent spaces between words.
3. The letters B, J, O, U, X, and Z will not appear in the messages because these letters are not used as single-letter abbreviations for amino acids.
13 Study Guide

13.1 RNA

- DNA-binding proteins in prokaryotes regulate genes by controlling transcription.
- By binding DNA sequences in the regulatory regions of eukaryotic genes, transcription factors control the expression of those genes.
- Master control genes are like switches that trigger particular patterns of development and differentiation in cells and tissues.

13.2 Ribosomes and Protein Synthesis

- The genetic code is read three “letters” at a time, so that each “word” is three bases long and corresponds to a single amino acid.
- Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains.
- The central dogma of molecular biology is that information is transferred from DNA to RNA to protein.

13.3 Mutations

- Mutations are heritable changes in genetic information.
- The effects of mutations on genes vary widely. Some have little or no effect; some produce beneficial variations. Some negatively disrupt gene function.

Mutations often produce proteins with new or altered functions that can be useful to organisms in different or changing environments.

- mutation (372)
- point mutation (373)
- frameshift mutation (373)
- strand break (374)
- mutagen (375)
- polymerase (376)

13.4 Gene Regulation and Expression

- DNA-binding proteins in prokaryotes regulate genes by controlling transcription.
- By binding DNA sequences in the regulatory regions of eukaryotic genes, transcription factors control the expression of those genes.
- Master control genes are like switches that trigger particular patterns of development and differentiation in cells and tissues.

Think Visually

Using the information in this chapter, complete the following flowchart about protein synthesis:

1. Translation begins at the start codon.
2. The polypeptide is complete.

Performance Tasks

SUMMATIVE TASK Ask students to write a newspaper story reporting on a “case” of gene regulation. All the factors involved in gene regulation (genes, transcription factors, repressor proteins, RNA polymerase, regulatory sites) should appear as characters in the story. The story should be a journalistic-style account of events and describe what happens to the characters as the events unfold.

TRANSFER TASK Have groups of students write a research proposal about RNA interference technology and a particular genetic disease. The proposal should have the following sections: Research Question, Literature Review, Research Hypothesis, Research Plan, What the Research Will Show, and Why the Research Is Important. Make sure students do an actual literature review before they write their proposal.

Answers

THINK VISUALLY

1. Sample answer: mRNA is transcribed and edited to transport information out of the nucleus and then goes to a ribosome in the cytoplasm.

2. Sample answer: As the ribosome reads each codon, tRNA brings the correct amino acid to the ribosome, where it is attached to other amino acids in a growing polypeptide. This continues until a “stop” codon is reached.
Lesson 13.1

UNDERSTAND KEY CONCEPTS

1. b 2. b

3. Messenger RNA carries the instructions for protein synthesis from DNA to the cytoplasm. Ribosomal RNA makes up ribosomes, where proteins are made. Transfer RNA carries amino acids to the ribosome and matches them to the coded mRNA message.

4. The enzyme knows to start transcribing DNA at a promoter, which is a region of DNA that has specific base sequences.

5. Introns are sections of mRNA that are not needed for protein synthesis. Exons are sections of mRNA that are needed for protein synthesis.

THINK CRITICALLY

6. UGGCAGUG

7. If the intron were not removed, its codons would be translated and become part of a protein. As a result, the protein might not function properly.

Lesson 13.2

UNDERSTAND KEY CONCEPTS

8. c 9. d 10. c 11. c

12. a three-base code “word” in the genetic code that specifies a particular amino acid, start, or stop

13. At the ribosome, anticodons in tRNA form bonds with the complementary codons in mRNA, and tRNA adds its amino acid to the polypeptide chain.

14. mRNA: GAU; tRNA: CUA

15. Proteins determine the characteristics of organisms because they are like microscopic tools, each specifically designed to build or operate a component of a living cell. Therefore, controlling the proteins in an organism controls the organism’s characteristics.

THINK CRITICALLY

16. Transcription in genetics means to “write out” the genetic code in DNA in the form of a strand of mRNA. The message in mRNA is still in the same “language,” the genetic code. Translation in genetics means to express the codons in mRNA in a different “language,” that is, as a chain of amino acids instead of as a string of codons.

17. The appearance of the sequence AAC does not necessarily mean that asparagine will appear in the protein. That nucleotide sequence could be part of an intron and edited out of the RNA before it leaves the nucleus and becomes involved in protein synthesis. Or, the nucleotide sequence AAC could appear in a long strand of RNA and could be divided over two codons (such as, GGA-ACC).

18. b 19. d 20. b

21. Sample answer: gene mutations and chromosomal mutations. An example of a gene mutation is an insertion mutation, in which an extra base is inserted into a codon. An example of a chromosomal mutation is an inversion, in which part of a chromosome is reversed. Gene mutations affect a single gene; whereas chromosomal mutations affect all or part of a chromosome.
13.3 Mutations

Understand Key Concepts

18. Changes in DNA sequences that affect genetic information are known as
   a. replications.    c. transformations.
   b. mutations.      d. translations.

19. A single-base mutation in a messenger RNA molecule could transcribe the DNA sequence CAGTAT into
   a. GTCTAT.        c. GTCTU.
   b. GUCAUA.        d. GAUAUA.

20. A substance that can cause a change in the DNA code of an organism is called a
   a. toxin.        c. nitrogenous base.
   b. mutagen.      d. nucleotide.

21. Name and give examples of two major types of mutations. What do they have in common? How are they different?

22. How does a deletion mutation differ from a substitution mutation?

23. Can mutations have a positive effect?

Think Critically

24. Compare and Contrast How does the possible impact of a chromosomal mutation that occurs during meiosis differ from that of a similar event that occurs during mitosis of a body cell that is not involved in reproduction?

25. Apply Concepts A mutation in the DNA of an organism changes one base sequence in a protein-coding region from CAC to CAT. What is the effect of the mutation on the final protein? Explain your answer.

13.4 Gene Regulation and Expression

Understand Key Concepts

26. An expressed gene
   a. functions as a promoter.
   b. is transcribed into RNA.
   c. codes for just one amino acid.
   d. is made of mRNA.

22. A deletion mutation occurs when a base is lost from a codon. This shifts the “reading frame,” so all the codons after the point of deletion are affected. A substitution mutation occurs when a single base is replaced by a different base. This does not shift the “reading frame.”

23. Yes, a mutation could produce a protein with a new or altered function that might be useful to an organism in a changing environment.

THINK CRITICALLY

24. A chromosomal mutation that occurs during meiosis will be carried by some of the organism’s gametes and possibly to the organism’s offspring. A mutation that occurs during mitosis in a body cell will be passed on to that cell’s daughter cells but not to the organism’s offspring.

25. The mutation in the DNA changes the codon in mRNA from GUG to GUU. Both of these codons code for the amino acid valine, so the final protein would not be affected.
Lesson 13.4

UNDERSTAND KEY CONCEPTS

26. b  27. b  28. a  29. c

30. DNA-binding proteins regulate genes by helping switch genes on or off before transcription.

31. The term cell specialization means the adaptation of eukaryotic cells for specialized functions by the regulation of gene expression.

32. A TATA box is usually found just before a gene. It binds transcription factor proteins that help position RNA polymerase at the point where transcription should begin. When transcription factors bind to the TATA box, they form a binding site for RNA polymerase, which can then start transcription.

33. A homeobox gene is a gene that codes for a transcription factor that activates other genes important to cell development and differentiation.

THINK CRITICALLY

34. Sample answer: In prokaryotes, genes are organized into operons, where groups of genes are regulated together. In eukaryotes, most genes are controlled individually and have more complex sequences. Gene expression in eukaryotes can also be regulated at many levels, and is more complicated in multicellular organisms, where there is cell specialization. Then there are microRNAs that can block gene expression through RNA interference.

Connecting Concepts

USE SCIENCE GRAPHICS

35. no effect

36. Sample answer: Substituting a C for a G in the first base of a codon that codes for valine would replace it with leucine. Substituting a C for a U in the second base of a codon that codes for valine would replace it with alanine. These substitutions may alter the function of the resulting protein.

WRITE ABOUT SCIENCE

37. Student explanations should address neutral, harmful, and beneficial mutations and explain ways in which each may occur.

38. DNA is transcribed to form mRNA. After the mRNA is edited, it leaves the nucleus and enters the cytoplasm. A ribosome containing rRNA attaches to the mRNA strand and translates it to form a polypeptide. In translation, tRNA molecules bring the correct amino acids to the ribosome to add to the polypeptide.

39. Interpret Graphics Which of the four types of viruses is most likely to use double-stranded RNA as its genetic material?
   a. Virus A  c. Virus C
   b. Virus B  d. Virus D

40. Infer The values in the two boxes labeled with an x would most likely be about
   a. 32.5% A and 32.5% U
   b. 17.5% A and 17.5% U
   c. 26.3% A and 29.3% U
   d. 32.5% A and 17.5% U
Answers

1. C
2. C
3. B
4. D
5. A
6. C
7. C
8. D

9. The lac repressor system controls the production of enzymes needed to digest lactose. When lactose is absent and the enzymes are not needed, repressor proteins turn off the genes, so that the enzymes are not produced. When lactose is present and the enzymes are needed, lactose prevents the repressor proteins from turning off the genes, so that the enzymes are produced.