LEGO® DNA/RNA
Booklet 1: Structure, Replication, and Transcription

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1. Remove all the nucleotides from the kit. Place each one on top of its picture on the DNA and RNA Layout Mats. Check each nucleotide with its picture.

2. Use the Team Kit Care Record as your teacher instructs. Record any missing, broken, or extra pieces.

There are 2 mats for the DNA nucleotides. There is only 1 mat for the RNA nucleotides. Which nucleotides have an orange brick? Which have the gray brick?

*Note: This LEGO Kit has 72 nucleotides total, including all the duplicates.*
Cell Structures

To understand how proteins can be made from DNA instructions, you will need to recognize a few structures inside the cell.

1. Look at the cell diagram below. Study the important cell parts and what they do.

2. Find the nucleus of the cell. The nucleus is filled with DNA, the instructions for life. DNA is built from smaller molecules called nucleotides.

- **nucleus** (gray): A sack of DNA in the cell. DNA is stored here and cannot leave.
- **cell membrane** (yellow): A layer of molecules around the cell that works like a skin.
- **cytoplasm** (blue): A gel-like substance in the cell that surrounds the nucleus. It contains many useful molecules.
- **ribsome** (green): A small, dense unit that works like a tool bench to help build proteins from instructions in the DNA.
Introduction to Nucleotides

1. Take 1 of each color nucleotide. Hold a nucleotide in your hand and study the picture to identify the parts (phosphate group, sugar, base).

2. Look at the bases of all nucleotides. Which bases are bigger?
1. DNA contains messages. **Build the bottom strand of DNA**: ATG CCC TAG. Make sure all the arrows point **to the right** (in the direction you read).

2. DNA is double stranded. **Create the top strand of DNA using these rules**:
   - DNA strands go in opposite directions
   - Bigger nucleotides pair with smaller nucleotides
   - Top and bottom DNA strands are parallel

   ![Diagram of DNA strands with arrows showing direction]

   Notice the direction of the arrows.
Which bases pair together? You have just discovered the famous base pairing rule!

Notice the direction of the arrows on each side of the DNA. DNA strands have a direction.

3. **Unsnap** the DNA by pinching and pulling up on the sides of the DNA ladder. The two DNA strands will snap apart. In a cell, the two DNA strands must separate to create new DNA.
Overview of DNA, Genes, and Chromosomes

These three terms are often confusing: DNA, genes, and chromosomes. Let's use the diagram below. The diagram represents a double stranded DNA molecule, which has been untwisted and laid flat. It looks like a ladder.

- DNA is made of two strands, Strand A (top) and Strand B (bottom), as shown here. The strands can be easily separated where they meet in the middle, like the LEGO DNA.
- Note that both strands contain coded messages of DNA nucleotides, called genes.
- The strands are like one-way streets. Molecules reading the codes can only read in one direction.
- DNA is an abbreviation for DeoxyriboNucleic Acid, the chemical name for the molecule. Both genes and chromosomes are made of DNA. Find the words in red below and review the picture definitions.

Chromosome

This is a very short example. The shortest human chromosome has 47 million base pairs (47 millions steps on the DNA ladder) and is made of hundreds of genes.
DNA Replication

The process of copying a DNA molecule is called DNA replication. Let's try it!

1. Build this strand of DNA: GCA TGC ACA TTG. (The gaps between every three letters will help you build the sequence correctly.) Add a white marker to the G on the GCA end.

2. Make a complementary DNA strand on top using the base pairing rules. Add a white marker to the second strand. Both strands of the original DNA are now marked so we can follow what happens to them.

Notice the white markers on the original strands.
3. Now we begin the process of DNA replication! **Unsnap** your DNA strands from one end, as shown below. In real DNA, weak hydrogen bonds (represented by the LEGO black joint) allow the two DNA strands to separate from each other easily.
4. Make base pairs following along after the opening as shown below.
5. Continue unsnapping the DNA strands and adding nucleotides until you have two complete DNA molecules.

Notice the white markers on the original strands.

Congratulations! DNA replication is complete.

6. Look carefully at your two molecules of DNA. Are both molecules identical? Was the copying perfect? Notice the markers on the molecules. Remember you marked the original DNA strands before the copying process began. Where did the original strands end up?

DNA replication is called a semi-conservative process. One strand is conserved (or kept) in the copying process. In other words, there is one original strand in each new molecule.
DNA Directs Protein Synthesis

The codes in DNA are the instructions for making proteins. Here is the gene for making the alpha chain of a channel protein. (If you aren't familiar with channel proteins, see LEGO Proteins Booklet 1.)

| Codon | A | T | G | C | C | C | G | G | A | G | C | G | T | A | C | T | A | T | A | G |
| Amino acid # | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

The DNA nucleotides have been grouped in threes. A group of 3 nucleotides is called a codon. Each codon codes for a different amino acid.

Here are the steps to make a protein inside the cell:
- The gene is copied into a temporary message. The process of copying is called transcription.
- The temporary message is called messenger RNA (mRNA). This message can leave the nucleus and attach to a ribosome.
- The ribosome uses transfer RNA (tRNA) to read the message and make a protein.

Let's reenact the process of making a protein from a gene using the LEGO molecules! Your teacher will tell you which gene to build on page 14.
1. Build the gene from DNA nucleotides exactly in the order shown above. Add a LEGO white marker to the A of the ATG end. Then add the correct base pairs to make the DNA double stranded.
Decoding the Messages in DNA

DNA can be decoded by reading in the direction of the arrows. Each arrow points towards the 3’ end of the nucleotide. In the picture, the bottom strand of DNA reads: ATG. What will the top strand read?

Three nucleotides in a row, called a codon, code for a particular amino acid. For instance, the DNA sequence ATG (shown below) codes for the amino acid, Methionine (Met). Decode your DNA with the following steps:

1. Obtain the pack of cards for your gene (alpha, alpha mutated, beta, or beta mutated).

2. Look up the nucleotides in groups of 3. Use the table on pages 16-17 to find the correct amino acid.

3. Select the correct amino acid card. Slide the amino acid card under the DNA strand as shown in the photo.

4. Continue decoding the DNA nucleotides, in groups of 3, until the end.

5. Look at the order of the amino acids. Imagine they are joined together in a chain. Notice this sequence of amino acids seems familiar.

You can now see that the DNA nucleotides determine the order of the amino acids in a protein.
## Amino Acid DNA Code

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>DNA Code</th>
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<tbody>
<tr>
<td>Lysine</td>
<td>AAA   AAG</td>
</tr>
<tr>
<td>Asparagine</td>
<td>AAT   AAC</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>ATT   ATC   ATA</td>
</tr>
<tr>
<td>Methionine</td>
<td>ATG</td>
</tr>
<tr>
<td>Threonine</td>
<td>ACT   ACC   ACA   ACG</td>
</tr>
<tr>
<td>Serine</td>
<td>TCT   TCC   TCA   TCG   AGT   AGC</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>TAT   TAC</td>
</tr>
<tr>
<td>Stop</td>
<td>TAA   TAG   TGA</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>TGG</td>
</tr>
<tr>
<td>Cysteine</td>
<td>TGT   TGC</td>
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Page 16
<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Codons</th>
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<tr>
<td>Phenylalanine</td>
<td>TTT TTC</td>
</tr>
<tr>
<td>Leucine</td>
<td>CTT CTC CTA CTG TTA TTG</td>
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<tr>
<td>Proline</td>
<td>CCT CCC CCA CCG</td>
</tr>
<tr>
<td>Glutamine</td>
<td>CAA CAG</td>
</tr>
<tr>
<td>Histidine</td>
<td>CAT CAC</td>
</tr>
<tr>
<td>Arginine</td>
<td>CGT CGC CGA CGG AGA AGG</td>
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<tr>
<td>Alanine</td>
<td>GCT GCC GCA GCG</td>
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<tr>
<td>Glycine</td>
<td>GGT GGC GGA GGG</td>
</tr>
<tr>
<td>Valine</td>
<td>GTT GTC GTA GTG</td>
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<tr>
<td>Glutamic acid</td>
<td>GAA GAG</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>GAT GAC</td>
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</table>
Transcription

Transcription is the process of copying a gene. The copy is made from RNA nucleotides. RNA is an abbreviation for Ribonucleic Acid, the chemical name for the molecule. These single stranded RNA molecules, called messenger RNA (mRNA), can leave the nucleus, while the DNA cannot. Thus the mRNA delivers copies of the DNA code to the ribosomes in the cytoplasm.

1. Position the ATG end of the gene on the bottom as shown in the photo.

2. Separate the two strands of DNA.

3. Pair with the top strand of DNA to make your mRNA. Follow the base pairing rules, except T (Thymine) is replaced by U (Uracil) in mRNA. The top strand of DNA is opposite the gene. Note that base pairing with the opposite strand ensures that an exact copy of the message is produced.

4. Check your mRNA strand with the bottom strand of DNA (the gene). It should be the same sequence except each T is now a U.

5. Attach a white LEGO marker to the A on the AUG end of the mRNA to mark the start. Now your mRNA is ready to leave the nucleus and attach to a ribosome, where the protein will be made.
## Amino Acid RNA Code (Genetic Code)

<table>
<thead>
<tr>
<th>First Letter</th>
<th>Second Letter</th>
<th>Third Letter</th>
</tr>
</thead>
<tbody>
<tr>
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<td>UUU</td>
<td>Leu</td>
</tr>
<tr>
<td></td>
<td>UUC</td>
<td>Leu</td>
</tr>
<tr>
<td></td>
<td>UUA</td>
<td>Leu</td>
</tr>
<tr>
<td></td>
<td>UUG</td>
<td>Leu</td>
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<tr>
<td></td>
<td>UCU</td>
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<td></td>
<td>UCC</td>
<td>Ser</td>
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<tr>
<td></td>
<td>UCG</td>
<td>Ser</td>
</tr>
<tr>
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<td>CUC</td>
<td>Leu</td>
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<tr>
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<td>Leu</td>
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</tr>
<tr>
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<tr>
<td></td>
<td>GGG</td>
<td>Gly</td>
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</table>

**Codons and Amino Acids:**

- **Leucine**
- **Proline**
- **Asparagine**
- **Glutamine**
- **Isoleucine**
- **Histidine**
- **Methionine**
- **Arginine**
- **Threonine**
- **Alanine**
- **Serine**
- **Valine**
- **Tyrosine**
- **Glycine**
- **Stop**
- **Tryptophan**
- **Glutamic acid***
- **Cysteine**
- **Aspartic acid***
- **Phenylalanine**

*Note: The table and diagram are color-coded for visual distinction.*

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Answer Key

Page 2: Orange = RNA ; Gray = DNA

Page 4: A (Adenine) and G (Guanine) are bigger bases.

Page 7: A pairs with T, C pairs with G.

Page 12: Yes, both molecules are identical. Yes, the copying was perfect. One original strand ended up in each new molecule.

Page 15: The top strand reads C A T (read with the arrows - right to left).