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Section 2  Gene Regulation and Structure
Objectives

- **Compare** the structure of RNA with that of DNA.
- **Summarize** the process of transcription.
- **Relate** the role of codons to the sequence of amino acids that results after translation.
- **Outline** the major steps of translation.
- **Discuss** the evolutionary significance of the genetic code.
Decoding the Information in DNA

- **Traits**, such as eye color, are determined by proteins that are built according to instructions coded in **DNA**.

- Proteins, however, are not built directly from **DNA**. **Ribonucleic acid** is also involved.

- Like DNA, **ribonucleic acid (RNA)** is a nucleic acid—a molecule made of nucleotides linked together.
Ribonucleic Acid
Decoding the Information in DNA, continued

• RNA differs from DNA in three ways:

1. RNA consists of a single strand of nucleotides instead of the two strands found in DNA.

2. RNA nucleotides contain the five-carbon sugar ribose rather than the sugar deoxyribose, which is found in DNA nucleotides.

3. In addition to the A, G, and C nitrogen bases found in DNA, RNA nucleotides can have a nitrogen base called uracil (U).
Comparing DNA and RNA
Decoding the Information in DNA, continued

- The instructions for making a protein are transferred from a gene to an RNA molecule in a process called transcription.

- Cells then use two different types of RNA to read the instructions on the RNA molecule and put together the amino acids that make up the protein in a process called translation.
The entire process by which proteins are made based on the information encoded in DNA is called **gene expression**, or protein synthesis.
Gene Expression
Transfer of Information from DNA to RNA

- The first step in the making of a protein, transcription, takes the information found in a gene in the DNA and transfers it to a molecule of RNA.

- **RNA polymerase**, an enzyme that adds and links complementary RNA nucleotides during transcription, is required.
Transfer of Information from DNA to RNA, continued

• The three steps of transcription are:

Step 1 RNA polymerase binds to the gene’s promoter.

Step 2 The two DNA strands unwind and separate.

Step 3 Complementary RNA nucleotides are added.
Transcription

Transcription: Making RNA

RNA polymerase adds complementary RNA nucleotides as it reads the gene.

1. RNA polymerase binds to the gene’s promoter.
2. The two DNA strands unwind and separate.
3. Complementary RNA nucleotides are added.

RNA polymerase

Promoter site on DNA
Transcription
Types of RNA
Types of RNA
The Genetic Code: Three-Nucleotide “Words”

- Different types of RNA are made during transcription, depending on the gene being expressed.
- When a cell needs a particular protein, it is messenger RNA that is made.
- **Messenger RNA (mRNA)** is a form of RNA that carries the instructions for making a protein from a gene and delivers it to the site of translation.
The Genetic Code: Three-Nucleotide “Words”, continued

• The information is translated from the language of RNA—nucleotides—to the language of proteins—amino acids.

• The RNA instructions are written as a series of three-nucleotide sequences on the mRNA called codons.

• The genetic code of mRNA is the amino acids and “start” and “stop” signals that are coded for by each of the possible 64 mRNA codons.
Genetic Code
## Codes in mRNA

<table>
<thead>
<tr>
<th>First base</th>
<th>U</th>
<th>Second base</th>
<th>A</th>
<th>G</th>
<th>Third base</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>UUU, UUC, UUA, UUG</td>
<td>Phenylalanine</td>
<td>UCU, UCC, UCA, UCG</td>
<td>UAU, UAC, UAA, UAG</td>
<td>Tyrosine, Stop</td>
</tr>
<tr>
<td></td>
<td>UGG</td>
<td>Leucine</td>
<td>CGU, CGC, CCA, CCG</td>
<td>CGU, CGC, CGA, CGG</td>
<td>Cysteine, UGA—Stop, UGG—Tryptophan</td>
</tr>
<tr>
<td></td>
<td>CUU, CUC, CUA, CUG</td>
<td>Leucine</td>
<td>CCU, CCC, CCA, CCG</td>
<td>CAU, CAC, CAA, CAG</td>
<td>Histidine, Glutamine</td>
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<td>UUC</td>
<td>Proline</td>
<td>GUU, GUC, GUA, GUG</td>
<td>GAU, GAC, GAA, GAG</td>
<td>Arginine</td>
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<tr>
<td></td>
<td>UAG</td>
<td>Isoleucine</td>
<td>GGU, GGC, GGA, GGG</td>
<td>GCU, GGC, GCA, GCG</td>
<td>Aspartic Acid, Glutamic Acid</td>
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<td>AUG</td>
<td>Start</td>
<td>GGU, GGC, GGA, GGG</td>
<td>GCU, GGC, GCA, GCG</td>
<td>Glycine</td>
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<tr>
<td></td>
<td>AUG</td>
<td>Valine</td>
<td>GCC, GCA, GGG, GGG</td>
<td>GCU, GGC, GCA, GCG</td>
<td>Alanine</td>
</tr>
</tbody>
</table>
Codons in mRNA

[Diagram showing mRNA with codons A, U, G, G, A, C, A, C, A, C, and a tRNA binding.]
RNA’s Roles in Translation

• Translation takes place in the cytoplasm. Here transfer RNA molecules and ribosomes help in the synthesis of proteins.

• Transfer RNA (tRNA) molecules are single strands of RNA that temporarily carry a specific amino acid on one end.

• An anticodon is a three-nucleotide sequence on a tRNA that is complementary to an mRNA codon.
Ribosomes

- Large subunit
- Small subunit
RNA’s Roles in Translation, continued

- Ribosomes are composed of both proteins and ribosomal RNA (rRNA).

- **Ribosomal RNA (rRNA)** molecules are RNA molecules that are part of the structure of ribosomes.

- Each ribosome temporarily holds one mRNA and two tRNA molecules.
tRNA and Anticodon

Rollover the image to learn more.
RNA’s Roles in Translation, continued

- The seven steps of translation are:

  Step 1 The ribosomal subunits, the mRNA, and the tRNA carrying methionine bind together.

  Step 2 The tRNA carrying the amino acid specified by the codon in the A site arrives.

  Step 3 A peptide bond forms between adjacent amino acids.
Translation: Forming the First Peptide Bond

4. The tRNA in the P site detaches and leaves its amino acid behind.

5. The tRNA in the A site moves to the P site. The tRNA carrying the amino acid specified by the codon in the A site arrives.

6. A peptide bond is formed. The tRNA in the P site detaches and leaves its amino acid behind.

7. The process is repeated until a stop codon is reached. The ribosome complex falls apart. The newly made protein is released.
Step 4 The tRNA in the P site detaches and leaves its amino acid behind.

Step 5 The tRNA in the A site moves to the P site. The tRNA carrying the amino acid specified by the codon in the A site arrives.

Step 6 A peptide bond is formed. The tRNA in the P site detaches and leaves its amino acid behind.

Step 7 The process is repeated until a stop codon is reached. The ribosome complex falls apart. The newly made protein is released.
Translation: Assembling Proteins

Amino acids are assembled from information encoded in mRNA.

1. The ribosomal subunits, the mRNA, and the tRNA carrying methionine bind together.
2. The tRNA carrying the amino acid specified by the codon in the P site arrives.
3. A peptide bond forms between adjacent amino acids.
4. The mRNA in the P site detaches and leaves its amino acid behind.
5. The tRNA carrying the amino acid specified by the codon in the A site arrives.
6. A peptide bond is formed. The tRNA in the P site detaches and leaves its amino acid behind.
7. The process is repeated until a stop codon is reached. The ribosome complex falls apart, and the newly made protein is released.
Translation

QuickTime™ and a Sorenson Video 3 decompressor are needed to see this picture.
Snapshot of Translation

Rollover the image to learn more.
Objectives

• **Describe** how the *lac* operon is turned on or off.

• **Summarize** the role of transcription factors in regulating eukaryotic gene expression.

• **Describe** how eukaryotic genes are organized.

• **Evaluate** three ways that point mutations can alter genetic material.
Protein Synthesis in Prokaryotes

• Both prokaryotic and eukaryotic cells are able to regulate which genes are expressed and which are not, depending on the cell’s needs.

• The piece of DNA that overlaps the promoter site and serves as the on-off switch is called an operator.

• In bacteria, a group of genes that code for enzymes involved in the same function, their promoter site, and the operator that controls them all function together as an operon.
Operon

An Operon

Structural genes

Regulator gene
Promoter
Operator

1 2 3
Protein Synthesis in Prokaryotes, continued

- The operon that controls the metabolism of lactose is called the *lac operon*.

- When there is no lactose in the bacterial cell, a repressor turns the operon off.

- A repressor is a protein that binds to an operator and physically blocks RNA polymerase from binding to a promoter site.
Mechanism of *lac* Operon

Lactose absent—the *lac* operon is off.

Lactose present—the *lac* operon is on.

Lactose bound to repressor protein

Transcription proceeds
Repression of Transcription in the *lac* Operon

*lac* operon

- Regulator gene
- Promoter
- Operator
- Structural genes

1 2 3
Section 2 Gene Regulation and Structure

Chapter 10

Activation of Transcription in the *lac* Operon

Diagram showing the *lac* operon with a Repressor protein, a Regulator gene, a Promoter, an Operator, and Structural genes 1, 2, and 3.
Protein Synthesis in Eukaryotes

Controlling the Onset of Transcription

• Most gene regulation in eukaryotes controls the onset of transcription—when RNA polymerase binds to a gene.

• Transcription factors help arrange RNA polymerases in the correct position on the promoter.

• An enhancer is a sequence of DNA that can be bound by a transcription factor.
Enhancers for Control of Gene Expression

- DNA
- Enhancer
- Promoter
- Coding region of gene
Controlling Transcription in Eukaryotes

Diagram:
- DNA
- Enhancer
- Promoter
- Coding region of gene
- Activator
- RNA polymerase
- Transcription factor
- Transcription begins
Intervening DNA in Eukaryotic Genes

- In eukaryotes, many genes are interrupted by **introns**—long segments of nucleotides that have no coding information.

- **Exons** are the portions of a gene that are translated (expressed) into proteins.

- After a eukaryotic gene is transcribed, the **introns** in the resulting mRNA are cut out by complex assemblies of RNA and protein called **spliceosomes**.
Removal of Introns After Transcription

1. DNA is transcribed into pre-mRNA.
2. Introns are removed.
3. The remaining exons are spliced together in mRNA.
4. The mRNA strand leaves the nucleus and enters the cytoplasm for translation into a protein.
Comparing Introns and Exons
Mutations
Mutations

- **Mutations** that move an entire gene to a new location are called **gene rearrangements**.

- Changes in a gene’s position often disrupt the gene’s function because the gene is exposed to new regulatory controls in its new location.

- Genes sometimes move as part of a **transposon**. Other times, the portion of the chromosome containing a gene may be rearranged during **meiosis**.
Mutations, continued

- Mutations that change a gene are called gene alterations.

- In a **point mutation**, a single nucleotide changes.

- In an **insertion mutation**, a sizable length of DNA is inserted into a gene.

- In a **deletion mutation**, segments of a gene are lost, often during meiosis.
Mutations, *continued*

- Because the genetic message is read as a series of triplet nucleotides, *insertions* and *deletions* of one or two nucleotides can upset the triplet groupings.

- A mutation that causes a gene to be read in the wrong three-nucleotide sequence is called a *frameshift mutation*.
Major Types of Mutations

No Mutation

Gene Rearrangements

Transposition

Chromosomal rearrangement

Gene Alterations

Point mutation

Insertion

Deletion
Section 2 Gene Regulation and Structure

Types of Gene Mutations

Click a thumbnail image to learn more.
Multiple Choice

Use the figure below to answer questions 1–3.
Multiple Choice, continued

1. Which cellular function does this model represent?

A. Transcription  
B. Translation  
C. Transformation  
D. DNA Replication
Multiple Choice, continued

1. Which cellular function does this model represent?

A. Transcription
B. Translation
C. Transformation
D. DNA Replication
Multiple Choice, continued

2. Which part of the model represents a codon?

F. A
G. B
H. C
J. D
Multiple Choice, continued

2. Which part of the model represents a codon?

F. A
G. B
H. C
J. D
Multiple Choice, continued

3. What does the part labeled E represent?

A. Ribosome
B. Growing protein chain
C. Messenger RNA
D. Transfer RNA
Multiple Choice, continued

3. What does the part labeled $E$ represent?

A. Ribosome
B. Growing protein chain
C. Messenger RNA
D. Transfer RNA