Lesson Summary

- The central dogma of molecular biology states that DNA contains instructions for making a protein, which are copied by RNA. RNA then uses the instructions to make a protein. In short: *DNA* $\rightarrow$ *RNA* $\rightarrow$ *Protein*.
- The work of several researchers led to the discovery that DNA is the genetic material. Other researchers discovered that DNA has a double helix shape, consisting of two polynucleotide chains held together by bonds between complementary bases.
- RNA differs from DNA in several ways. There three main types of RNA: messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA). Each type plays a different in role in making proteins.

Lesson Review Questions

Recall

1. State the central dogma of molecular biology.
2. Outline research that determined that DNA is the genetic material.
3. What are Chargaff's rules?
4. Identify the structure of the DNA molecule.
5. Why is DNA replication said to be semi-conservative?

Apply Concepts

6. Create a diagram that shows how DNA replication occurs.

Think Critically

7. Explain why complementary base pairing is necessary to maintain the double helix shape of the DNA molecule.

8. Compare and contrast DNA and RNA.

Points to Consider

All three types of RNA are needed by cells to make proteins.

- Can you develop a model in which the three types of RNA interact to make a protein?
- How do you think mRNA copies the genetic instructions in DNA? How are these instructions encoded in the DNA molecule?

7.2 Protein Synthesis Lesson Objectives

- Give an overview of transcription.
- Describe the genetic code.
- Explain how translation occurs.

Vocabulary

- codon
- genetic code
- promoter
- protein synthesis
- transcription
- translation

Introduction

The process in which cells make proteins is called protein synthesis. It actually consists of two processes: transcription and translation. Transcription takes place in the nucleus. It uses DNA as a template to make an RNA molecule. RNA then leaves the nucleus and goes to a ribosome in the cytoplasm, where translation occurs. Translation reads the genetic code in mRNA and makes a protein.

Transcription

Transcription is the .rst part of the central dogma of molecular biology: DNA → RNA. It is the transfer of genetic instructions in DNA to mRNA. During transcription, a strand of mRNA is made that is complementary to a strand of DNA. Figure 7.6 shows how this occurs. You can watch an animation of the process at this link: http://www.biostudio.com/d_%20Transcription.htm.

- A detailed video about transcription is available at this link: http://vcell.ndsu.edu/animations/transcription/movie-flash.htm.

Steps of Transcription

Transcription takes place in three steps: initiation, elongation, and termination. The steps are illustrated in Figure 7.7.

1. Initiation is the beginning of transcription. It occurs when the enzyme RNA polymerase binds to a region of a gene called the promoter. This signals the DNA to unwind so the enzyme can "read" the bases in one of the DNA strands. The enzyme is ready to make a strand of mRNA with a complementary sequence of bases.
2. Elongation is the addition of nucleotides to the mRNA strand.
3. Termination is the ending of transcription. The mRNA strand is complete, and it detaches from DNA.

Processing mRNA

In eukaryotes, the new mRNA is not yet ready for translation. It must go through more processing before it leaves the nucleus. This may include splicing, editing, and polyadenylation. These processes modify the mRNA in various ways. Such modi.cations allow a single gene to be used to make more than one protein.

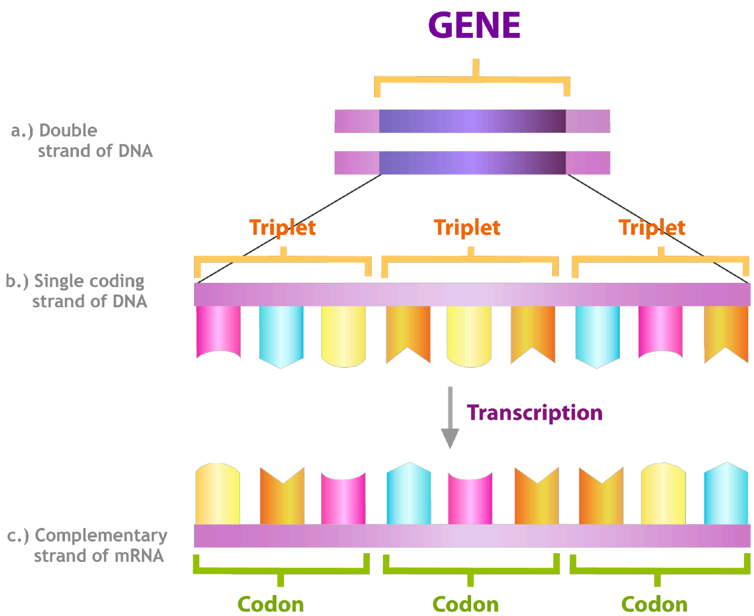

Figure 7.6: Overview of Transcription. Transcription uses the sequence of bases in a strand of DNA to make a complementary strand of mRNA. Triplets are groups of three successive nucleotide bases in DNA. Codons are complementary groups of bases in mRNA.

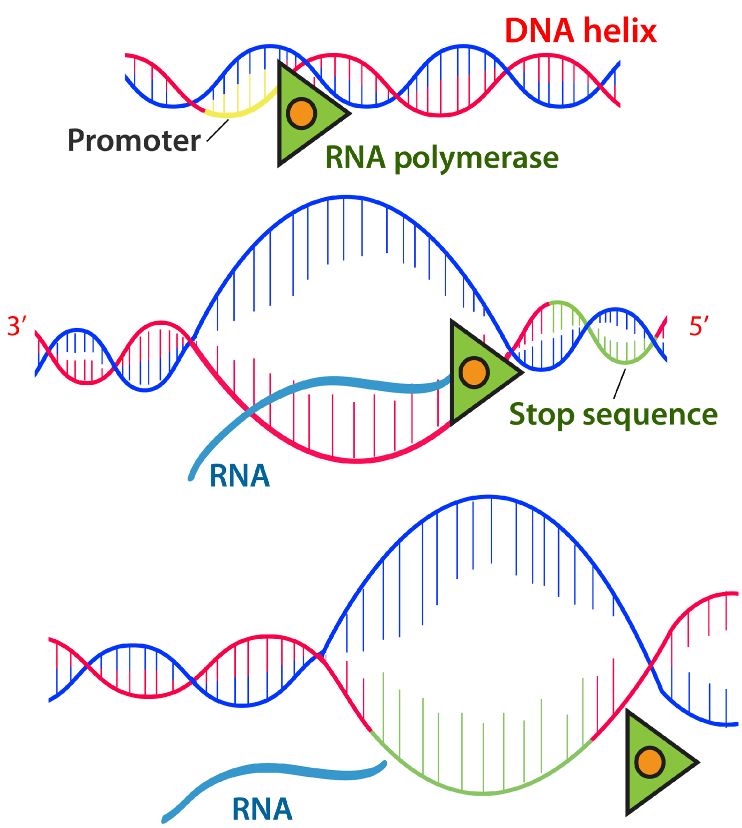

Figure 7.7: Steps of Transcription. Transcription occurs in the three steps - initiation, elongation, and termination - shown here.

- Splicing removes introns from mRNA (see **Figure** 7.8). Introns are regions that do not code for proteins. The remaining mRNA consists only of regions that do code for proteins, which are called exons. You can watch a video showing splicing in more detail at this link: http://vcell.ndsu.edu/animations/mrnasplicing/movie-flash.htm.
- Editing changes some of the nucleotides in mRNA. For example, the human protein called APOB, which helps transport lipids in the blood, has two different forms because of editing. One form is smaller than the other because editing adds a premature stop signal in mRNA.
- Polyadenylation adds a "tail" to the mRNA. The tail consists of a string of As (adenine bases). It signals the end of mRNA. It is also involved in exporting mRNA from the nucleus. In addition, the tail protects mRNA from enzymes that might break it down.

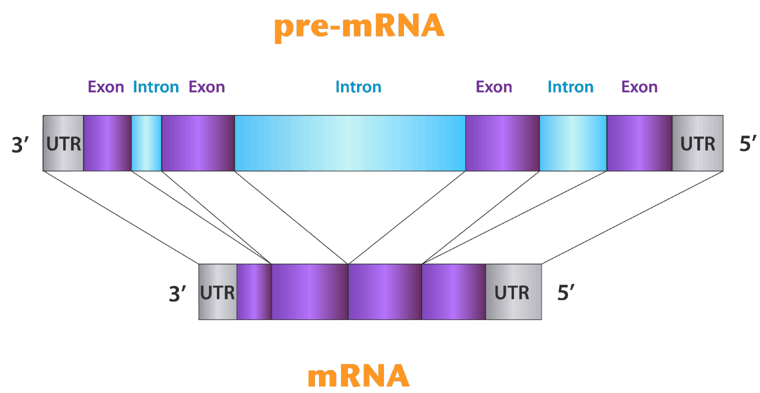

Figure 7.8: Splicing. Splicing removes introns from mRNA. UTR is an untranslated region of the mRNA.

The Genetic Code

How is the information in a gene encoded? The answer is the genetic code. The **genetic code** consists of the sequence of nitrogen bases—A, C, G, T (or U)—in a polynucleotide chain. The four bases make up the "letters" of the genetic code. The letters are combined in groups of three to form code "words," called **codons**. Each codon stands for (encodes) one amino acid, unless it codes for a start or stop signal. There are 20 common amino acids in proteins. There are 64 possible codons, more than enough to code for the 20 amino acids. The genetic code is shown in **Figure** 7.9. To see how scientists cracked the genetic code, go to this link: http://www.dnalc.org/view/16494-Animation-22-DNA-words-are-three-letters-long-.html.

Reading the Genetic Code

As shown in **Figure** 7.9, the codon AUG codes for the amino acid methionine. This codon is also the start codon that begins translation. The start codon establishes the reading frame of mRNA. The reading frame is the way the letters are divided into codons. After the AUG start codon, the next three letters are read as the second codon. The next three letters after that are read as the third codon, and so on. This is illustrated in **Figure** 7.10. The mRNA molecule is read, codon by codon, until a stop codon is reached. UAG, UGA, and UAA are all stop codons. They do not code for any amino acids.

Characteristics of the Genetic Code

The genetic code has a number of important characteristics.

1st base	2nd base: U	2nd base: C	2nd base: A	2nd base: G
U	UUU (Phe/F) Phenylalanine	UCU (Ser/S) Serine	UAU (Tyr/Y) Tyrosine	UGU (Cys/C) Cysteine
U	UUC (Phe/F) Phenylalanine	UCC (Ser/S) Serine	UAC (Tyr/Y) Tyrosine	UGC (Cys/C) Cysteine
U	UUA (Leu/L) Leucine	UCA (Ser/S) Serine	UAA Ochre (*Stop*)	UGA Opal (*Stop*)
U	UUG (Leu/L) Leucine	UCG (Ser/S) Serine	UAG Amber (*Stop*)	UGG (Trp/W) Tryptophan
C	CUU (Leu/L) Leucine	CCU (Pro/P) Proline	CAU (His/H) Histidine	CGU (Arg/R) Arginine
C	CUC (Leu/L) Leucine	CCC (Pro/P) Proline	CAC (His/H) Histidine	CGC (Arg/R) Arginine
C	CUA (Leu/L) Leucine	CCA (Pro/P) Proline	CAA (Gln/Q) Glutamine	CGA (Arg/R) Arginine
C	CUG (Leu/L) Leucine	CCG (Pro/P) Proline	CAG (Gln/Q) Glutamine	CGG (Arg/R) Arginine
A	AUU (Ile/I) Isoleucine	ACU (Thr/T) Threonine	AAU (Asn/N) Asparagine	AGU (Ser/S) Serine
A	AUC (Ile/I) Isoleucine	ACC (Thr/T) Threonine	AAC (Asn/N) Asparagine	AGC (Ser/S) Serine
A	AUA (Ile/I) Isoleucine	ACA (Thr/T) Threonine	AAA (Lys/K) Lysine	AGA (Arg/R) Arginine
A	AUG[A] (Met/M) Methionine	ACG (Thr/T) Threonine	AAG (Lys/K) Lysine	AGG (Arg/R) Arginine
G	GUU (Val/V) Valine	GCU (Ala/A) Alanine	GAU (Asp/D) Aspartic acid	GGU (Gly/G) Glycine
G	GUC (Val/V) Valine	GCC (Ala/A) Alanine	GAC (Asp/D) Aspartic acid	GGC (Gly/G) Glycine
G	GUA (Val/V) Valine	GCA (Ala/A) Alanine	GAA (Glu/E) Glutamic acid	GGA (Gly/G) Glycine
G	GUG (Val/V) Valine	GCG (Ala/A) Alanine	GAG (Glu/E) Glutamic acid	GGG (Gly/G) Glycine

nonpolar	polar	basic	acidic	(stop codon)

Figure 7.9: The Genetic Code. To find the amino acid for a particular codon, find the cell in the table for the first and second bases of the codon. Then, within that cell, find the codon with the correct third base. For example CUG codes for leucine, AAG codes for lysine, and GGG codes for glycine.

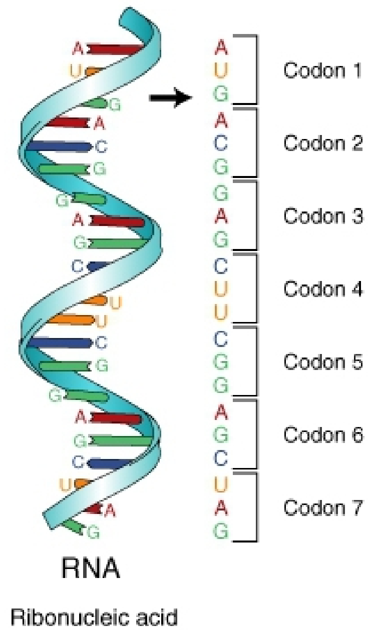

Figure 7.10: Reading the Genetic Code. The genetic code is read three bases at a time. Codons are the code words of the genetic code. Which amino acid does codon 2 in the drawing stand for?

- The genetic code is universal. All known living things have the same genetic code. This shows that all organisms share a common evolutionary history.
- The genetic code is unambiguous. Each codon codes for just one amino acid (or start or stop). What might happen if codons encoded more than one amino acid?
- The genetic code is redundant. Most amino acids are encoded by more than one codon. In **Figure** 7.9, how many codons code for the amino acid threonine? What might be an advantage of having more than one codon for the same amino acid?

Translation

Translation is the second part of the central dogma of molecular biology: **RNA → Protein**. It is the process in which the genetic code in mRNA is read to make a protein. **Figure** 7.11 shows how this happens. After mRNA leaves the nucleus, it moves to a ribosome, which consists of rRNA and proteins. The ribosome reads the sequence of codons in mRNA. Molecules of tRNA bring amino acids to the ribosome in the correct sequence. To understand the role of tRNA, you need to know more about its structure. Each tRNA molecule has an anticodon for the amino acid it carries. An anticodon is complementary to the codon for an amino acid. For example, the amino acid lysine has the codon AAG, so the anticodon is UUC. Therefore, lysine would be carried by a tRNA molecule with the anticodon UUC. Wherever the codon AAG appears in mRNA, a UUC anticodon of tRNA temporarily binds. While bound to mRNA, tRNA gives up its amino acid. Bonds form between the amino acids as they are brought one by one to the ribosome, forming a polypeptide chain. The chain of amino acids keeps growing until a stop codon is reached. To see how this happens, go the link below. http://www.youtube.com/watch?v=B6O6uRb1D38&feature=related (1:29)

After a polypeptide chain is synthesized, it may undergo additional processes. For example, it may assume a folded shape due to interactions among its amino acids. It may also bind with other polypeptides or with

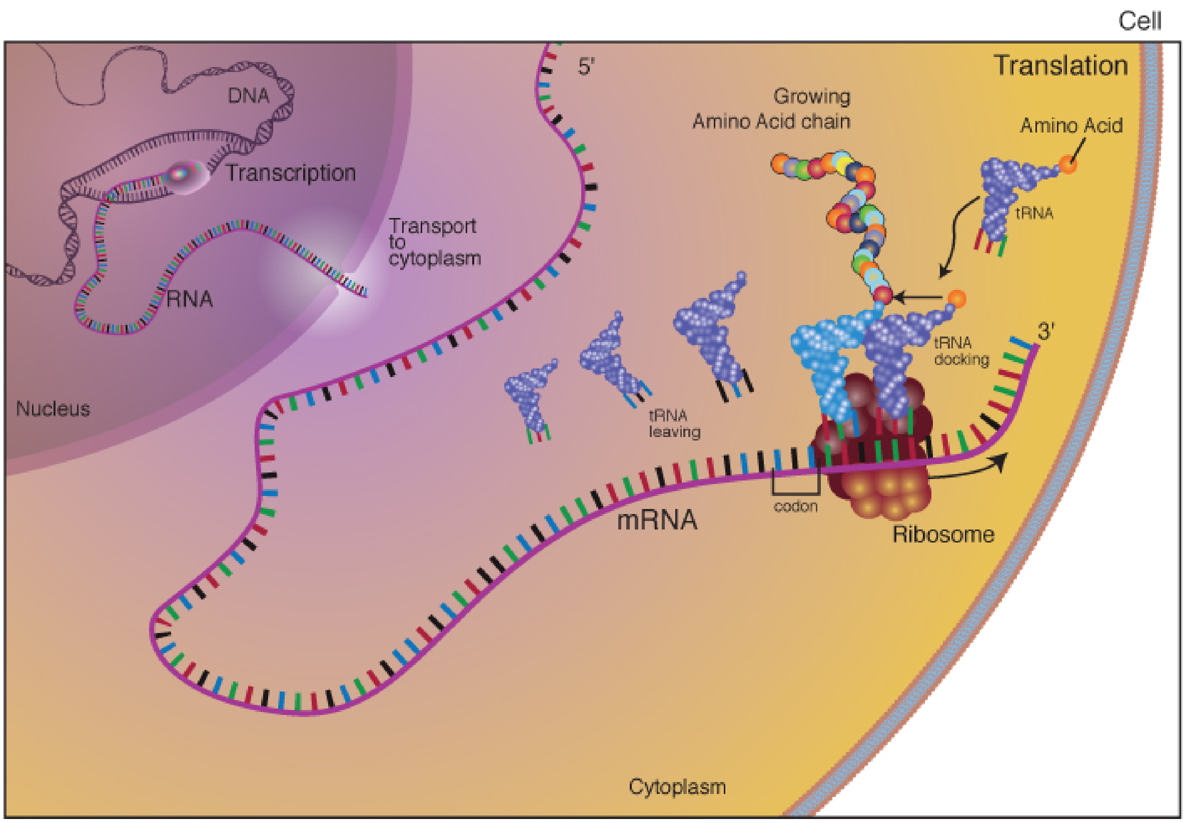

Figure 7.11: Translation. Translation of the codons in mRNA to a chain of amino acids occurs at a ribosome. Find the different types of RNA in the diagram. What are their roles in translation?

different types of molecules, such as lipids or carbohydrates. Many proteins travel to the Golgi apparatus to be modified for the specific job they will do. You can see how this occurs by watching the animation at this link: http://vcell.ndsu.edu/animations/proteinmodification/movie-flash.htm.

Lesson Summary

- Transcription is the *DNA → RNA* part of the central dogma of molecular biology. It occurs in the nucleus. During transcription, a copy of mRNA is made that is complementary to a strand of DNA. In eukaryotes, mRNA may be modified before it leaves the nucleus.
- The genetic code consists of the sequence of bases in DNA or RNA. Groups of three bases form codons, and each codon stands for one amino acid (or start or stop). The codons are read in sequence following the start codon until a stop codon is reached. The genetic code is universal, unambiguous, and redundant.
- Translation is the *RNA → protein* part of the central dogma. It occurs at a ribosome. During translation, a protein is synthesized using the codons in mRNA as a guide. All three types of RNA play a role in translation.

Lesson Review Questions

Recall

1. Describe transcription.

2. How may mRNA be modified before it leaves the nucleus?

3. What is the genetic code? What are codons?

4. Outline the steps of translation.

Apply Concepts

5. Use the genetic code in **Figure** 7.9 to translate the following segment of RNA into a sequence of five amino acids:

GUC-GCG-CAU-AGC-AAG

Think Critically

6. The genetic code is universal, unambiguous, and redundant. Explain what this means and why it is important.

7. How are transcription and translation related to the central dogma of molecular biology?

Points to Consider

When DNA is replicated or transcribed, accidents can happen, leading to a change in the base sequence.

- What do you think could cause such accidents to occur?
- How might the changes affect the reading frame? How might the encoded protein be affected?