

Getting Started

Objectives

- 12.1.1 Summarize** the process of bacterial transformation.
- 12.1.2 Describe** the role of bacteriophages in identifying genetic material.
- 12.1.3 Identify** the role of DNA in heredity.

Student Resources

Study Workbooks A and B, 12.1 Worksheets
Spanish Study Workbook, 12.1 Worksheets



Lesson Overview • Lesson Notes

- Activities: Art in Motion, Visual Analogy
- Assessment: Self-Test, Lesson Assessment



For corresponding lesson in the **Foundation Edition**, see pages 288–291.

Activate Prior Knowledge

Have several volunteers describe how the information they learned in elementary and middle school prepared them for the academic work they are now doing in high school. Point out that, without the skills they learned earlier in life, they would be unable to carry out high-school level work. Explain that scientific knowledge grows in a similar way. Tell students this lesson will describe experiments that laid the groundwork for current work in the scientific field of genetics.



NEXT GENERATION SUNSHINE STATE STANDARDS

For the full text of all benchmarks, see the Course Overview in the front matter of this book.

Other key benchmarks: **SC.912.L.16.3** Describe the basic process of DNA replication and how it relates to the transmission and conservation of the genetic information.

12.1

SC.912.N.1.6 Describe how scientific inferences are drawn from scientific observations and provide examples from the Benchmark being studied.
 Also covered: SC.912.L.16.3

Key Questions

- **What clues did bacterial transformation yield about the gene?**
- **What role did bacterial viruses play in identifying genetic material?**
- **What is the role of DNA in heredity?**

Vocabulary

transformation
bacteriophage

Taking Notes

Flowchart As you read this section, make a flowchart that shows how scientists came to understand the molecule known as DNA.

Identifying the Substance of Genes

THINK ABOUT IT How do genes work? To answer that question, the first thing you need to know is what genes are made of. After all, you couldn't understand how an automobile engine works without understanding what the engine is made of and how it's put together. So, how would you go about figuring out what molecule or molecules go into making a gene?

Bacterial Transformation

• What clues did bacterial transformation yield about the gene?

In the first half of the twentieth century, biologists developed the field of genetics to the point where they began to wonder about the nature of the gene itself. To truly understand genetics, scientists realized they first had to discover the chemical nature of the gene. If the molecule that carries genetic information could be identified, it might be possible to understand how genes actually control the inherited characteristics of living things.

Like many stories in science, the discovery of the chemical nature of the gene began with an investigator who was actually looking for something else. In 1928, the British scientist Frederick Griffith was trying to figure out how bacteria make people sick. More specifically, Griffith wanted to learn how certain types of bacteria produce the serious lung disease known as pneumonia.

Griffith had isolated two very similar types of bacteria from mice. These were actually two different varieties, or strains, of the same bacterial species. Both strains grew very well in culture plates in Griffith's lab, but only one of them caused pneumonia. The disease-causing bacteria (S strain) grew into smooth colonies on culture plates, whereas the harmless bacteria (R strain) produced colonies with rough edges. The difference in appearance made the two strains easy to tell apart.

Griffith's Experiments When Griffith injected mice with disease-causing bacteria, the mice developed pneumonia and died. When he injected mice with harmless bacteria, the mice stayed healthy. Griffith wondered what made the first group of mice get pneumonia. Perhaps the S-strain bacteria produced a toxin that made the mice sick? To find out, he ran the series of experiments shown in **Figure 12–1**. First, Griffith took a culture of the S strain, heated the cells to kill them, then injected the heat-killed bacteria into laboratory mice. The mice survived, suggesting that the cause of pneumonia was not a toxin from these disease-causing bacteria.

338

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Lesson 12.1

• Lesson Overview • Lesson Notes

Teach for Understanding

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.

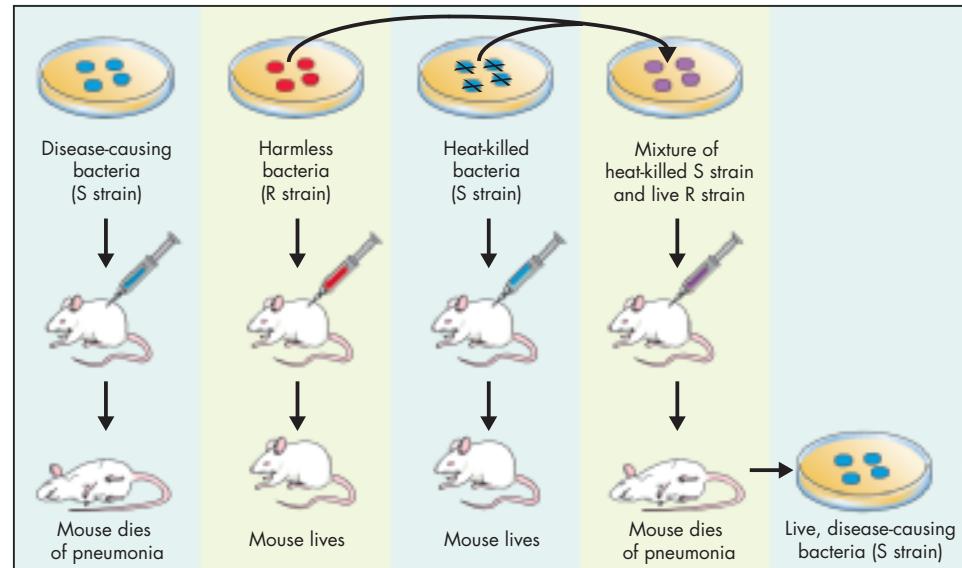
GUIDING QUESTION How did scientists determine that DNA is responsible for storing, copying, and transmitting genetic information?

EVIDENCE OF UNDERSTANDING *After completing the lesson, give students the following assessment to show they understand how scientists identified the genetic material in cells.* Have students work in small groups to write a newspaper article describing the work of either Frederick Griffith, Oswald Avery, or Alfred Hershey and Martha Chase. Explain that newspaper articles usually provide answers to the following set of questions: *Who? What? Where? When? and Why?* Have each group share its completed newspaper article with the class.

In Griffith's next experiment, he mixed the heat-killed, S-strain bacteria with live, harmless bacteria from the R strain. This mixture he injected into laboratory mice. By themselves, neither type of bacteria should have made the mice sick. To Griffith's surprise, however, the injected mice developed pneumonia, and many died. When he examined the lungs of these mice, he found them to be filled not with the harmless bacteria, but with the disease-causing bacteria. How could that happen if the S-strain cells were dead?

Transformation Somehow, the heat-killed bacteria passed their disease-causing ability to the harmless bacteria. Griffith reasoned that, when he mixed the two types of bacteria together, some chemical factor transferred from the heat-killed cells of the S strain into the live cells of the R strain. This chemical compound, he hypothesized, must contain information that could change harmless bacteria into disease-causing ones. He called this process **transformation**, because one type of bacteria (the harmless form) had been changed permanently into another (the disease-causing form). Because the ability to cause disease was inherited by the offspring of the transformed bacteria, Griffith concluded that the transforming factor had to be a gene.

In Your Notebook Write a summary of Griffith's experiments.



DNA 339

How Science Works

EARLY INVESTIGATION OF NUCLEIC ACIDS

Well before the work of Frederick Griffith, experiments had provided information about nucleic acids. In the late 1860s, Friedrich Miescher, a medical researcher, isolated a substance called nuclein while working with white blood cells. Miescher was able to determine that this substance, found in the nuclei of cells, was a complex of protein and an additional compound, which today is known to be nucleic acid, or DNA. He was also able to discover the chemical makeup of nuclein—hydrogen, oxygen, nitrogen, and phosphorus. These results were published in 1871.

Teach

Use Visuals

Tell students the word *transformation* means "change."

Ask Why is the word *transformation* a good description of what happened in Griffith's experiment? (Sample answer: One strain of bacteria transformed, or changed, into another.)

Ask Why did Griffith conclude that the transforming factor had to be a gene? (*The factor was inherited by offspring of the transformed bacteria.*)

DIFFERENTIATED INSTRUCTION

LPR Less Proficient Readers Have struggling readers use **Figure 12–1** to learn about Griffith's experiment. Point out and describe what happens in each vertical panel of the figure.

Ask In this experiment, which strain of bacteria caused disease? (*the S strain*)

Ask What happened when heat-killed S strain was injected into a mouse? (*It no longer caused disease.*)

Ask What happened when the heat-killed S strain was mixed with the harmless R-strain bacteria? (*The mouse got sick.*)

ELL Focus on ELL: Extend Language

INTERMEDIATE SPEAKERS To understand the content of this lesson, students need a working knowledge of terms such as *experiment*, *inferred*, *concluded*, and *observed*. As students read about the experiments in this lesson, have them locate these terms in the text. Ask students to find a definition for each term in a dictionary and to practice pronouncing each term aloud.

Answers

FIGURE 12–1 to determine whether the substance transferred from the heat-killed bacteria to the R strain was heritable

IN YOUR NOTEBOOK Students' summaries should include a description of the four different samples of bacteria Griffith injected into the mice, the fate of the mice injected with each strain, and the conclusion Griffith drew based on his results.

DNA 339

Teach continued

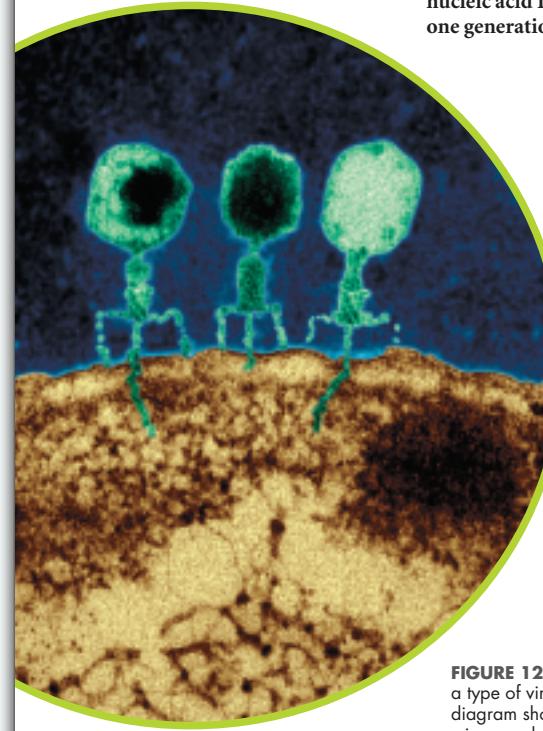
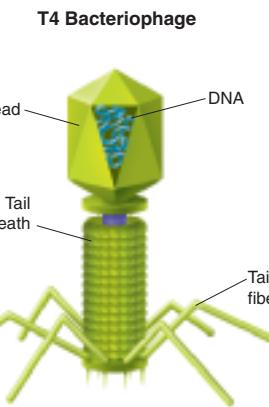
Lead a Discussion

Review with students the experimental design used by Avery and his team. Have students identify the manipulated, or independent, variable in the experiment. (*the type of enzyme used to treat the extract from heat-killed bacteria*) Make sure they realize that only one enzyme was used in each experiment. Then, have them identify the responding, or dependent, variable in this experiment. (*whether transformation occurred*) Have students state the conclusion that was reached using the results of these experiments. (*DNA stores and transmits genetic information.*)

DIFFERENTIATED INSTRUCTION

L1 Struggling Students Provide students with a visual representation of Avery's experiment. Start by drawing a cluster of heat-killed bacteria on the board. Then, draw an arrow from the bacteria to a test tube with liquid in it, while explaining that Avery extracted cellular materials from the bacteria. Draw protein-destroying enzymes being added to this test tube. Then, draw another arrow to a cluster of live R-strain bacteria, and tell students that Avery mixed the enzyme-treated material with the live R-strain bacteria. Finally, show another arrow pointing to live S-strain bacteria. Explain that transformation occurred. Repeat this drawing process to show the effects of an RNA-destroying enzyme. Finally, draw the process for a DNA-destroying enzyme. For this one, talk about why transformation did not occur and how Avery used this result to reach his conclusion that DNA is the transforming factor.

ELL English Language Learners Introduce students to the term *bacteriophage*. Tell students that the word part *-phage* is based on the Greek word *phagein*, meaning "to eat." Explain that when *-phage* is added to a noun, it signifies "one who eats." Have students apply this knowledge to *bacteriophage* and discuss its meaning. (*Students should conclude that bacteriophages "eat," or destroy, the bacteria they infect.*)



340 Chapter 12 • Lesson 1

The Molecular Cause of Transformation In 1944, a group of scientists at the Rockefeller Institute in New York decided to repeat Griffith's work. Led by the Canadian biologist Oswald Avery, the scientists wanted to determine which molecule in the heat-killed bacteria was most important for transformation. They reasoned that if they could find this particular molecule, it might reveal the chemical nature of the gene.

Avery and his team extracted a mixture of various molecules from the heat-killed bacteria. They carefully treated this mixture with enzymes that destroyed proteins, lipids, carbohydrates, and some other molecules, including the nucleic acid RNA. Transformation still occurred. Clearly, since those molecules had been destroyed, none of them could have been responsible for transformation.

Avery's team repeated the experiment one more time. This time, they used enzymes that would break down a different nucleic acid—DNA. When they destroyed the DNA in the mixture, transformation did not occur. There was just one possible explanation for these results: *DNA was the transforming factor.* **By observing bacterial transformation, Avery and other scientists discovered that the nucleic acid DNA stores and transmits genetic information from one generation of bacteria to the next.**

Bacterial Viruses

What role did bacterial viruses play in identifying genetic material?

Scientists are a skeptical group. It usually takes several experiments to convince them of something as important as the chemical nature of the gene. The most important of the experiments relating to the discovery made by Avery's team was performed in 1952 by two American scientists, Alfred Hershey and Martha Chase. They collaborated in studying viruses—tiny, nonliving particles that can infect living cells.

Bacteriophages A **bacteriophage** is a kind of virus that infects bacteria. When a bacteriophage enters a bacterium, it attaches to the surface of the bacterial cell and injects its genetic information into it, as shown in **Figure 12–2**. The viral genes act to produce many new bacteriophages, which gradually destroy the bacterium. When the cell splits open, hundreds of new viruses burst out.

FIGURE 12–2 Bacteriophages A bacteriophage is a type of virus that infects and kills bacteria. The top diagram shows a bacteriophage known as T4. The micrograph shows three T2 bacteriophages (green) invading an *E. coli* bacterium (gold).

Compare and Contrast How large are viruses compared with bacteria?

Check for Understanding

HAND SIGNALS

Ask students the following questions, and have them show a thumbs-up sign if they can answer a question, a thumbs-down sign if they cannot, or a waving-hand sign if they are unsure.

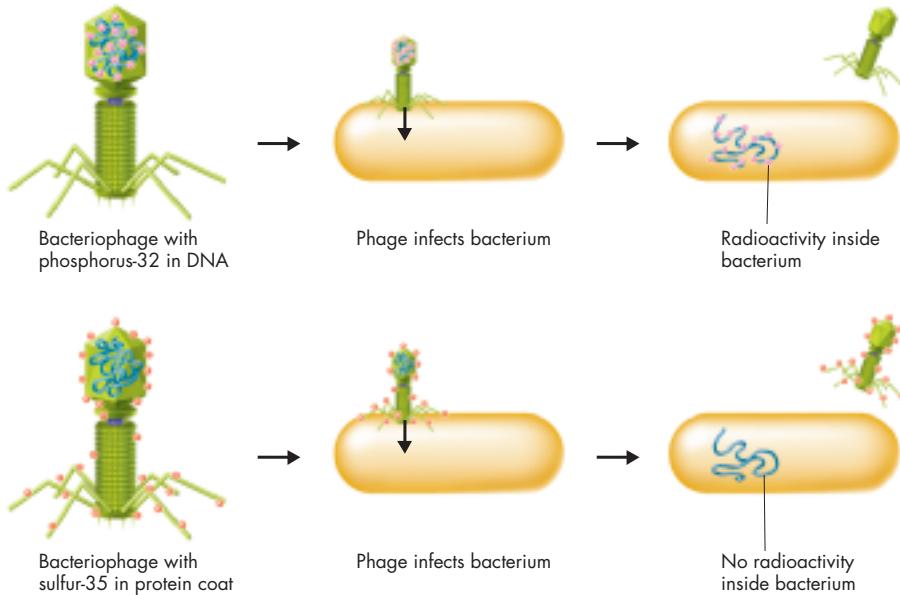
- What is bacterial transformation?
- What conclusion did Frederick Griffith draw from his experimental results?
- What conclusion did Oswald Avery draw from his experimental results?

ADJUST INSTRUCTION

If students are confused, have pairs work together to write a one-sentence response to each question.

Answers

FIGURE 12–2 Viruses are much smaller than bacteria.



The Hershey-Chase Experiment Hershey and Chase studied a bacteriophage that was composed of a DNA core and a protein coat. They wanted to determine which part of the virus—the protein coat or the DNA core—entered the bacterial cell. Their results would either support or disprove Avery's finding that genes were made of DNA.

The pair grew viruses in cultures containing radioactive isotopes of phosphorus-32 (^{32}P) and sulfur-35 (^{35}S). This was a clever strategy, because proteins contain almost no phosphorus, and DNA contains no sulfur. Therefore, these radioactive substances could be used as markers, enabling the scientists to tell which molecules actually entered the bacteria, carrying the genetic information of the virus. If they found radioactivity from ^{35}S in the bacteria, it would mean that the virus's protein coat had been injected into the bacteria. If they found ^{32}P , then the DNA core had been injected.

The two scientists mixed the marked viruses with bacterial cells. They waited a few minutes for the viruses to inject their genetic material. Next, they separated the viruses from the bacteria and tested the bacteria for radioactivity. Figure 12–3 shows the steps in this experiment. What were the results? Nearly all the radioactivity in the bacteria was from phosphorus (^{32}P), the marker found in DNA. Hershey and Chase concluded that the genetic material of the bacteriophage was indeed DNA, not protein. **Hershey and Chase's experiment with bacteriophages confirmed Avery's results, convincing many scientists that DNA was the genetic material found in genes—not just in viruses and bacteria, but in all living cells.**

In Your Notebook Identify the independent and dependent variables in the Hershey-Chase experiment, and list some possible control variables.

FIGURE 12–3 Hershey-Chase Experiment Alfred Hershey and Martha Chase used different radioactive markers to label the DNA and proteins of bacteriophages. The bacteriophages injected only DNA, not proteins, into bacterial cells.

Lead a Discussion

Begin a discussion on the Hershey-Chase experiment.

Ask What happens when a bacteriophage infects a bacterium? (*The bacteriophage injects its genetic material into the bacterium.*)

Ask What did the bacteriophage used by Hershey and Chase consist of? (*protein and DNA*)

Ask What question did Hershey and Chase seek to answer with their experiment? (*Does DNA or protein transmit genetic information?*)

DIFFERENTIATED INSTRUCTION

L1 Struggling Students To help students understand the Hershey-Chase experiment, walk them through the steps of how a bacteriophage infects a bacterium. As a class, construct a **Flowchart** that shows these steps. First, the bacteriophage attaches to the surface of the bacterium and injects its genetic information. Next, the viral genes are replicated, and many new bacteriophages are produced. Last, the bacterium splits open, and new viruses burst out.

Study Wkbks A/B, Appendix S25, Flowchart. **Transparencies**, GO8.

BIOLOGY.com To help students better visualize the experiment, suggest they watch **Art in Motion: Hershey-Chase Experiment**.

How Science Works

RADIOISOTOPES—A TOOL FOR BIOLOGISTS

Radioisotopes, or radioactive isotopes, are commonly used by biologists to study cell processes because they can be substituted into biochemical reactions without changing the chemistry of the reactions. Isotopes of an element contain the same number of protons but different numbers of neutrons in their nuclei. Radioisotopes are isotopes that have an unstable nucleus. For example, ^{32}P is an isotope of phosphorus. ^{32}P is not stable, so it "decays" into a more stable form. This decay is detected as radioactivity. Scientists studying a particular biochemical reaction that involves phosphorus can use ^{32}P to monitor the reaction. Radioisotopes of many other elements also exist, giving biologists a wide range of these "tools" to work with.

Answers

IN YOUR NOTEBOOK The independent variable is the substance that was labeled, DNA or protein. The dependent variable is the presence of radioactivity in the infected cell. An example of a control variable is the amount of time Hershey and Chase waited for the viruses to infect the bacteria.

Teach continued

VISUAL ANALOGY

Have students examine **Figure 12–4**, which uses the analogy of a book to describe the functions of DNA.

Ask Look at the title of the book. In what ways is DNA like a how-to book? (*It stores instructions.*)

Ask How does DNA store information? (*Sample answer: in its molecular structure*)

Ask Why is it important that DNA can be accurately copied? (*so that each daughter cell receives a complete and correct copy of the genetic material during cell division*)

DIFFERENTIATED INSTRUCTION

L1 Special Needs Make a bulleted list on the board of the three main functions of DNA presented in this lesson (*storing information, copying information, and transmitting information*). Have students use this list to remind them of DNA's basic functions as they learn more about DNA's structure and replication in this chapter.

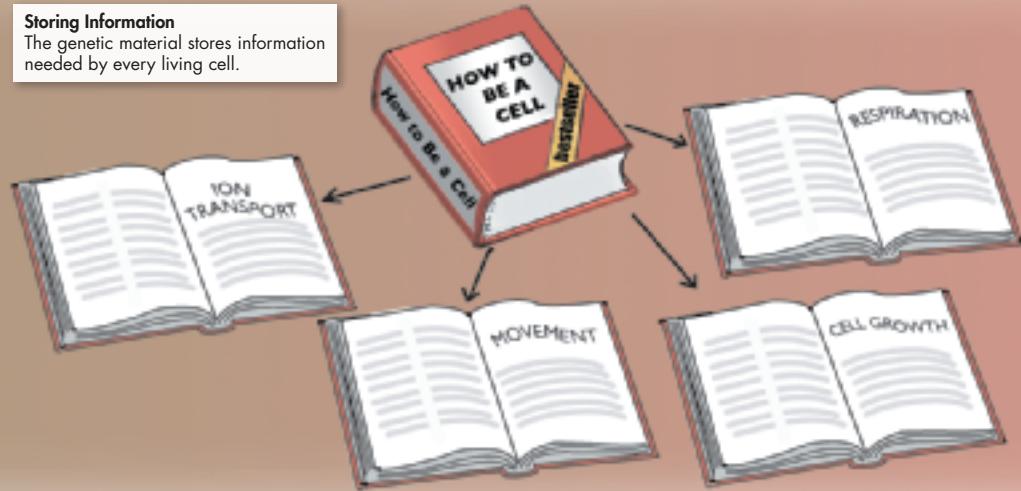


Students can explore this analogy further by completing the online activity **Visual Analogy: The Main Functions of DNA and Books**.

Address Misconceptions

Genes Although most students are familiar with the word *gene*, many cannot describe the chemical basis of inheritance. As students are introduced to the function of DNA in this lesson, remind them that genes, which are made of DNA, carry a chemical code for biological processes. It is this chemical code that stores genetic information, is copied when a cell divides, and transmits information from one generation to the next.

Storing Information
The genetic material stores information needed by every living cell.



VISUAL ANALOGY

THE MAIN FUNCTIONS OF DNA

FIGURE 12–4 Like DNA, the book in this diagram contains coded instructions for a cell to carry out important biological processes, such as how to move or transport ions. The book, like DNA, can also be copied and passed along to the next generation. These three tasks—storing, copying, and transmitting information—are also the three main functions of DNA.

The Role of DNA

What is the role of DNA in heredity?

You might think that scientists would have been satisfied knowing that genes were made of DNA, but that was not the case at all. Instead, they wondered how DNA, or any molecule for that matter, could do the critical things that genes were known to do. The next era of study began with one crucial assumption. **The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell.** These three functions are analogous to the way in which you might share a treasured book, as pictured in Figure 12–4.

Storing Information The foremost job of DNA, as the molecule of heredity, is to store information. The genes that make a flower purple must somehow carry the information needed to produce purple pigment. Genes for blood type and eye color must have the information needed for their jobs as well, and other genes have to do even more. Genes control patterns of development, which means that the instructions that cause a single cell to develop into an oak tree, a sea urchin, or a dog must somehow be written into the DNA of each of these organisms.

Copying Information Before a cell divides, it must make a complete copy of every one of its genes. To many scientists, the most puzzling aspect of DNA was how it could be copied. The solution to this and other puzzles had to wait until the structure of the DNA molecule became known. Within a few weeks of this discovery, a copying mechanism for the genetic material was put forward. You will learn about this mechanism later in the chapter.

342



Search

Lesson 12.1

Visual Analogy

Check for Understanding

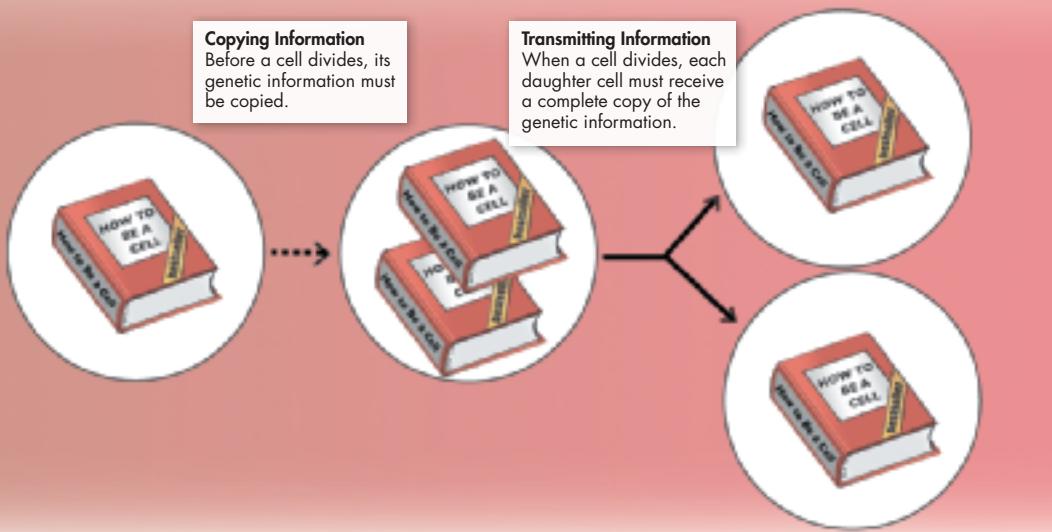
ONE-MINUTE RESPONSE

Write the following prompt on the board, and give students about a minute to write a response summarizing their understanding.

What are the three functions of DNA, and why is each function important to living things? (*Responses should identify storing, copying, and transmitting information, and they should include an explanation of the importance of each function.*)

ADJUST INSTRUCTION

If responses show that students do not understand the three functions of DNA, divide the class into three groups. Assign one function to each group. Then, have each group develop and give a short, creative presentation, such as a rap or song, to help others remember the function.



Transmitting Information As Mendel's work had shown, genes are transmitted from one generation to the next. Therefore, DNA molecules must be carefully sorted and passed along during cell division. Such careful sorting is especially important during the formation of reproductive cells in meiosis. Remember, the chromosomes of eukaryotic cells contain genes made of DNA. The loss of any DNA during meiosis might mean a loss of valuable genetic information from one generation to the next.

12.1 Assessment

Review Key Concepts

1. a. **Review** List the conclusions that Griffith and Avery drew from their experiments.
- b. **Identify Variables** What was the experimental variable that Avery used when he repeated Griffith's work?
2. a. **Review** What conclusion did Hershey and Chase draw from their experiments?
- b. **Infer** Why did Hershey and Chase grow viruses in cultures that contained both radioactive phosphorus and radioactive sulfur? What might have happened if they had used only one radioactive substance?
3. a. **Review** What are the three key roles of DNA?
- b. **Apply Concepts** Why would the storage of genetic information in genes help explain why chromosomes are separated so carefully during mitosis?

SC.912.N.1.6, SC.912.L.16.3

Apply the Big Idea

Science as a Way of Knowing

4. Choose either Griffith, Avery, or Hershey and Chase, and develop a flowchart that shows how that scientist or team of scientists used various scientific methods. Be sure to identify each method. You may use your flowchart from Taking Notes as a guide. If you need to, refer to the descriptions of scientific methods in Chapter 1.

Assess and Remediate

EVALUATE UNDERSTANDING

Call on a student to name a scientist described in this lesson. Then, ask volunteers to describe that scientist's experiment and conclusion. Continue until students have described the work of Griffith, Avery, and Hershey and Chase. Then, have students complete the 12.1 Assessment.

REMEDIATION SUGGESTION

L1 Struggling Students If students have trouble with **Question 2**, ask them to write short paragraphs summarizing Hershey and Chase's experiment in their own words. Tell them that rephrasing the information in their own words promotes comprehension and can help them grasp concepts that are difficult to understand. Then, have students work in pairs to review and revise their paragraphs.



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

Assessment Answers

- 1a. Griffith concluded that a heritable substance transforms harmless bacteria into harmful bacteria. Avery found that this heritable substance is DNA.
- 1b. The experimental variable in Avery's experiment was the type of molecule-destroying enzyme he used.
- 2a. Hershey and Chase concluded that DNA is the genetic material found in genes.
- 2b. Growing viruses in separate cultures that contained both radioactive sulfur and radioactive phosphorus ensured that one

- sample of the virus had radioactive protein and the other sample had radioactive DNA. If only one type of molecule had been marked, they would not have been able to detect both types of molecule, and the results would not have been conclusive.
- 3a. storing, copying, and transmitting genetic information
 - 3b. During mitosis, the cell's DNA is replicated, and each daughter cell receives a copy. If the chromosomes do not separate correctly, the information they carry in

DNA might not be passed correctly to the daughter cells.

4. **Big Idea** Students' flowcharts should describe the work of Griffith, Avery, or Hershey and Chase, including their procedures and conclusions.