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Supplemental Materials

for

Teaching the Central Dogma of Molecular Biology using Jewelry

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Cracking the Code

Teacher Instructions

Summary

In this activity, students learn about the central dogma of molecular biology – the transfer of information from DNA to RNA to protein. In the first part of the activity, students use pencil and paper to transcribe a DNA code into messenger RNA (mRNA). In the second part, they translate this RNA message using transfer RNA (tRNA) cards to determine which amino acid each codon is coding for. Once they determine the correct amino acids, beads corresponding to those amino acids are strung together to make a "protein" bracelet.

Intended audience: 5th -10th grade
Class time: 30 – 45 minutes
Preparation time: 15 – 30 minutes

National Science Education Standards addressed

NSES Standard	NSES concepts	"Cracking the Code" concepts
Life Science Standards (5-8): Structure and function in living systems	"Living systems at all levels of organization demonstrate the complementary nature of structure and function."	DNA is an information molecule; structure of DNA; bases and base pairing.
Life Science Standards (5-8): Reproduction and heredity	"Hereditary information is contained in genes…each gene carries a single unit of information."	The information in DNA is organized as genes; Genes can be copied; A single gene is translated into a single protein product.
Life Science Standards (9-12): The cell	1. "Cells have particular structures that underlie their functions…[including] the storage of genetic material." 2. "Most cell functions involve chemical reactions." 3. "Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires."	1. Genetic material (DNA) is in every cell, and has all the information needed to make that cell or organism. 2. RNA polymerase and ribosomes are enzymes that catalyze the polymerization of RNA and peptides, respectively. 3. Central dogma of molecular biology: DNA is transcribed to RNA then translated to protein.
Life Science Standards (9-12): Molecular basis of heredity	1. "In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes and replicated." 2. "Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms."	1. DNA is an information molecule; structure of DNA; bases and base pairing; replication mechanisms. 2. An extension of this activity shows the effects of DNA or RNA mutations on the resulting peptides. Silent, missense and nonsense mutations can be demonstrated and discussed.

Learning Objectives

At the end of this activity, the students will:

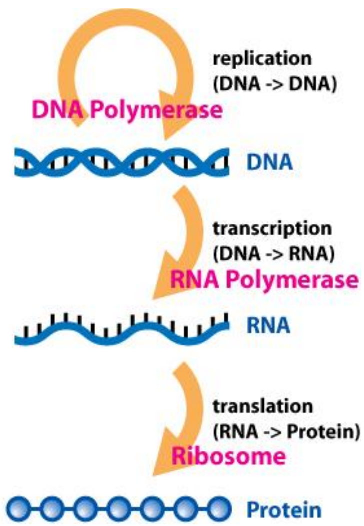
- Understand the basic structure of DNA base pairing rules
- Relate the structure of DNA (base pairs) to its function (information storage and transfer)
- Be able to define transcription and translation
- Be able to explain how information moves from DNA to protein

Background

DNA is a molecule full of information. It has all the instructions to make a living thing. Every one of the cells in your body has all the instructions to make skin, hair, digestive enzymes, immune system factors, everything!

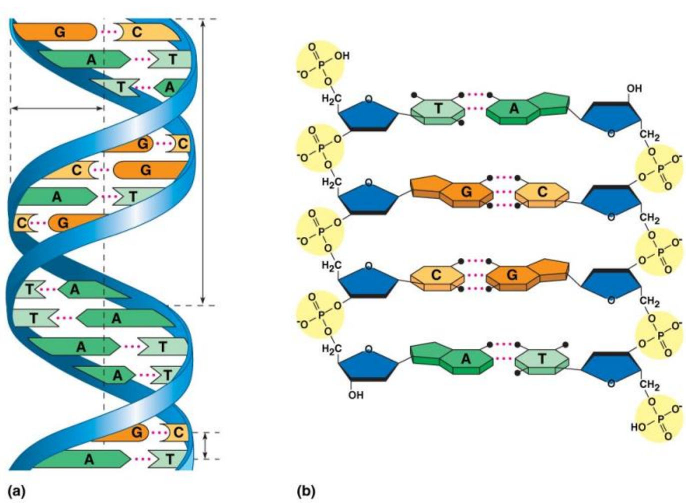
All this information, all of an organism's DNA, is called the **genome.** A genome is sort of like a recipe book – it has all the instructions to make all different sorts of proteins, just like recipes have instructions to make many types of meals. But how does that information get translated to proteins?

The information transfer begins with an enzyme called an **RNA polymerase.** This enzyme is like a scribe, and makes a copy of the DNA called messenger RNA or **mRNA**. This process is called **transcription.** If you think of the DNA like a recipe book, then transcription is like someone copying out recipes from the book.



The Central Dogma of Molecular Biology: DNA → RNA → Protein
(Image from Dhorspool at en.wikipedia)

The mRNA is then **translated** to **proteins** by **ribosomes**. Each set of three bases codes for one amino acid. The ribosomes use transfer RNAs (or tRNAs), which have bases on one side and an amino acid on the other. They match up the RNA code to amino acids, which are strung together to make a peptide or protein. Think about a chef that reads a recipe and create a meal based on the instructions in the recipe. In the cell, the ribosomes are like chefs, making peptide "meals" based on the instructions in the RNA "recipes." You can see how the ribosome works to translate here: http://www.microbelibrary.org/images/kaiser/proteinsynthesis/translation.html (Animation by G. Kaiser, ASM Microbe Library)



All this copying works because of the **base pairing rules**. DNA is made up of four bases: adenine (A), cytosine (C), guanine (G) and thymine (T). **A always pairs with T** and **C always pairs with G**. Because of these "rules," the information in DNA can be copied many times and still keep the same message.

Delivery

Prior to starting the activity review DNA with your students:

1. Explain that DNA is an information molecule, and that it contains all the codes necessary to make a living thing.
2. Review double helix structure and the 4 bases: adenine (A), thymine (T), cytosine (C), guanine (G).
3. Describe how the DNA code is organized into codons. Emphasize that code is complementary: A always pairs with T and C always pairs with G.
4. Demonstrate how RNA polymerase copies the DNA code with complementary bases. Mention that RNA uses uracil (U) instead of thymidine (T).
5. Demonstrate how the RNA is then translated into amino acids/proteins by the ribosome, using special structures called transfer RNAS (tRNAs).

The Chef Analogy. A good analogy for teaching your students about transcription and translation is the chef analogy. This metaphor, used by Nova Science Now to describe the action of RNAi (Krock 2005), describes the genome as a recipe book locked in a high tower (nucleus). It has all the information for creating a delicious meal, but unfortunately is locked up – it can't be taken in or out. Fortunately, there's a tower scribe (= RNA polymerase) that can read the book, and make copies of the recipes (= messenger RNA). These copies can leave the tower, and are pickup up by the little chefs below (= ribosomes). These chefs can then read the recipes (= mRNA), and use raw ingredients (= amino acids) to create a meal (= peptides and proteins). (Find an animation of this metaphor here: http://www.pbs.org/wgbh/nova/body/rnai-explained.html)

This recipe book analogy can also be extended to describe the organization of DNA. We can think of the genome as a book, and all the letters in the book are individual nucleotides. These nucleotides are organized into codons (= words), genes (= paragraphs or recipes), and chromosomes (= chapters).

Another extension is to use the recipe book analogy to describe cell differentiation and gene regulation. All the cells in an organism have the same genome (= recipe book), but it is through turning on and off different genes (= recipes) that we get skin cell or brain cells or blood cells doing very different jobs. Compare it to how the set of recipes you would use to prepare a Thanksgiving meal will be very different from the recipes you'd use for a 4^{th} of July summer barbeque. All the recipes are present in the same book, but by using different subsets we get different outcomes.

Materials

- Printer
- Heavyweight paper
- Pencils
- 20 colors (or styles) of beads. *Tip: pony beads are available at most craft stores, are inexpensive and come in lots of colors!*
- Organizational box with 20 slots or 20 small jars/containers to keep beads in (OPTIONAL). One box or set of jars for every 4-6 students.
- String or elastic or cord or thin tubing to string the beads on; plan for 10” per student.

Note: This activity can be done as individuals, but also works very well groups of 2-4 students, especially with younger students. Have students work in groups to “decode,” but let them each make their own bracelet to take home.

Prepare in advance

1. Print and cut:
    a. DNA: One or more of the DNA (purple backbone, double stranded) sequences to use as the template. There are four different sequences provided with this package, 2 sequences taken from the human lactase gene, 2 from the human keratin gene. Cut the printouts between each double strand, and attach them end to end with tape to make one long strip of nucleic acid (Figure 1A). (*Note:* these are not full genes; they are just 21 amino acid segments of the above genes with a start and stop codon inserted at the beginning and end).
    b. RNA: One blank RNA sheet (single stranded, green backbone) for each group. Cut between each single strand and attach to make a long strip the same length as the DNA (Figure 1A).
    c. tRNAs: One set (3 pages) per group. Cut out tRNAs on the grey lines. There will be 64 cards per group (Figure 1B). *Tip:* These will be used like playing cards, so print on heavy paper or cardstock, especially if you plan to use them more than once.
    d. Labels for the amino acid beads OR an amino acid legend (Figure 1B).

> **Optional:** Make a DNA template of a gene of your choice, perhaps a gene that has been discussed in class. Make sure the gene starts with a start codon (ATG) on the sense strand and ends with a stop codon (TAA, TAG or TGA).

2. Prepare the “amino acids” beads: Use 20 colors of pony beads. Assign an amino acid letter to each color bead.
    a. Option 1: Use an organizational box with 20 places or 20 small jars to keep different colors in. Label each with an amino acid letter (Figure 1B).
    b. Option 2: Beads are mixed; create a legend sheet by assigning a bead for each amino acid. Tape the bead to the amino acid letters page.

3. Precut string or elastic into approximately 10-12” lengths. Prepare 1 per student.

Figure 1. Preparation.
A. Print and cut out the DNA strand (purple backbone), RNA strand (green backbone) and tape together.
B. Cut out the tRNA cards. Assign beads for each amino acid and create a legend (here, beads are sorted by color with the amino acid label affixed to each).

Activity

1. Hand out a DNA template to each group. Use this time to describe the protein they will be working on.
    a. Lactase – key enzyme in digesting lactose, the sugar in dairy products. Most students have heard of someone who is lactose-intolerant, and can relate to this enzyme.
    a. Keratin – the fibrous structural protein that is a key component of our skin, hair and fingernails.

2. Students then transcribe the DNA code into RNA by lining up the green RNA strand with the antisense (top) DNA strand and filling in complementary bases. Remember that for RNA A pairs with U (Figure 2A).

3. Once the RNA is transcribed, students will then use the tRNA cards to determine which amino acid each codon codes for (Figure 2B).
    a. Find the tRNA with the complimentary sequence to the first codon in the RNA strand. (Hint: the first tRNA sould be Methionine, or START). Tip: If time is an issue, sort the tRNA cards according to the first letter to speed up searching.
    b. Once the correct tRNA is found, look to see what amino acid is on that tRNA. Find the bead that corresponds to that amino acid and add it to your bracelet (Figure 2C).
    c. Repeat for the next codon, add that amino acid bead. Continue adding beads until you reach the STOP codon. That's the end of the peptide bracelet!

Tip: To make searching through the tRNAs move more quickly, presort the tRNAs according to their first base.

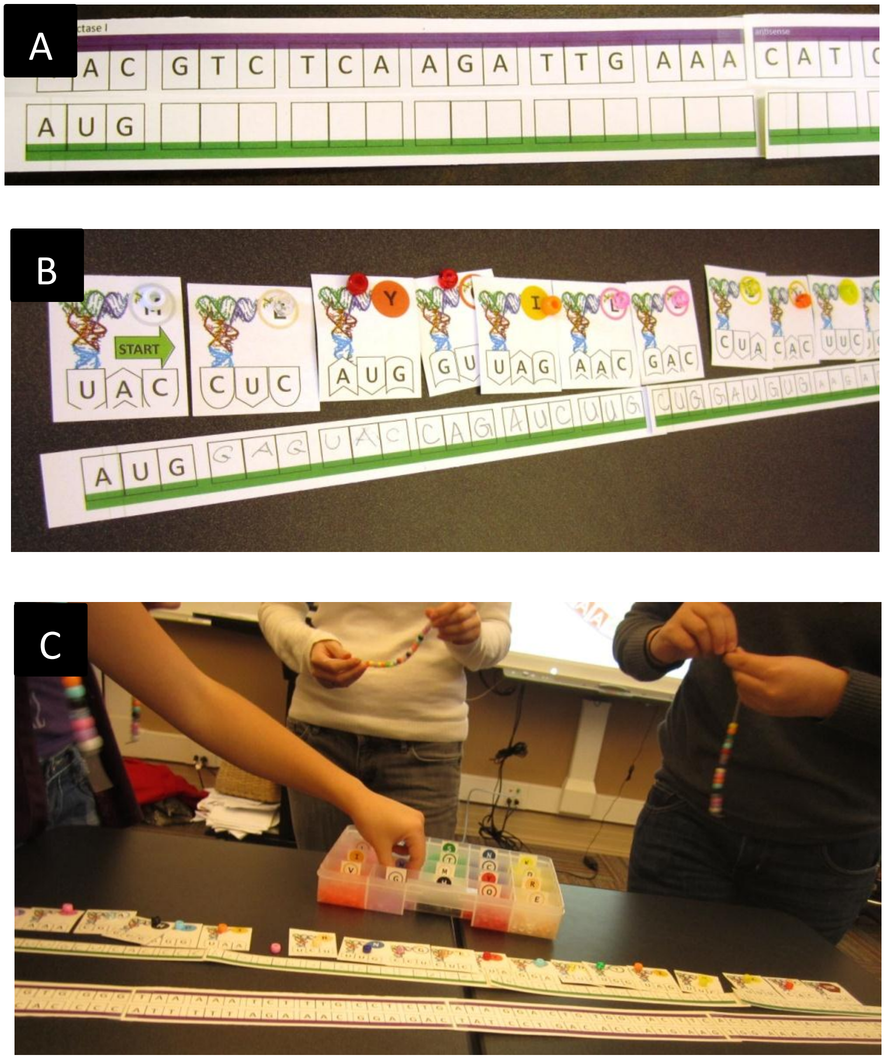


Figure 2. Activity.

A. Line up the RNA strand with the antisense (top) DNA strand and transcribe the code. Remember that RNA uses U instead of T bases!

B. To translate, find the tRNA molecules complimentary to each codon, and locate the bead corresponding to the correct amino acid.

C. String the beads to create a peptide bracelet.

Assessment and Evaluation

"TEST YOUR KNOWLEDGE" Answer Key

1. In DNA and RNA, C always pairs with **G**.
2. RNA uses **U or uracil** instead of T bases.
3. Transcription is carried out by an enzyme called **RNA Polymerase**.
4. Ribosomes translate a RNA message into **amino acids or peptides or proteins.**
5. A string of amino acids is called a **peptide or protein**.

"THINK ABOUT IT" Answer Key

What would happen if the RNA polymerase made a mistake when it copied the DNA?

Discuss this question with your students. Use it to teach your students about mutation; you can demonstrate types of mutations by purposefully introducing mistakes during transcription and showing students the outcome in the amino acid sequence.

Possible answers:
-Nothing, a mistake in the RNA might still mean the same amino acid. This is called a **silent mutation**.
-The mistake might mean the wrong amino acid is put into the peptide. This can affect the properties of the protein (how it folds, how it functions). This could be detrimental or beneficial. This is called a **missense mutation.**
-The mistake might mean that a stop codon gets put in instead of an amino acid. This results in a premature stopping of translation and a short (often non-functional) peptide. This is called a **nonsense mutation.**

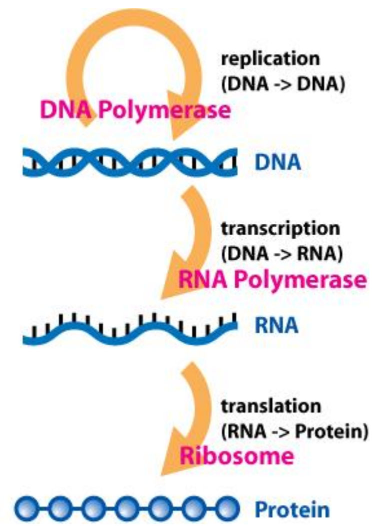
Cracking the Code

Student Handout

DNA is an information molecule.

DNA is a molecule full of information. It has all the instructions to make a living thing. Every one of the cells in your body has all the instructions to make skin, hair, digestive enzymes, immune system factors, everything!

All this information, all of an organism's DNA is called the **genome.** A genome is sort of like a recipe book – it has all the instructions to make all different sorts of proteins, just like recipes have instructions to make many types of meals. But how does that information get translated to proteins?



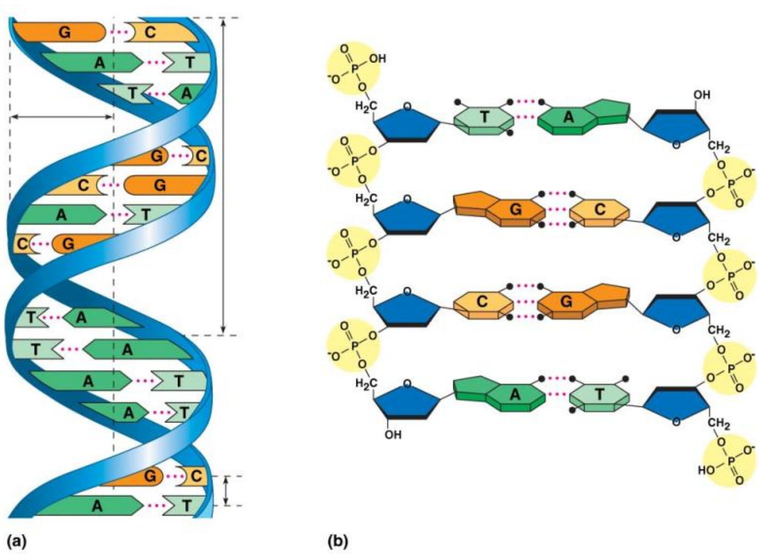
The Central Dogma of Molecular Biology: DNA → RNA → Protein

(Image from Dhorspool at en.wikipedia)

How do cells "read" the information?

The information transfer begins with an enzyme called an **RNA polymerase.** This enzyme is like a scribe, and makes a copy of the DNA called messenger RNA or **mRNA**. This process is called **transcription.** If you think of the DNA like a recipe book, then transcription is like someone copying out recipes from the book.

The mRNA is then **translated** to **proteins** by **ribosomes**. Each set of three bases codes for one amino acid. The ribosomes use transfer RNAs (or tRNAs), which have bases on one side and an amino acid on the other. They match up the RNA code to amino acids, which are strung together to make a peptide or protein. Think about a chef that reads a recipe and create a meal based on the instructions in the recipe. In the cell, the ribosomes are like chefs, making peptide "meals" based on the instructions in the RNA "recipes." You can see how the ribosome works to translate here: http://www.microbelibrary.org/images/kaiser/proteinsynthesis/translation.html (Animation by G. Kaiser, ASM Microbe Library)



Base Pairing

All this copying works because of the **base pairing rules**. DNA is made up of four bases: adenine (A), cytosine (C), guanine (G) and thymine (T). **A always pairs with T** and **C always pairs with G**. Because of these "rules," the information in DNA can be copied many times and still keep the same message.

Vocabulary

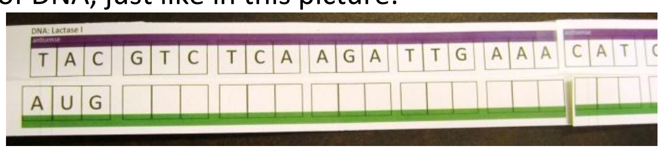
DNA	Bases	RNA polymerase
RNA	Transcription	Ribosome
Protein	Translation	Amino Acid

Materials

- Pencils
- Printouts of a DNA strand and an RNA strand
- 64 tRNA cards
- 20 colors (or styles) of beads to represent the 20 amino acids
- String or elastic or cord or thin tubing to string the beads on

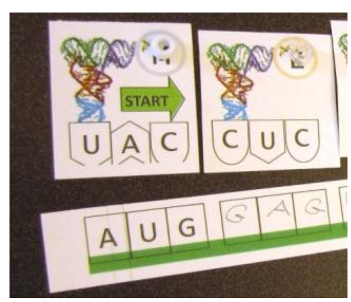
Procedure

1. Your teacher will give you strand of DNA code (purple) and a blank strand of RNA (green). Your first task is to act like RNA polymerase. Line up your RNA with the top (antisense) strand of DNA, just like in this picture:



2. Now, **transcribe** the message by writing down the complimentary bases on the RNA strand. Remember the rules? A always pairs with T and C always pairs with G.
   BUT WAIT! RNA is a little different from DNA. Instead of thymine (T) it uses uracil (U), so when you transcribe, make sure that you use **U** instead of **T**. The first three bases (TAC) are done for you: A is complimentary to T, U is complimentary to A and G is complimentary to C.

3. When you are done transcribing your RNA message, it's time to **translate**! Find the tRNA card with bases that are complimentary to the first three bases on your RNA. Don't forget the base pairing rules! Once you find the tRNA that is complimentary to the first three bases, look to see what amino acid is on that card. Find the bead corresponding to that amino acid and put it on your bracelet.



4. Keep translating: find the tRNA that is complimentary to the next three bases to see what amino acid goes next. Keep going until you get a STOP signal. (These are special codes that tell the cell to stop making the protein.) Then tie off your bracelet and enjoy your new peptide!

Results

Write your final amino acid sequence here:

_M_ __

TEST YOUR KNOWLEDGE!

Fill in the blanks:

1. In DNA and RNA, C always pairs with _____________.
2. RNA uses ____________________ instead of T bases.
3. Transcription is carried out by an enzyme called _____________________.
4. Ribosomes translate a RNA message into ____________________________.
5. A string of amino acids is called a ___________________________________.

Think about it:

What would happen if the RNA polymerase made a mistake when it copied the DNA?

mRNA strand—print one for every 2 groups

A U G

A U G

DNA: Lactase I

antisense	T A C	G T C	T C A	A G A	T T G	A A A
sense	A T G	C A G	A G T	T C T	A A C	T T T

antisense	C A T	C G T	C C C	C T G	T T T	C T G
sense	G T A	G C A	G G G	G A C	A A A	G A C

antisense	T A C	A T A	C A A	A C A	G T G	G T C
sense	A T G	T A T	G T T	T G T	C A C	C A G

antisense	G G T	G G G	T G A	A T T	T G A	T G A
sense	C C A	C C C	A C T	T A A	A C T	A C T

DNA: Lactase II

antisense	TAC	ACC	AAA	CGA	GTG	GGG
sense	ATG	TGG	TTT	GCT	CAC	CCC

antisense	TAA	AAA	TCT	TTG	CCT	CTG
sense	ATT	TTT	AGA	AAC	GGA	GAC

antisense	ATA	GGA	CTG	TGG	TAC	TTC
sense	TAT	CCT	GAC	ACC	ATG	AAG

antisense	ACC	TTT	CAC	ATC	TGA	TGA
sense	TGG	AAA	GTG	TAG	ACT	ACT

DNA: Keratin I

antisense	TAC	ATG	CTC	GTC	TAC	CGT
sense	ATG	TAC	GAG	CAG	ATG	GCA

antisense	CTC	TTT	TTG	GCG	TCT	CTG
sense	GAG	AAA	AAC	CGC	AGA	GAC

antisense	CGA	CTC	TGG	ACC	AAG	GAC
sense	GCT	GAG	ACC	TGG	TTC	CTG

antisense	TCG	TTC	TGG	ATT	TGA	TGA
sense	AGC	AAG	ACC	TAA	ACT	ACT

DNA: Keratin II

antisense

T	A	C	C	T	C	A	T	G	G	T	C	T	A	G	A	A	C
A	T	G	G	A	G	T	A	C	C	A	G	A	T	C	T	T	G

sense

antisense

G	A	C	C	T	A	C	A	C	T	T	C	T	G	C	G	C	C
C	T	G	G	A	T	G	T	G	A	A	G	A	C	G	C	G	G

sense

antisense

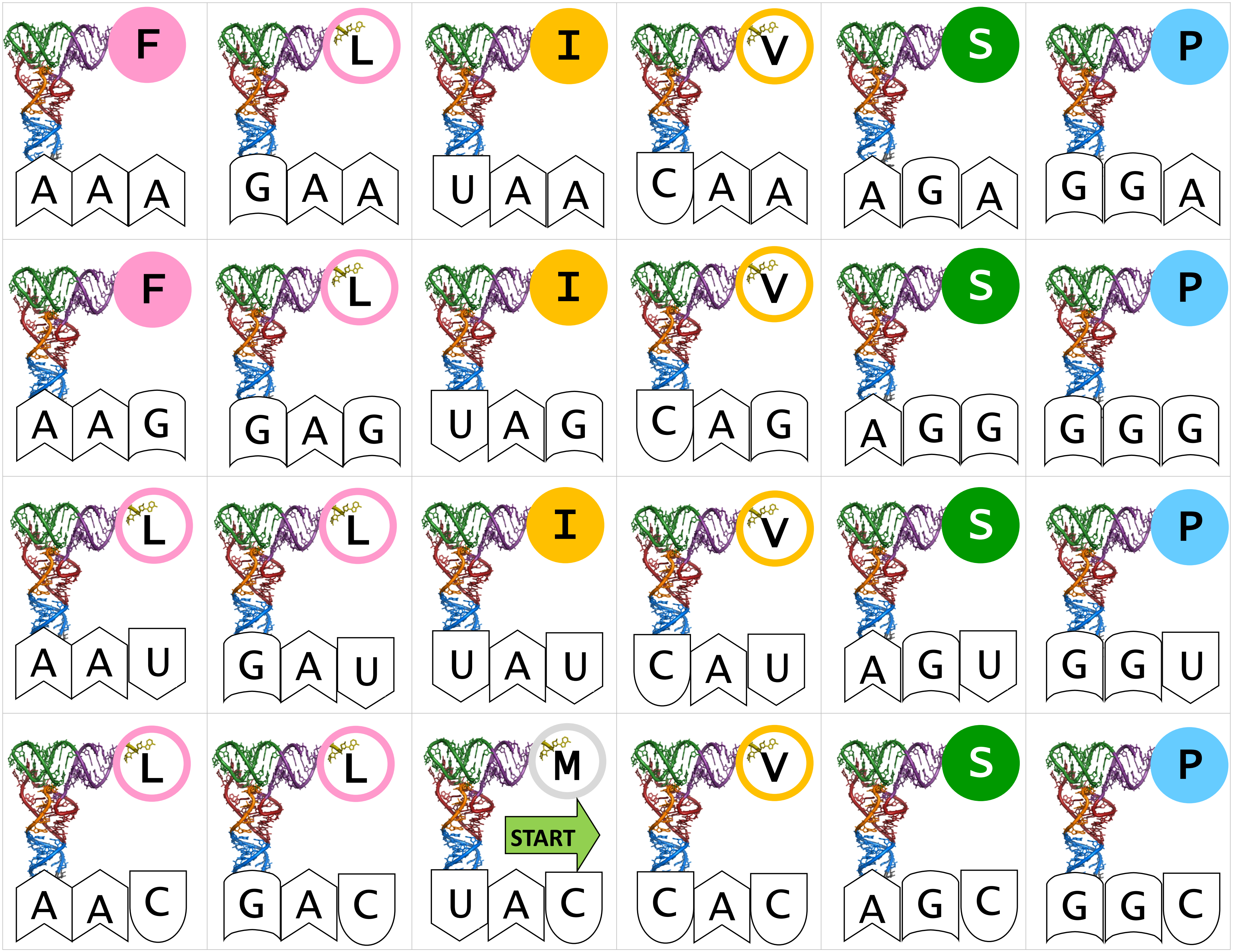
G	A	C	C	T	C	G	T	A	C	T	C	T	A	A	C	G	G
C	T	G	G	A	G	C	A	T	G	A	G	A	T	T	G	C	C

sense

antisense

T	G	G	A	T	G	G	C	G	A	T	C	T	G	A	T	G	A
A	C	C	T	A	C	C	G	C	T	A	G	A	C	T	A	C	T

sense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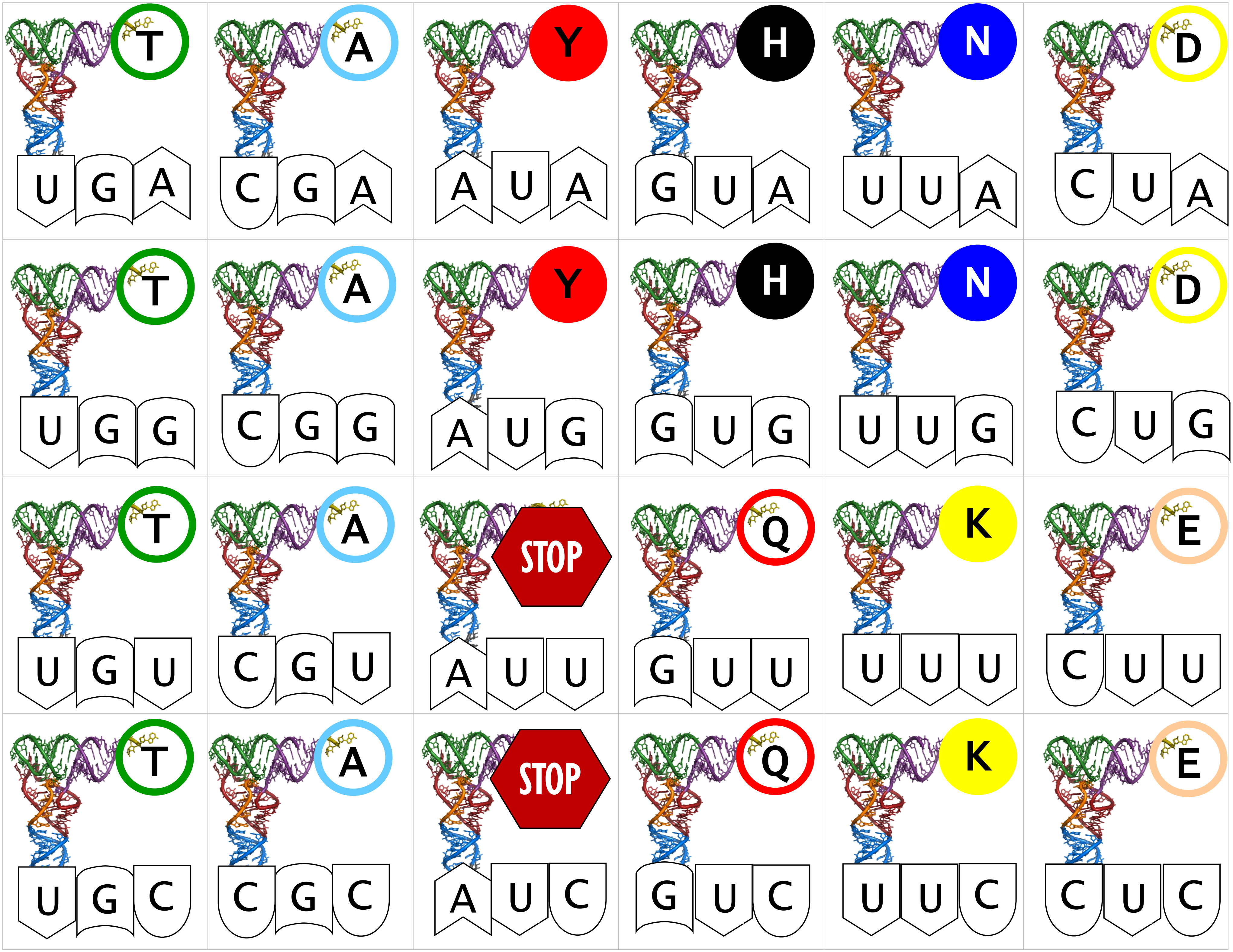
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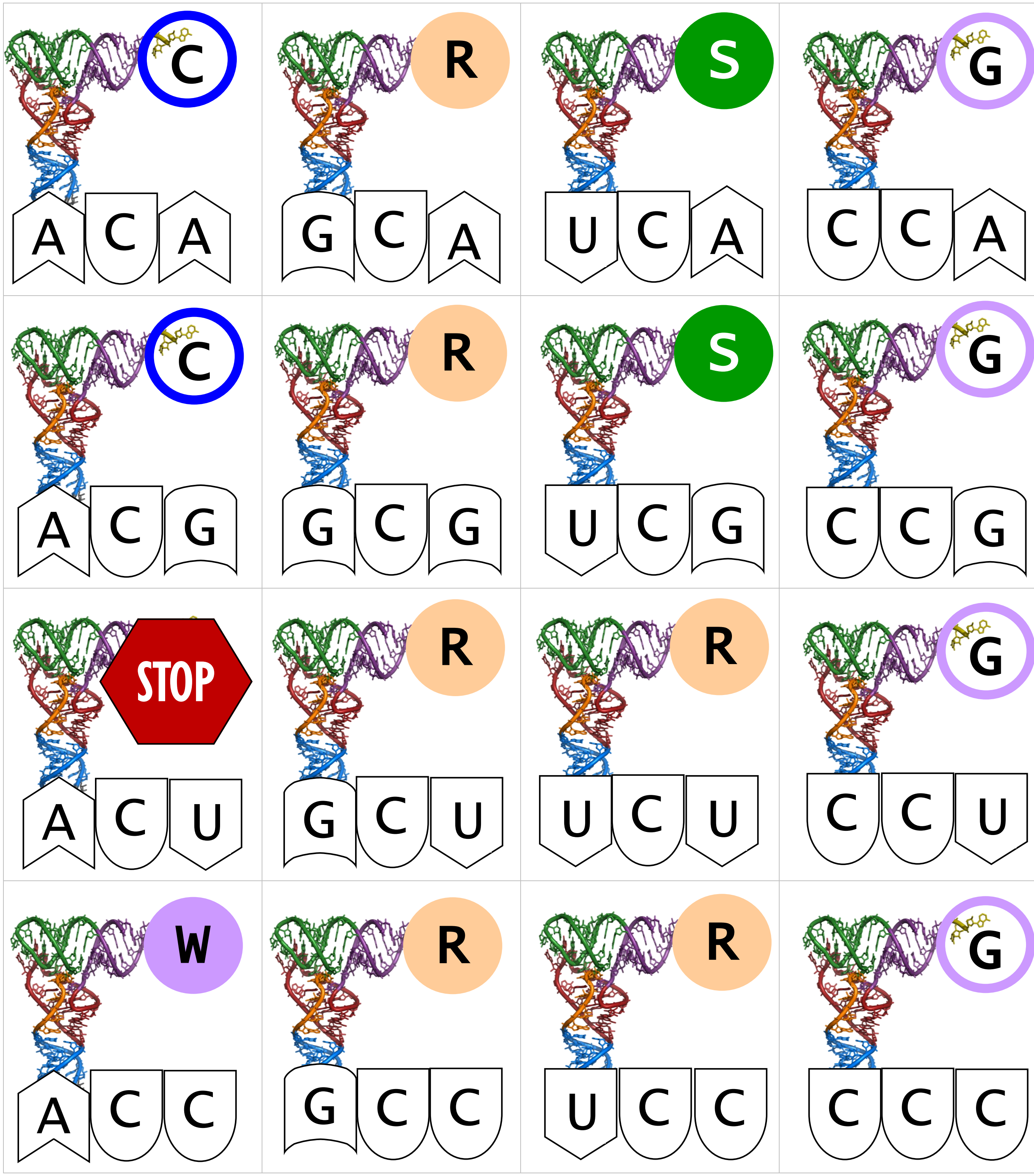
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R
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R
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G
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R
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R
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G
C C C

F Phenylalanine (Phe)

L Leucine (Leu)

I Isoleucine (Ile)

M Methionine (Met)

V Valine (Val)

P Proline (Pro)

A Alanine (Ala)

W Tryptophan (Trp)

G Glycine (Gly)

S Serine (Ser)

T Threonine (Thr)

Y Tyrosine (Y)

Q Glutamine (Gln)

N Asparagine (Asn)

C Cysteine (Cys)

H Histidine (His)

K Lysine (Lys)

R Arginine (Arg)

D Aspartic Acid (Asp)

E Glutamic Acid (Glue)