The Central Dogma: How our DNA code makes Phenotype

DNA → RNA → Protein

How are we so different? Why are we not identical to a plant? Or a bacterium? Or each other?

The DNA code is the same in all organisms but the sequence of the letters is different. All life uses A,C,T,G in double-stranded base pairs. This is the same concept that *War and Peace* is not identical to your IPod Warranty, but they’re still written in English. DNA is just a language. A very, very, very important language.

This is why scientists can manipulate life in the laboratory so easily. This is also the key to understanding a single common ancestor.

**DNA is the code of life** – ACTGs are the alphabet of life, just like 0s and 1s are the binary code of computers. The ACTGs of DNA can be read by enzymes to create a triplet codon that is interpreted into 20 amino acids to make very diverse proteins. **DNA is letters; codons are words; proteins are messages that make sense.**
**1st Idea: LifeContainsDNA:** it is a **SELF-REPLICATINGmolecule.**

DNA replicates itself (via DNA polymerase and other enzymes) in a **semi-conservative** manner. This means that at the end of replication, each of the daughter molecules has one old strand, from the parent strand of DNA, and one strand that is newly synthesized. (see pic).

Adenine pairs with Thymine (A = T)
Guanine pairs with Cytosine (G = C)
The bonds between the base pairs are **hydrogen bonds**

If given the template strand of DNA below, what is the complementary sequence?

5’ A T G T A T G C C A A T G C A 3’

3’ T A C A T A C G G T T A C G T 5’

*FYI: How’d they figure this stuff out? With radioactive isotopes of nitrogen, sulfur and phosphorus.*

**DNA proofreading:** the enzymes involved make sure this process makes an exact message (only 1 in 10 billion base pairs would be incorrect; better than computer coding mechanisms)

**DNA STRUCTURE**
Nucleic Acid (polymer) is made of nucleotides (monomer)

**IDENTIFY EACH AS W, X, OR Z IN THE DIAGRAM**
A nucleotide is made of: a sugar,  X, 
 a phosphate group = W,  
 and a nitrogenous base = Z.

**DNA REPLICATION**
DNA polymerase is an enzyme (ends in -ase). **All enzymes have a specific active site.** The DNA in this example is the substrate and only can fit into the enzyme (DNA polymerase) a certain way. This is why DNA replication has a **leading** and a **lagging** strand when made. The enzyme can only fit onto DNA via the 3’ hydroxyl side, not the 5’ phosphate side.

What letter in this diagram represents the **continuous** leading strand? b  
What letter represents the Okazaki **fragments** of the lagging strand? c
PROKARYOTES VS EUKARYOTES

Prokaryotes (“before nucleus”) evolved before eukaryotes (“true nucleus”) and have slight differences in their DNA structure.

What can you deduce from the picture?

- **Prokaryote** - less complex, no organelles (including nucleus), circular DNA
- **Eukaryote** - has a nucleus, DNA in multiple non-looped chromatids

Both have DNA

Page 43

2nd Idea: DNA is the source message but RNA is the working copy

<table>
<thead>
<tr>
<th>Major Differences Between DNA and RNA</th>
<th>DNA</th>
<th>RNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>deoxyribose sugar</td>
<td>ribose sugar</td>
<td></td>
</tr>
<tr>
<td>thymine</td>
<td>uracil</td>
<td></td>
</tr>
<tr>
<td>double helix</td>
<td>single stranded (mRNA) or unit (tRNA)</td>
<td></td>
</tr>
<tr>
<td>permanent</td>
<td>temporary</td>
<td></td>
</tr>
<tr>
<td>in nucleus (some in mitochondria)</td>
<td>leaves nucleus, works in cytoplasm</td>
<td></td>
</tr>
<tr>
<td>one kind</td>
<td>many kinds (at least 3)</td>
<td></td>
</tr>
</tbody>
</table>

The DNA is like the encyclopedia you can never check out of the library. However, you are allowed to make copies of the information. That’s what RNA is - a copied message of the important pages. Making copies ensures that you don’t ‘ruin’ the original by taking it out of the nucleus (this only applies to eukaryotes), you can make copies in bulk, AND you only have to make copies of what you need. You wouldn’t copy all 6000 pages of an encyclopedia would you? No! Only the 4-5 pages you might need for a report. In eukaryotes, we only code for ~ 2% of our DNA!

RNA (ribonucleic acid) is the intermediate between DNA and protein. It has slight differences to DNA. See the chart.

TRANSCRIPTION is the process of making RNA from DNA (via the enzyme RNA polymerase). This happens in the nucleus for eukaryotes, but would happen in cytoplasm for prokaryotes.

Watch a refresher video of the process on the protein synthesis page for [www.udkeystone.wikispaces.com](http://www.udkeystone.wikispaces.com)

Can you complete this message?
Important Points about TRANSCRIPTION: DNA → RNA → Protein

- **RNA Polymerase** scans the genome for the promoter region of DNA (the start signal)
- A single-stranded copy of RNA is made of the DNA gene, where U is complementary to A instead of T.
- Transcription and Translation occur simultaneously in the cytoplasm for prokaryotes, with no editing needed.
- **Transcription occurs in nucleus for eukaryotes.**
- Eukaryotic messageRNA has EXONS (expressed message) and INTRONS (in-between message)
- Introns get spliced (cut out) of the mRNA to make the mature transcript.

**WHY INTRONS?**

Alternative splicing allows to mix-n-match exons to make different proteins from the same sequence. This is a major source of eukaryotic evolution!

This is like you being able to make 20 different outfits in your closet from 4 pairs of pants and 5 shirts.

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3rd Idea: **Translation is matching an amino acid to the messageRNA in order to make the protein code**

Important points about TRANSLATION

- The mRNA leaves the nucleus à cytoplasm (in eukaryotes)
- Message is read at the **ribosome**
- mRNA is read 3 letters at a time
- AUG is the start signal
- 1 Codon (3 letter message) is translated into 1 amino acid
- transferRNA molecule has one end (anticodon) that matches the mRNA. Each anticodon specifies an amino acid.
- There are 20 amino acids
- The amino acids are bonded together as peptide chains…which fold into proteins
If a mature mRNA transcript has 300 nucleotides, how many amino acids would that code for? 100

TRANSLATION :  
DNA → RNA → Protein

Ex: the message AUGGGGCAAUAA codes for Met-Gly-Gln-*  
(the * tells the ribosome to stop)

What does this message code for?

AUG        CUU    CCA    GAG    UGA  
MET(start)  LEU    PRO    GLU    STOP

- After a polypeptide chain is made from amino acids (at a ribosome), it might be used right away in the cytoplasm, or it might be sent to the Golgi apparatus to have more folding or carbohydrates added.
- Proteins made on free ribosomes will work in the cytoplasm
- Proteins made on the rough ER will go the cell membrane or be excreted

The Genetic Code

4th Idea: Mutations in the DNA or RNA sequence produce the wrong amino acid sequence.

*****The ultimate source of evolution is mutation*****

MUTATION : A change in DNA sequence
- Point Mutations: Change one or two base pairs
  ➔ Insertion, Deletion, Substitution
  Only 2 of these are “frameshift mutations” - that is, they change the codon reading frame.
- Silent Mutation = the mutation goes unnoticed – it does not change the amino acid sequence or is not in a coding region (the mutation is in an intron, or the 98% of the genome that doesn’t code for protein, or in the 3rd base of a codon)
- Missense – an insertion, deletion, or substitution that would make the message different
- Nonsense – really bad; a stop codon is created and the message stops prematurely
Example: Remember that DNA and RNA are just a language. To emphasize the point of mutation, I am using English (an alphabet with 26 letters, not 4!) Imagine you have the following message:

**THE CAT ATE THE RAT**

Using the above bolded mutations, label the type of mutation each must be:

- **Point Mutation / Substitution**
  - **THE HAT ATE THE RAT**

- **Insertion / Frameshift**
  - **THE H EHA TAT ETH ERA T**

- **Deletion / Frameshift**
  - **THE ETA TET HER AT**

The “Central Dogma of Biology” is summarized as:

**DNA → RNA → PROTEIN**

Fill in the chart:

<table>
<thead>
<tr>
<th>DNA Triplet</th>
<th>mRNA Codon</th>
<th>tRNA</th>
<th>Amino Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

return to top of document
<table>
<thead>
<tr>
<th>Anticodon</th>
<th>Anticodon</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAC</td>
<td>AUG</td>
</tr>
<tr>
<td>GGA</td>
<td>CCU</td>
</tr>
<tr>
<td>TTC</td>
<td>AAG</td>
</tr>
<tr>
<td>ATC</td>
<td>UAG</td>
</tr>
</tbody>
</table>

Page 46

ORDER THE FOLLOWING 1 - 7

3. Intron sequences are spliced out and exons are joined together
7. amino acids form peptide bonds as tRNA molecules match the mRNA
2. RNA polymerase reads the DNA and builds complimentary sequence
5. The mRNA attaches to the ribosome
4. The ends of the mature transcript are protected before it leaves the nucleus
1. RNA polymerase finds the promoter sequence on DNA
6. Transfer RNA arrives at the ribosome and the anticodon complements to the mRNA codon

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Practice Questions:

1. Which process helps to preserve the genetic information stored in DNA during DNA replication?
   A. the replacement of nitrogen base thymine with uracil
   B. enzymes quickly linking nitrogen bases with hydrogen bonds
   C. the synthesis of unique sugar and phosphate molecules for each nucleotide
   D. nucleotides lining up along the template strand according to base pairing rule

2. In a flowering plant species, red flower color is dominant over white flower color. What is the genotype of any red-flowering plant resulting from this species?
   A. red and white alleles present on one chromosome
   B. red and white alleles present on two chromosomes
   C. a red allele present on both homologous chromosomes
   D. a red allele present on at least one of two homologous chromosomes

3. The endoplasmic reticulum is a network of membranes within the cell, and it is often classified as rough or smooth, depending on whether there are ribosomes on its surface. Which statement best describes the role of rough endoplasmic reticulum in the cell?
   A. It stores all proteins for later use.
   B. It provides an attachment site for larger organelles.
   C. It aids in the production of membrane and secretory proteins.
   D. It stores amino acids required for the production of all proteins.
Use the table below to answer the question.

<table>
<thead>
<tr>
<th>Blood Types</th>
<th>Genotypes</th>
<th>Phenotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>II</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>I^A I^A, I^A i</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>I^B I^B, I^B i</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>I^A I^B</td>
<td>AB</td>
</tr>
</tbody>
</table>

4. Blood type is inherited through multiple alleles, including I^A, I^B, and i. A child has type A blood. If the father has type AB blood, what are all the possible phenotypes of the mother?
   A. phenotypes O or A
   B. phenotypes A or AB
   C. phenotypes A, B, AB
   D. phenotypes O, A, B, AB

5. Which type of change in chromosome composition is illustrated in the diagram?
   A. deletion
   B. insertion
   C. inversion
   D. translocation

6. Which statement describes a cell process that is common to both eukaryotic and prokaryotic cells?
   A. Both cell types carry out transcription in the nucleus.
   B. Both cell types use ribosomes to carry out translation.
   C. Both cell types assemble amino acids to carry out transcription.
   D. Both cell types carry out translation in the endoplasmic reticulum.

7. A genetic mutation resulted in a change in the sequence of amino acids of a protein, but the function of the protein was not changed. Which statement best describes the genetic mutation?
   A. It was a silent mutation that caused a change in the DNA of the organism.
   B. It was a silent mutation that caused a change in the phenotype of the organism.
   C. It was a nonsense mutation that caused a change in the DNA of the organism.
   D. It was a nonsense mutation that caused a change in the phenotype of the organism.
infections. Which outcome would most likely be a reason why some scientists recommend caution in planting genetically modified plants?
A. unplanned ecosystem interactions
B. reduced pesticide and herbicide use
C. improved agricultural yield and profit
D. increased genetic variation and diversity

9. Which of the following is primarily responsible for the coding of the amino acids used in the synthesis of cellular proteins?
   A. DNA
   B. transfer RNA
   C. ribosomes
   A. Golgi apparatus

10. Which statement describes the diagram above?
    A. DNA transcription is producing ribosomal RNA.
    B. DNA translation is producing messenger RNA.
    C. DNA transcription is producing messenger RNA.
    D. DNA translation is producing ribosomal RNA.

Open-ended Question:
10. A cattle farmer genetically crosses a cow (female) with a white coat with a bull (male) with a red coat. The resulting calf (offspring) is roan, which means there are red and white hairs intermixed in the coat of the calf. The genes for coat color in cattle are co-dominant.

   Part A: Although a farm has cattle in all three colors, the farmer prefers roan cattle over white or red cattle. Use the Punnett square to show a cross that would produce only roan offspring.

   \[
   \text{RR} \times \text{WW} \\
   \begin{array}{c|c|c}
   \text{W} & \text{W} & \text{W} \\
   \text{RW} & \text{RW} & \text{RW} \\
   \text{RW} & \text{RW} & \text{RW} \\
   \end{array}
   \]
Part B: Explain how a roan calf results from one white- and one red-coated parent. In your explanation, use letters to represent genes. Be sure to indicate what colors the letters represent.

A ROAN cow has both red and white hair. **It is an example of CO-dominance.** One trait isn't hidden (dominant/recessive) or blended together (incomplete dominance). Some of the hairs are totally white and others totally red. "RW" would be used to represent a roan cow. A white cow would be WW and a red cow would be RR. A cow will be roan if it inherits a "R" from one parent and a "W" from the other one.

Part C: Predict the possible genotypes and phenotypes of the offspring produced from two roan cattle.

<table>
<thead>
<tr>
<th></th>
<th>RR</th>
<th>RW</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW</td>
<td></td>
<td>WW</td>
</tr>
</tbody>
</table>

Possible genotypes = 1 RR; 2 RW; 1WW

Possible phenotypes = 25% Red; 50% Roan; 25% White