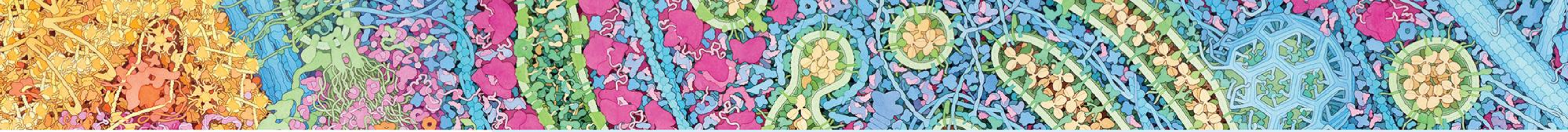
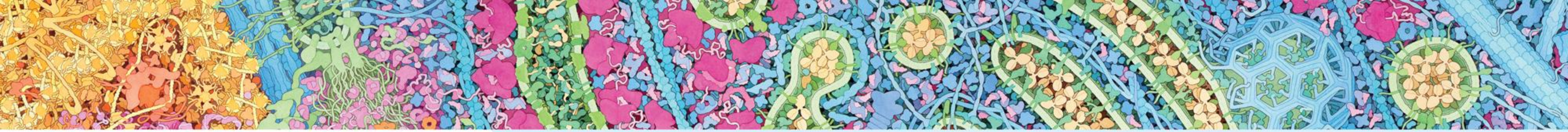


3d molecular designs
Transforming Science Learning

Unwinding the Complexities of the Central Dogma

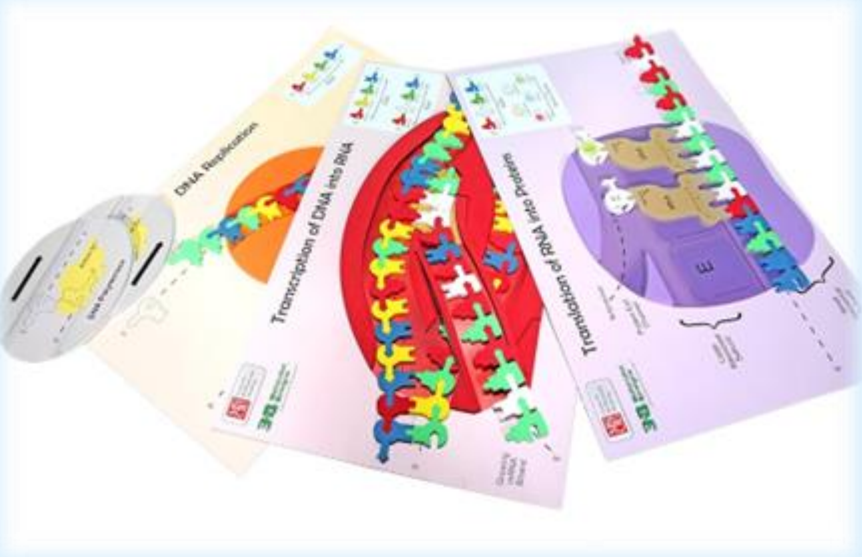
Ruth Hutson, MSSE

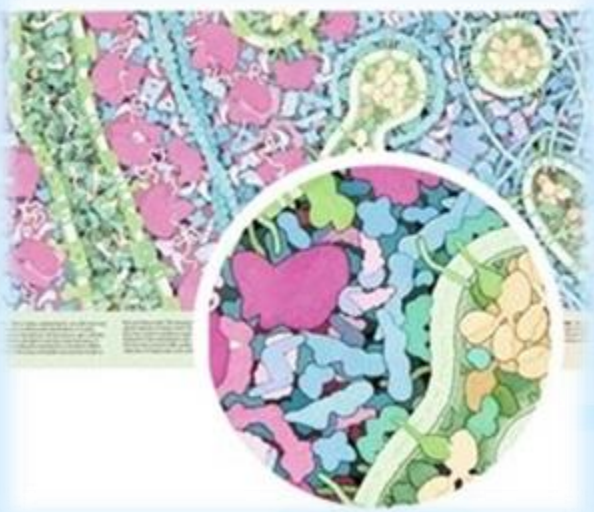
OSTA 2023



3d molecular designs

Transforming Science Learning

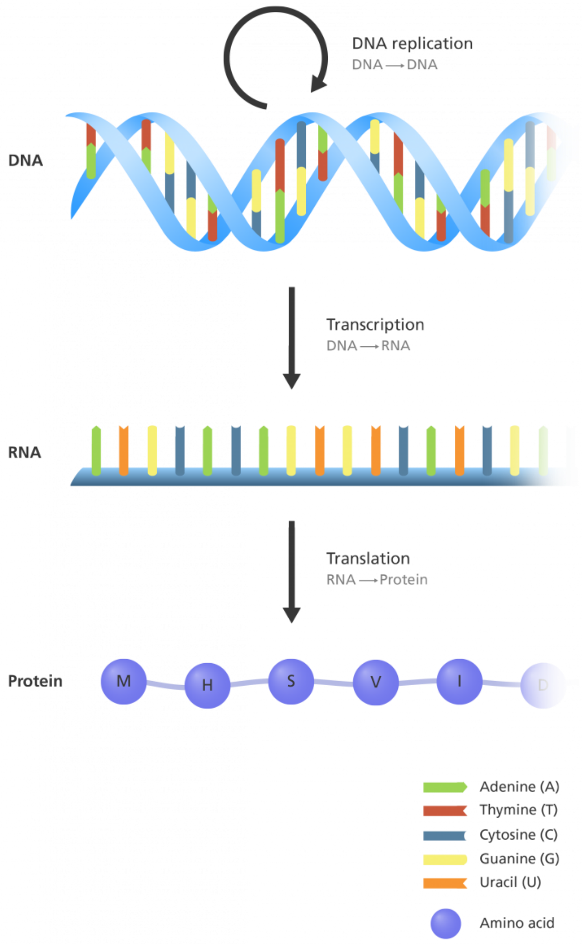




Workshop Learning Objectives

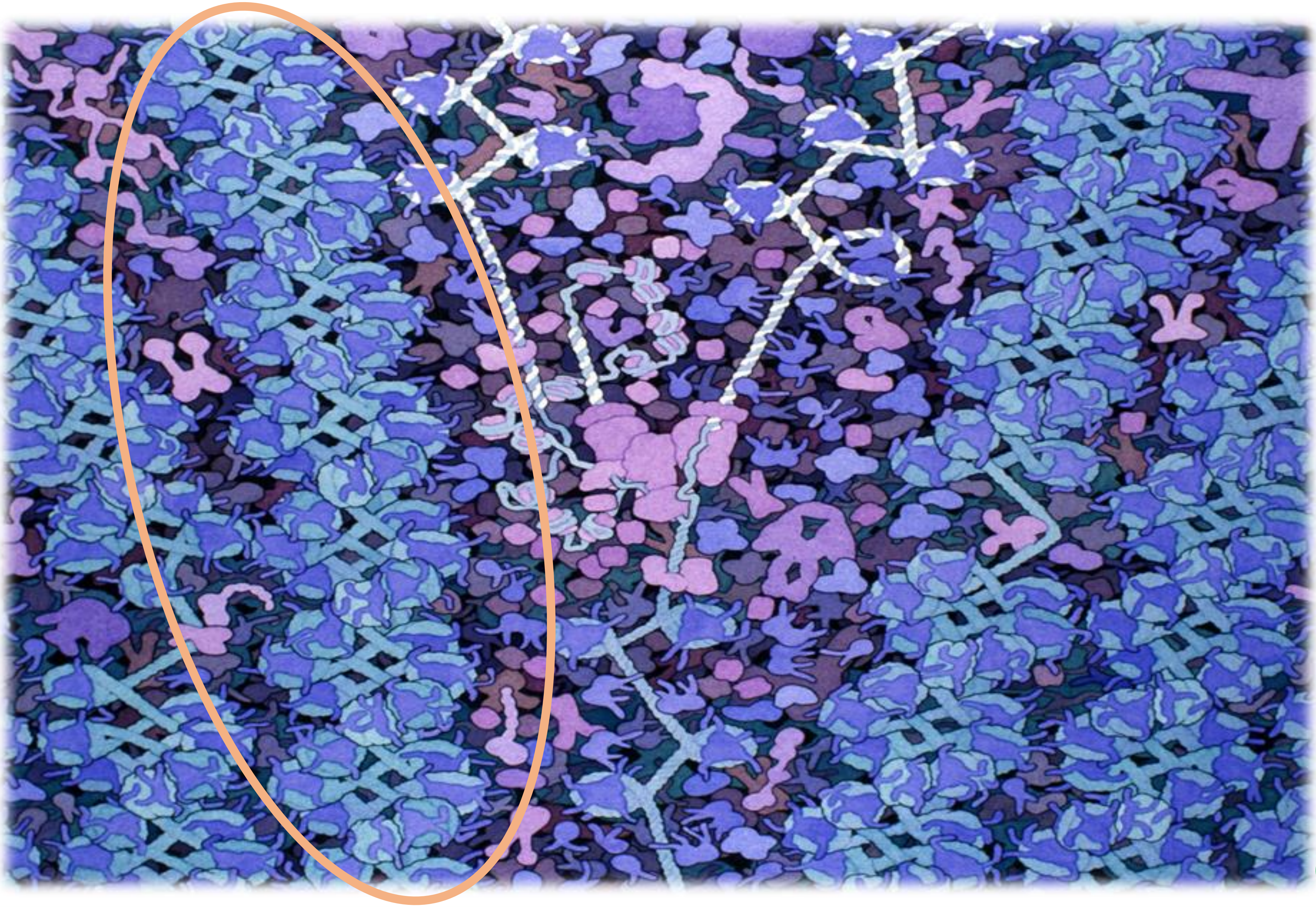
- Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.
- Explain the purpose and process of replication, transcription, and translation using models of DNA and RNA.
- Examine patterns within and between side chains of amino acids.
- Model protein secondary and tertiary structure based on the primary structure of amino acid sequence.

What do your students find confusing about the central dogma?

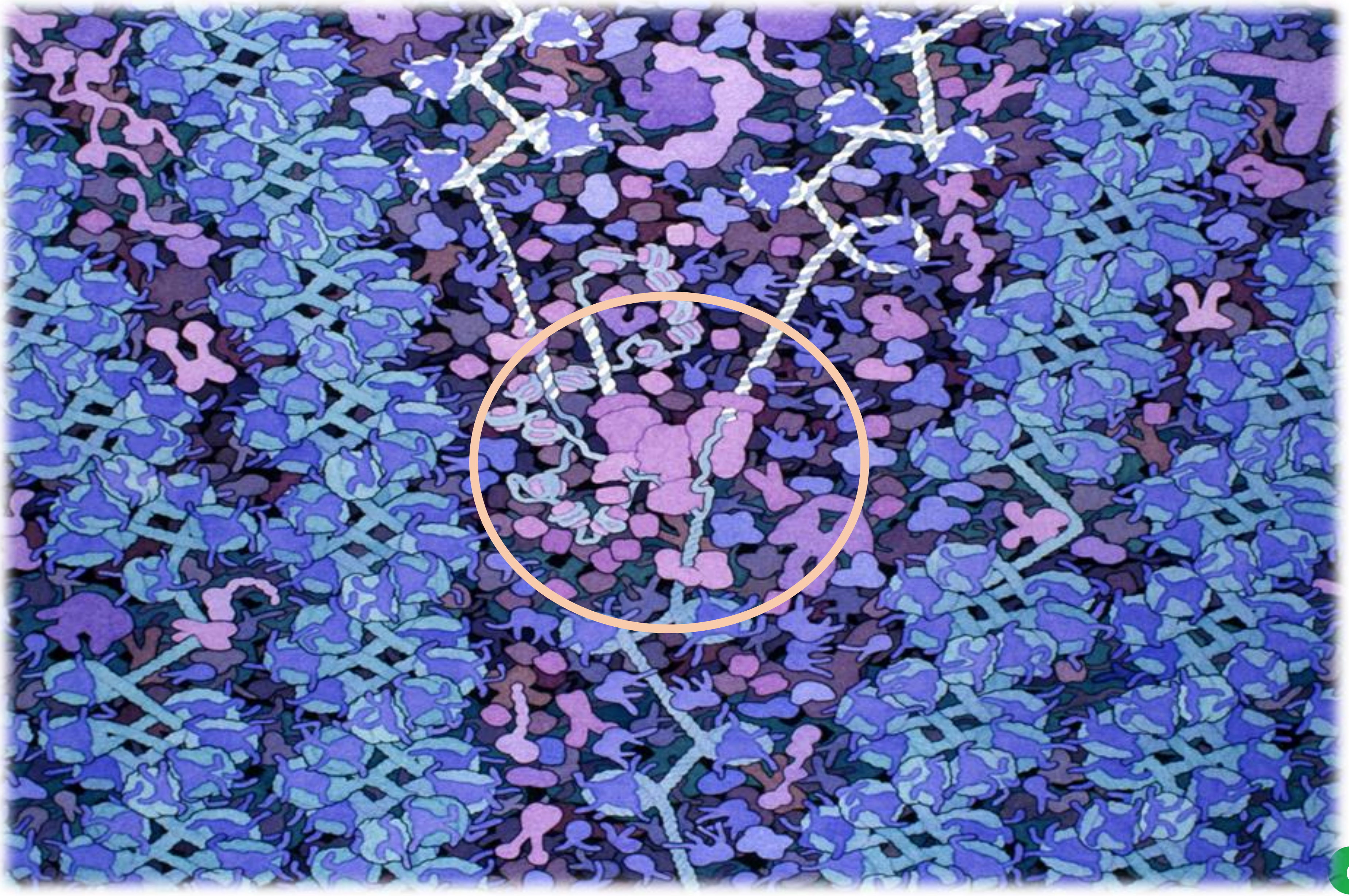


- Don't understand how the processes are related.
- Don't understand the relevance to their own body.
- All the vocabulary!

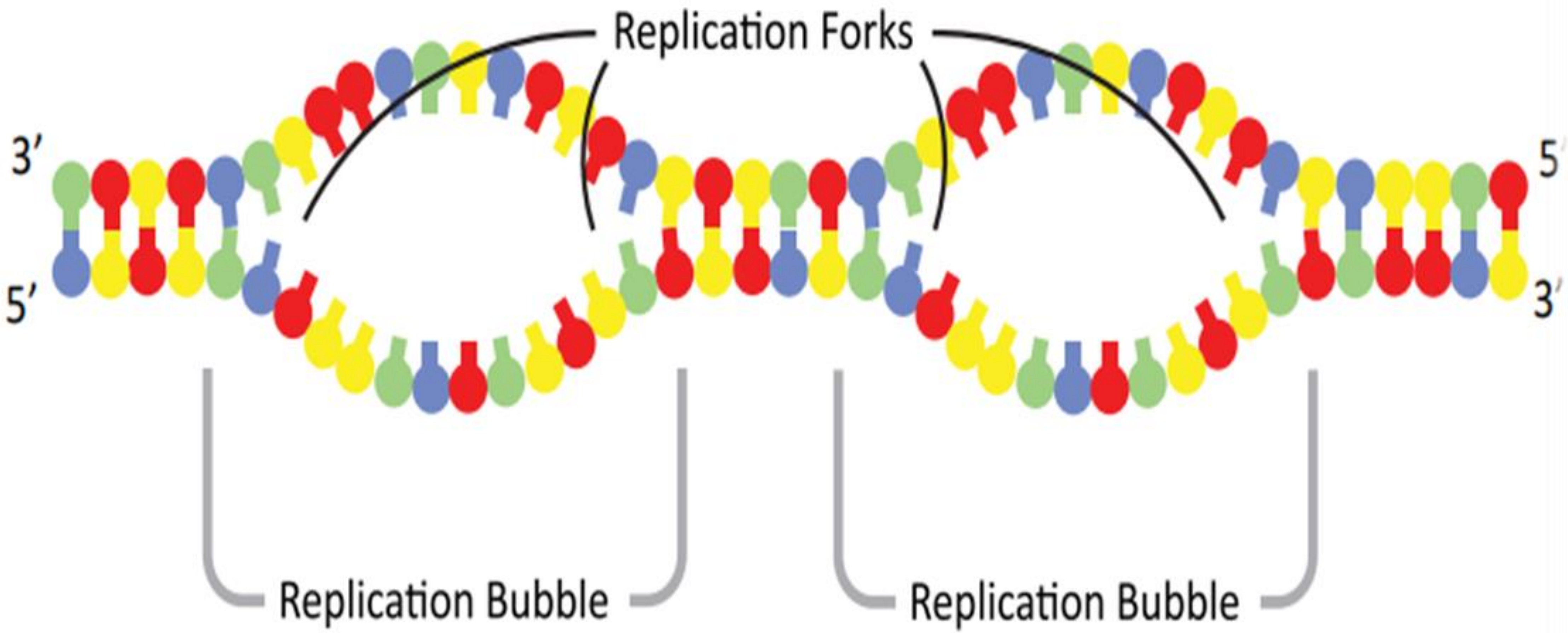
Replication in the Eukaryotic Nucleus



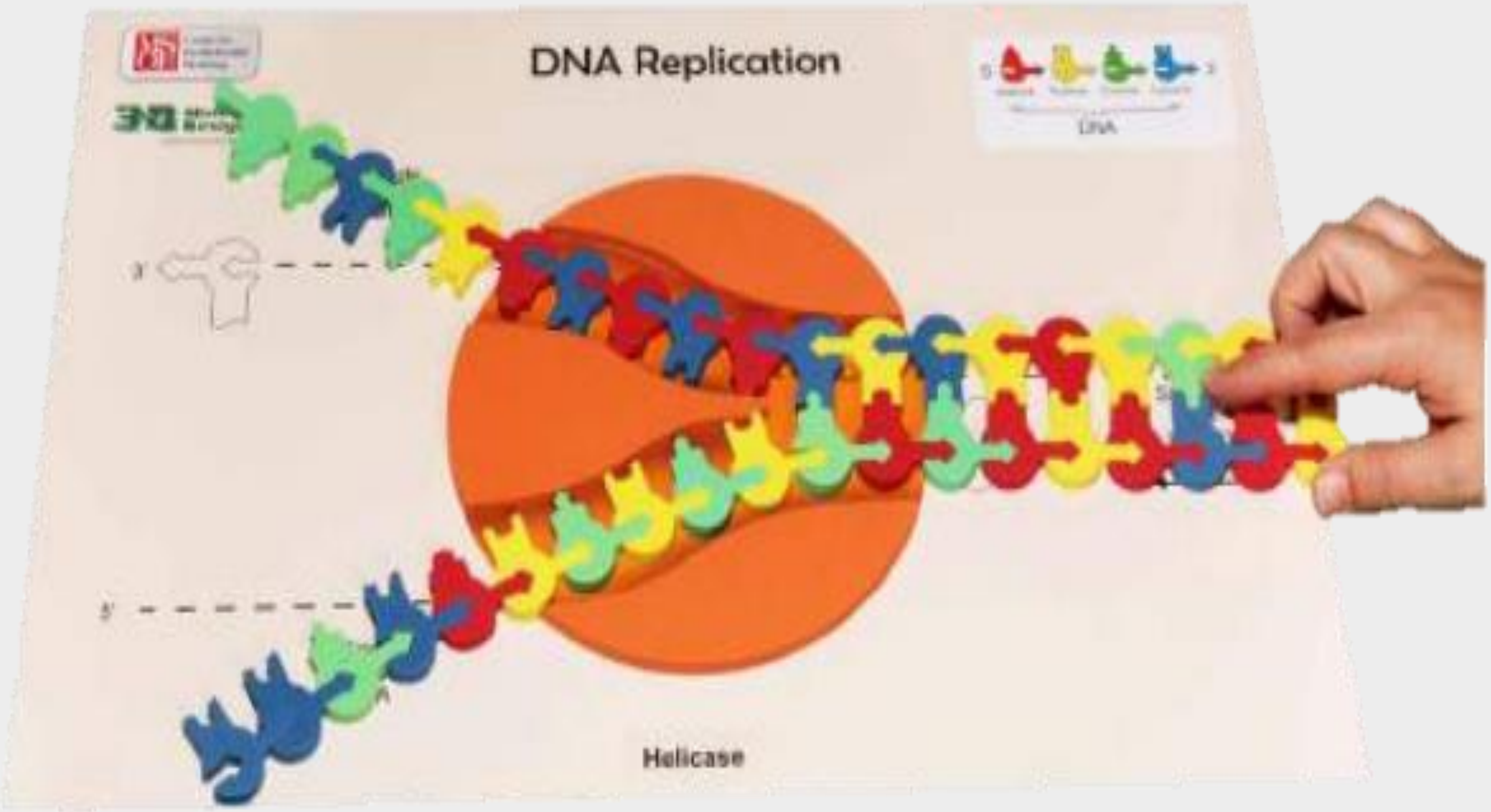
Replication in the Eukaryotic Nucleus



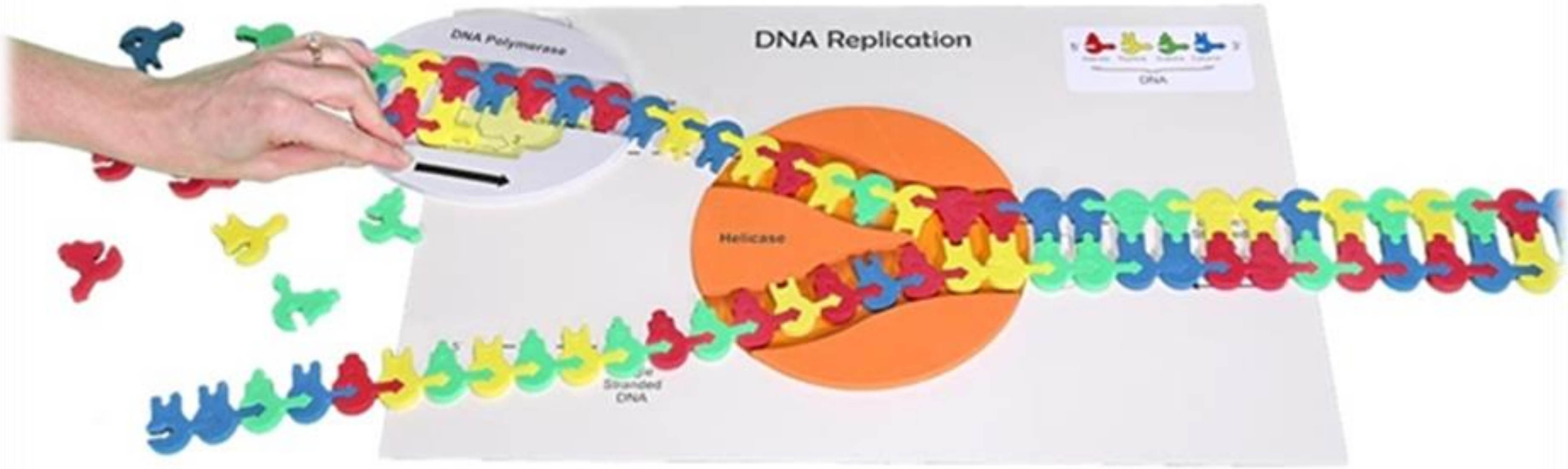
Replication Forks



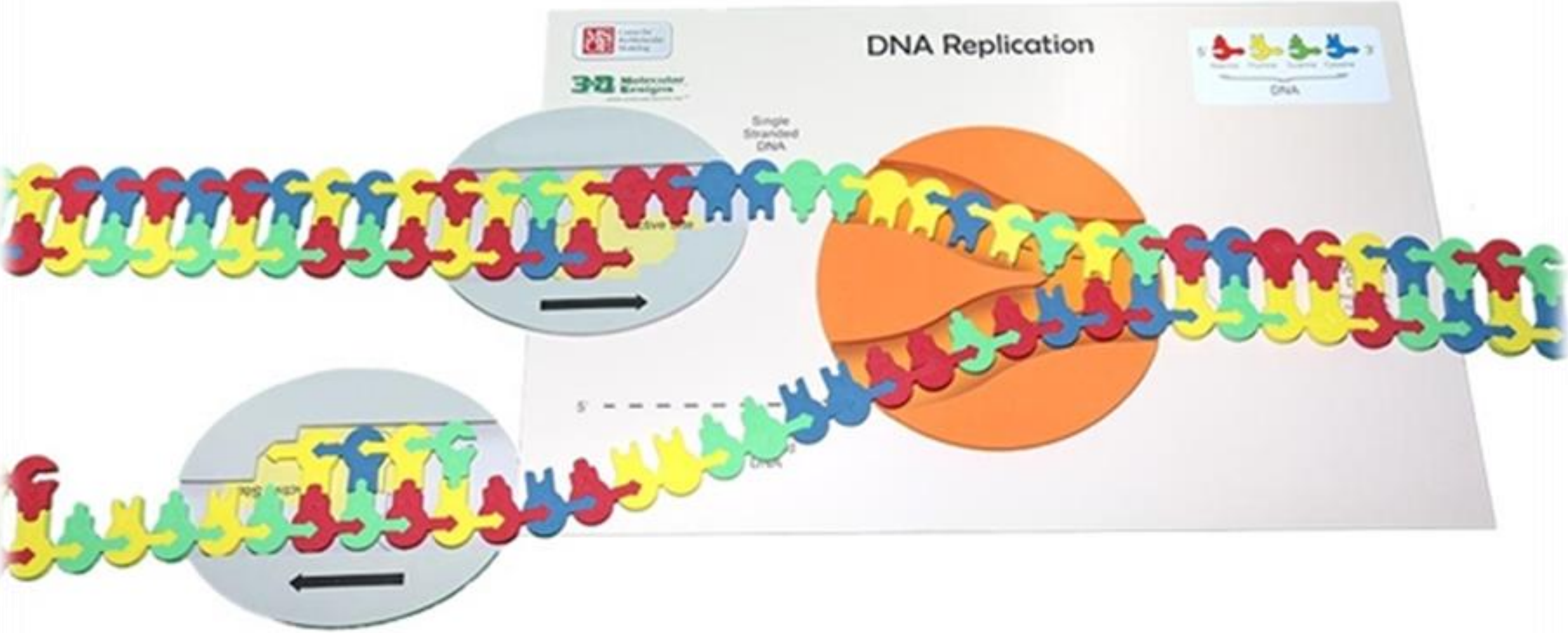
Replication



Continuous Replication



Discontinuous Replication



Comparing Leading and Lagging Strands

Template

Non-template

Diagram 1

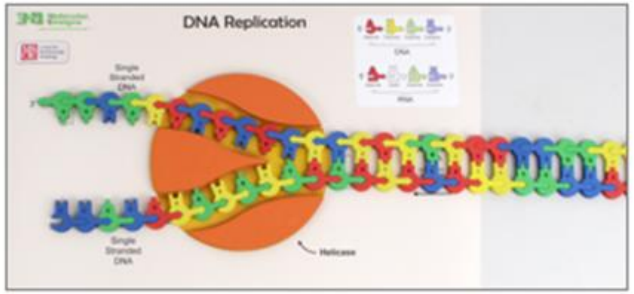
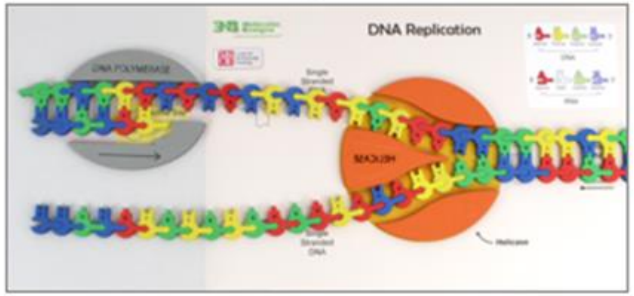


Diagram 2



Helicase unwinds the DNA at the replication fork

Helicases are enzymes that untwist the double helix and separate the two strands.

DNA polymerase catalyzes the synthesis of new DNA

Leading Strand: New DNA can elongate only in the 5′ → 3′ direction. The DNA strand that is made **continuously** is referred to as the leading strand. DNA polymerase moves toward the replication fork.

Diagram 3

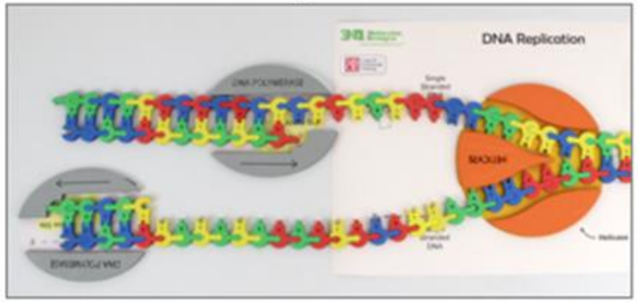
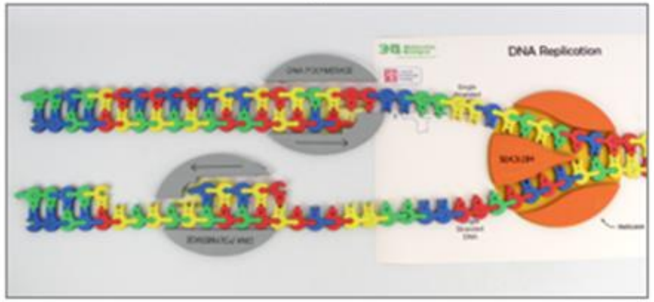
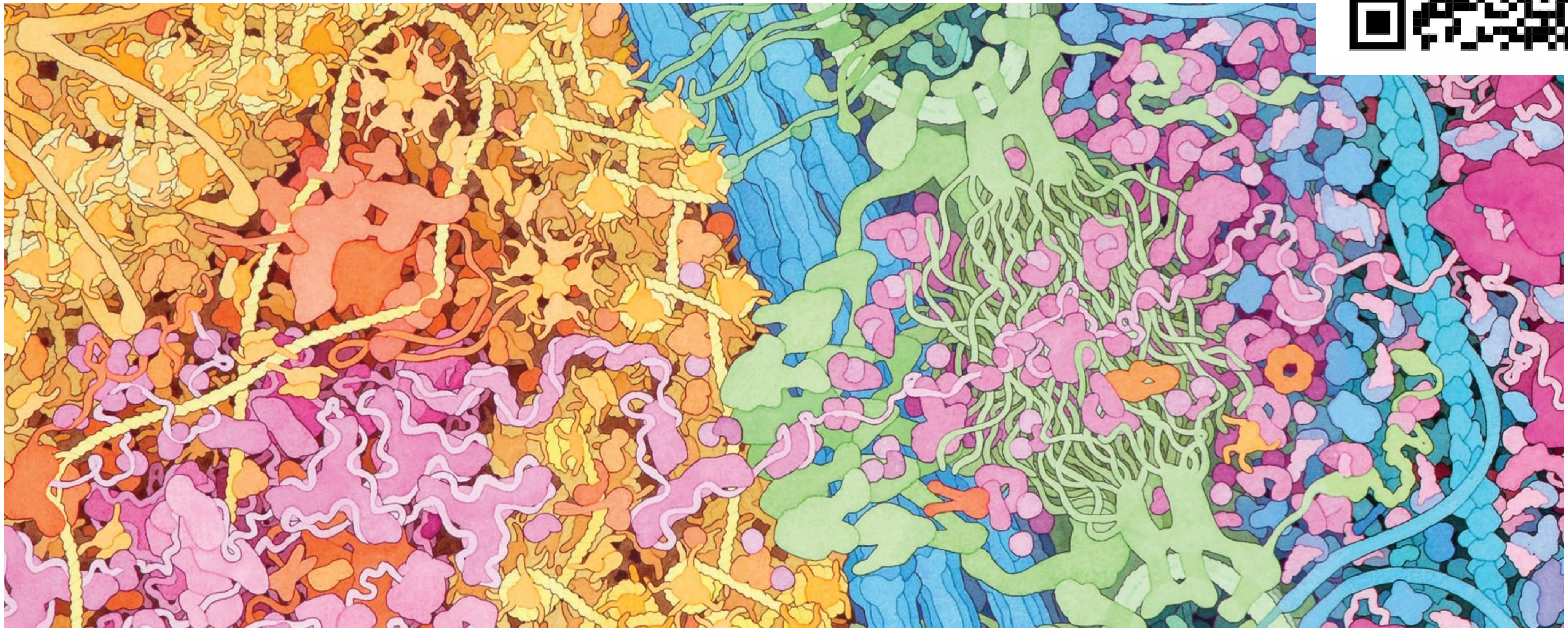


Diagram 4



Lagging Strand: DNA polymerase must move away from the fork instead of toward the fork as it did in the leading strand in order to maintain 5′ → 3′ DNA synthesis (diagram 3). The lagging strand is synthesized in a series of **discontinuous** fragments referred to as Okazaki fragments (diagram 4).

A brief tour through the cell



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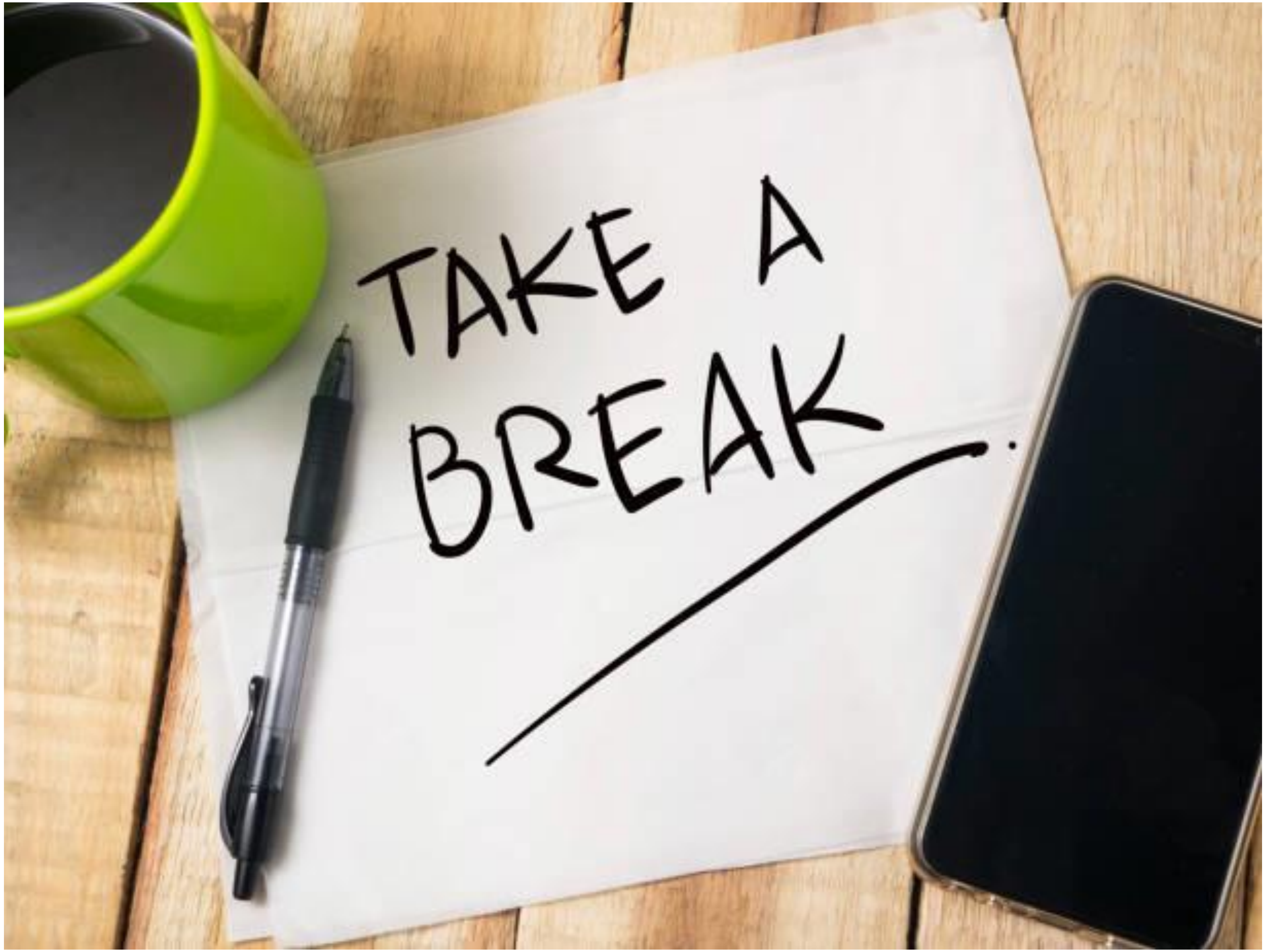
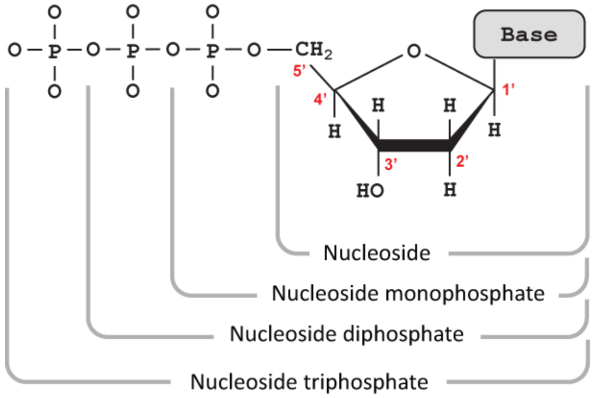
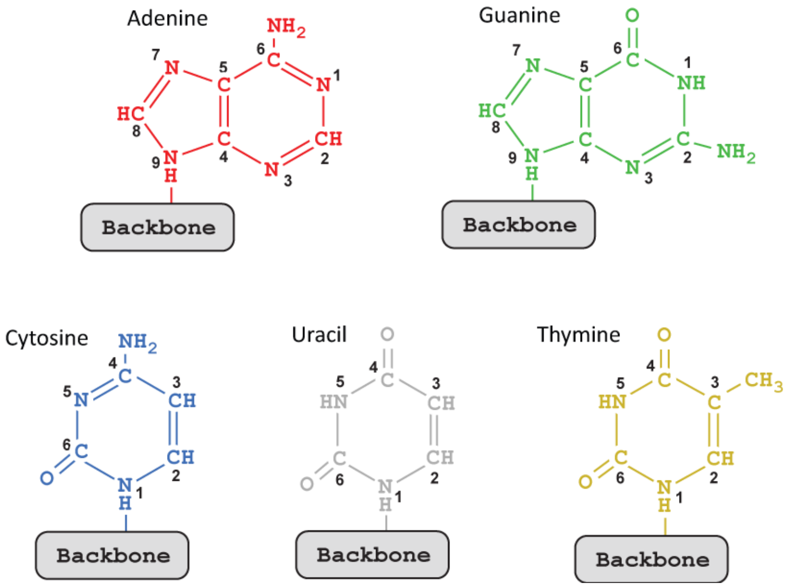
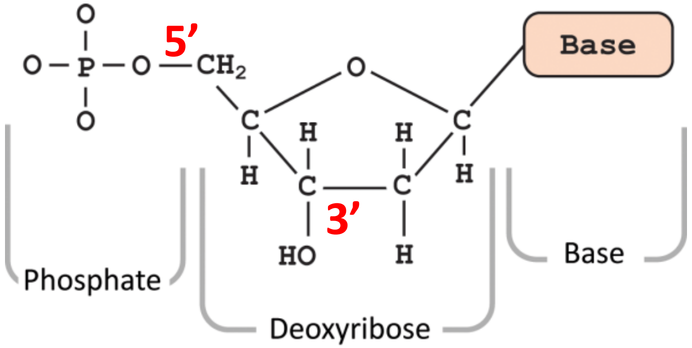
See you back in five minutes.

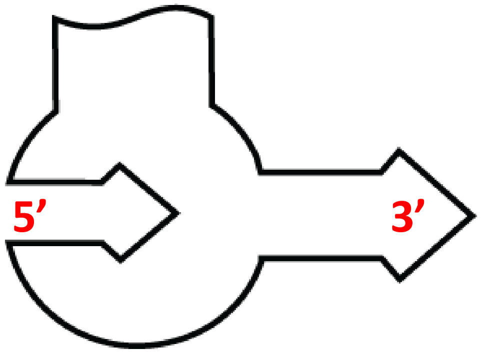


Transcription







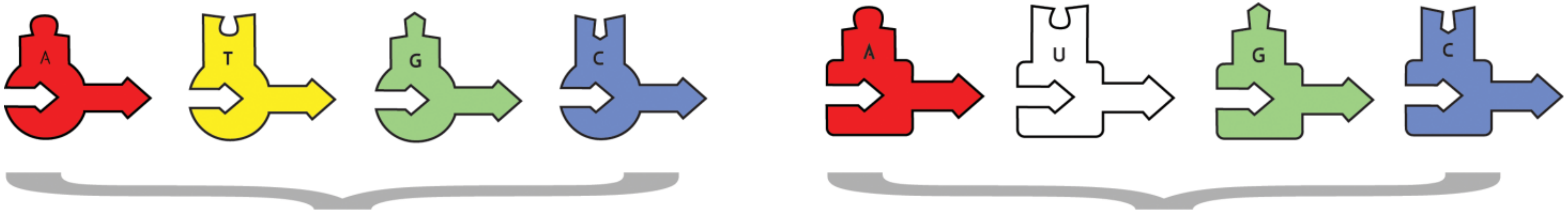


Helpful Hints:

Take care in loading the DNA in the RNA polymerase.

Remember RNA is synthesized from the 5' to the 3' end.

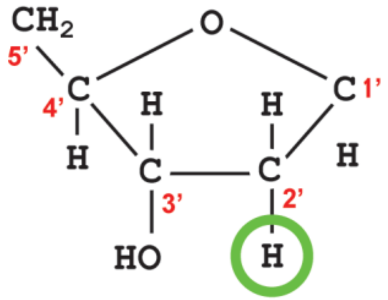
Transcription



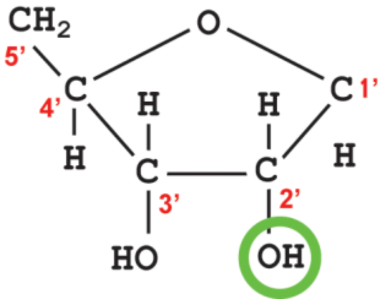
DNA

RNA

Deoxyribose
found in DNA



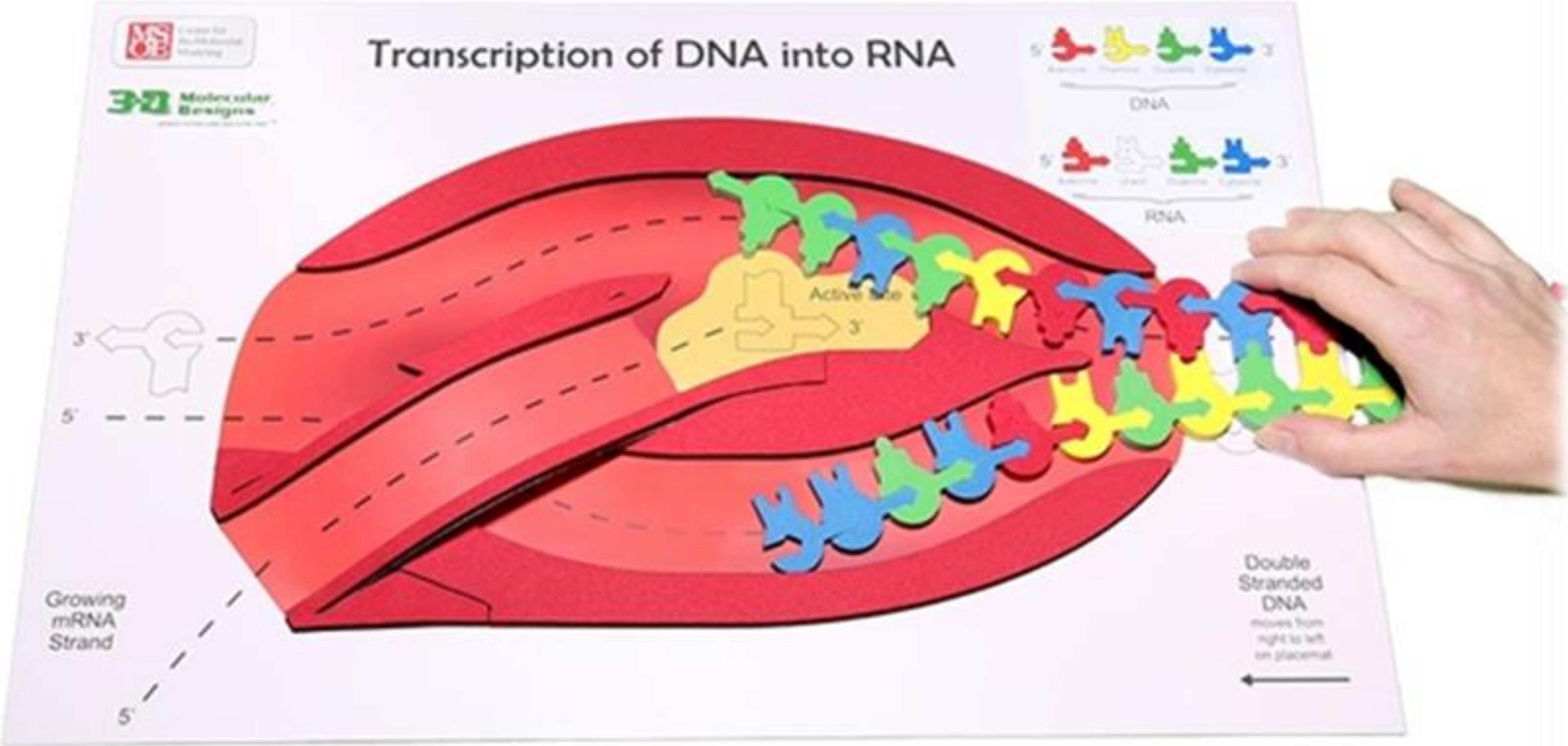
Ribose
found in RNA



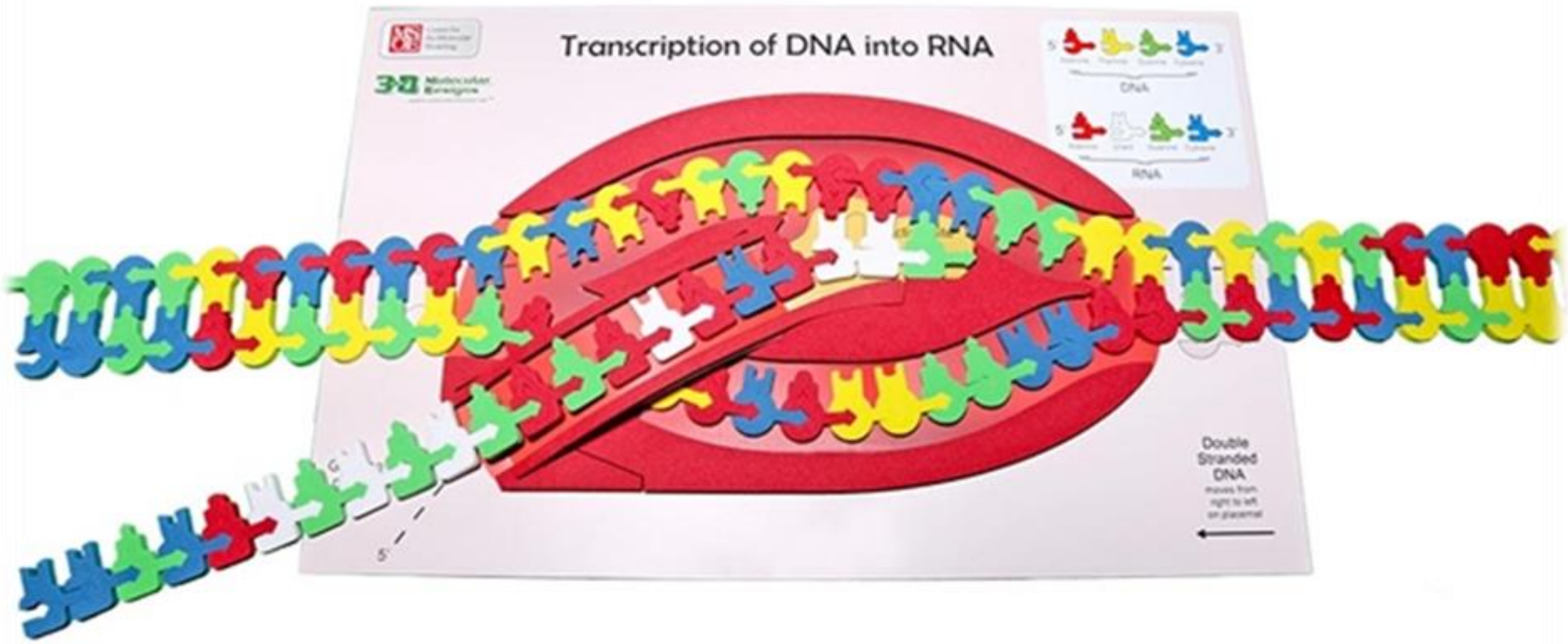
Helpful Hint:

The DNA pieces are different than the RNA pieces!

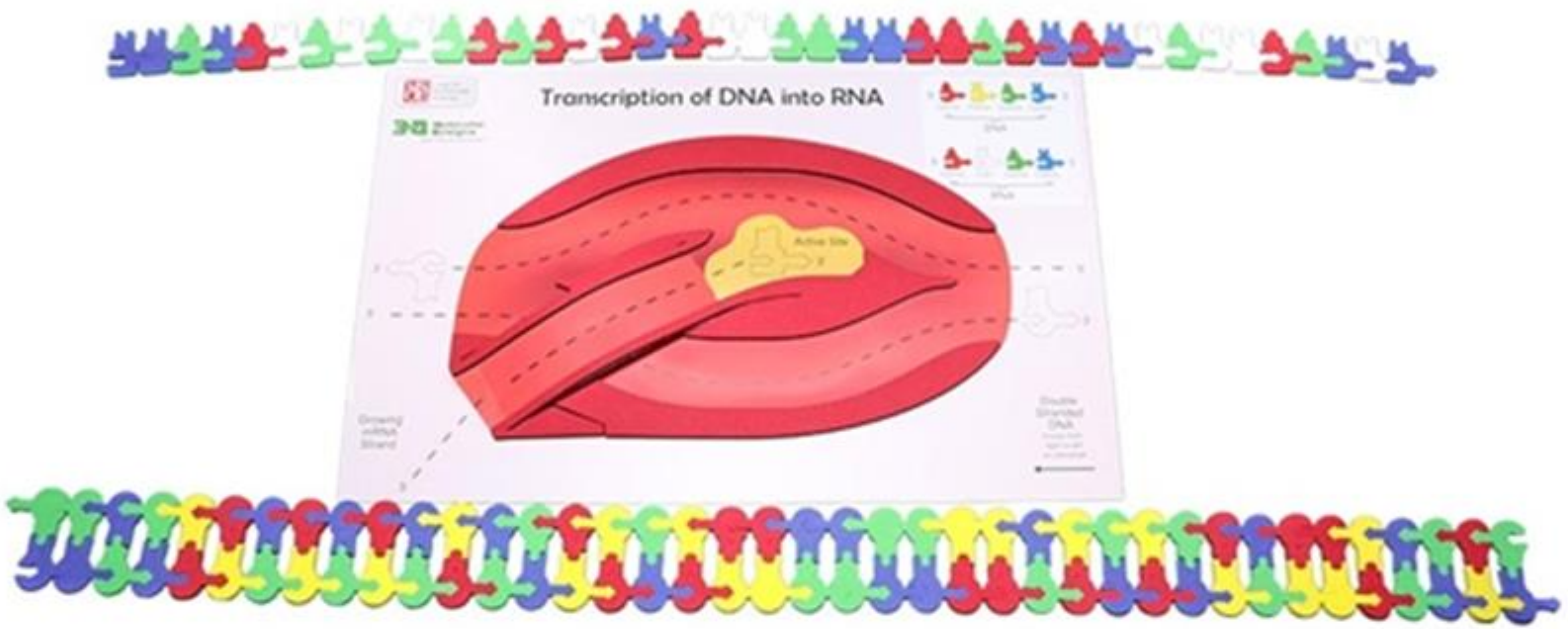
Transcription: Initiation



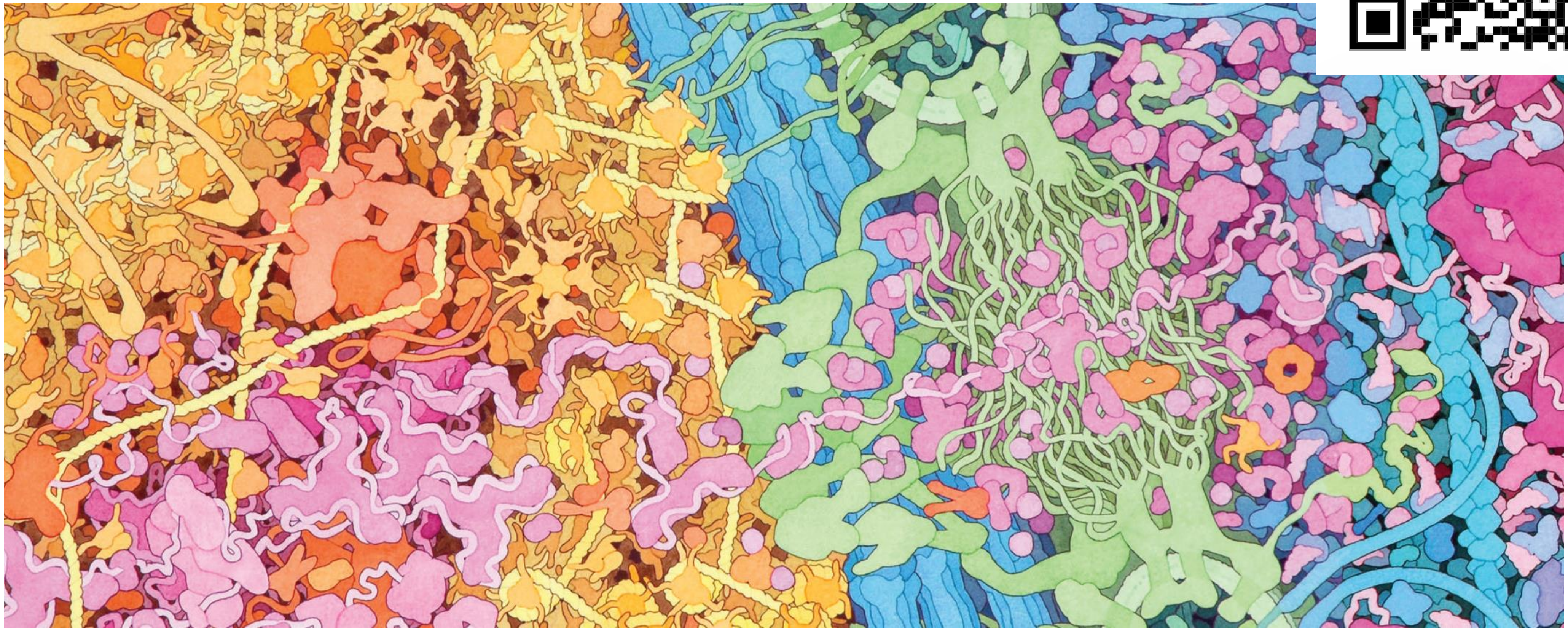
Transcription: Elongation



Transcription: Termination



A brief tour through the cell



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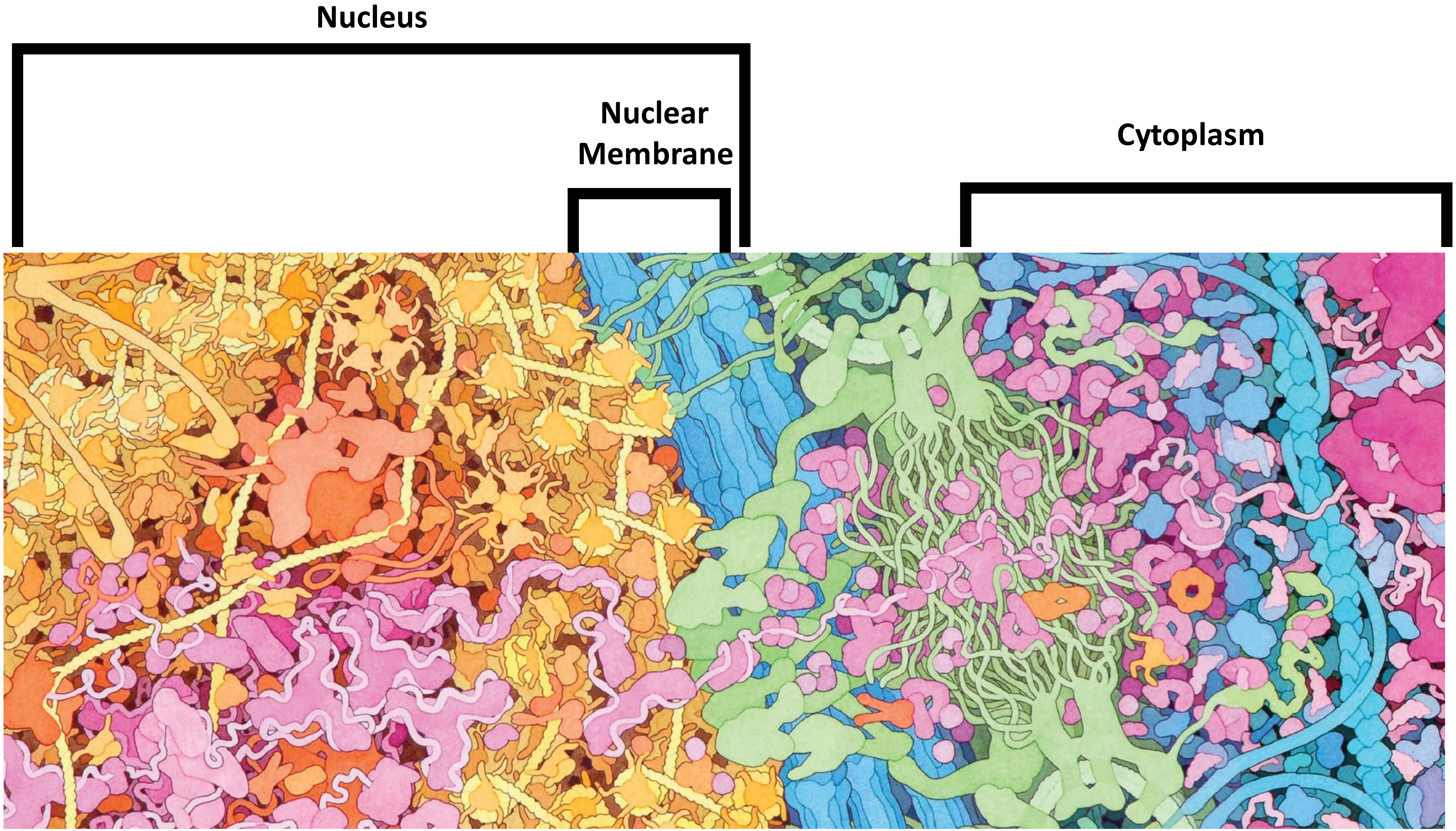

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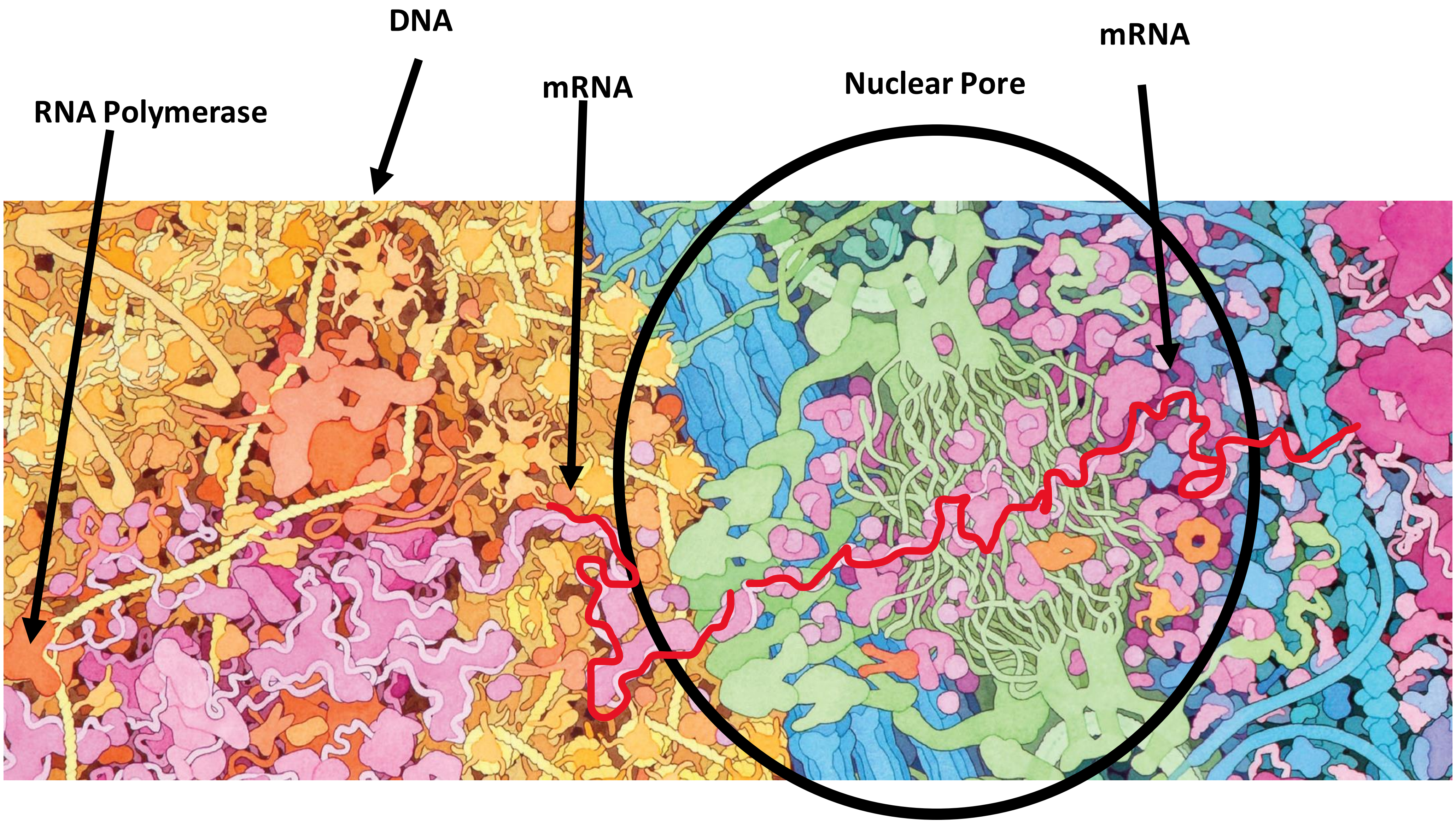

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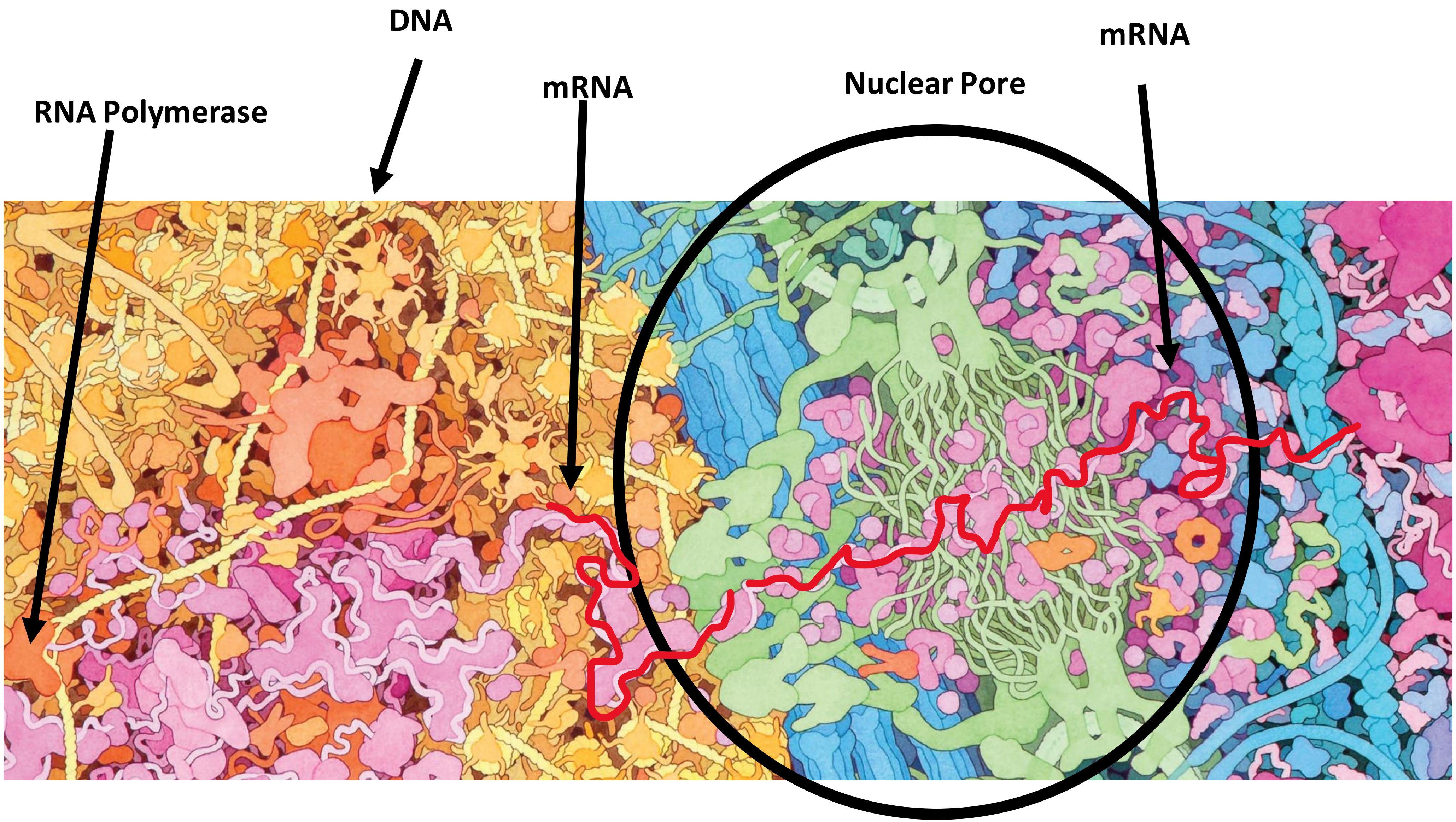

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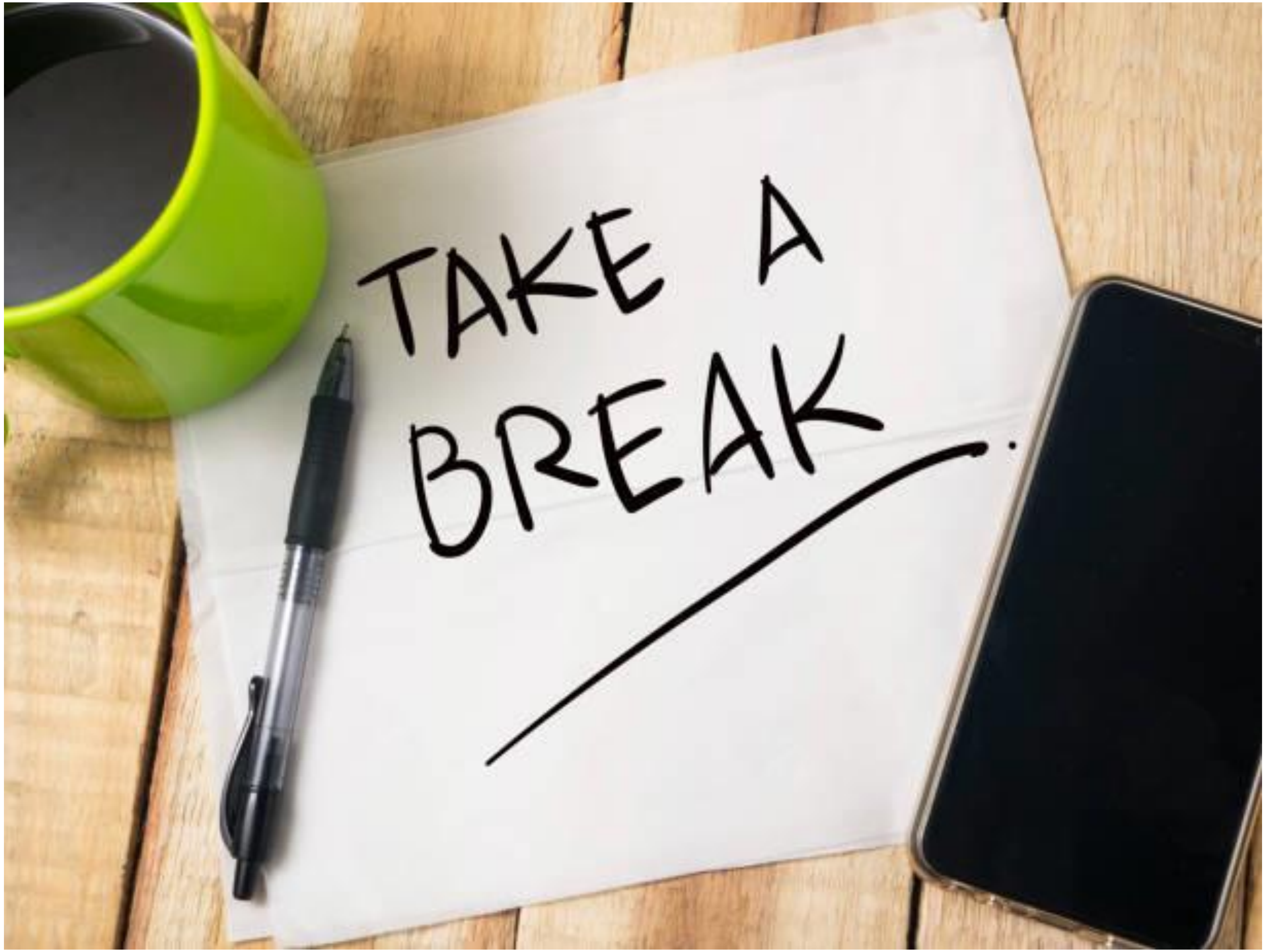
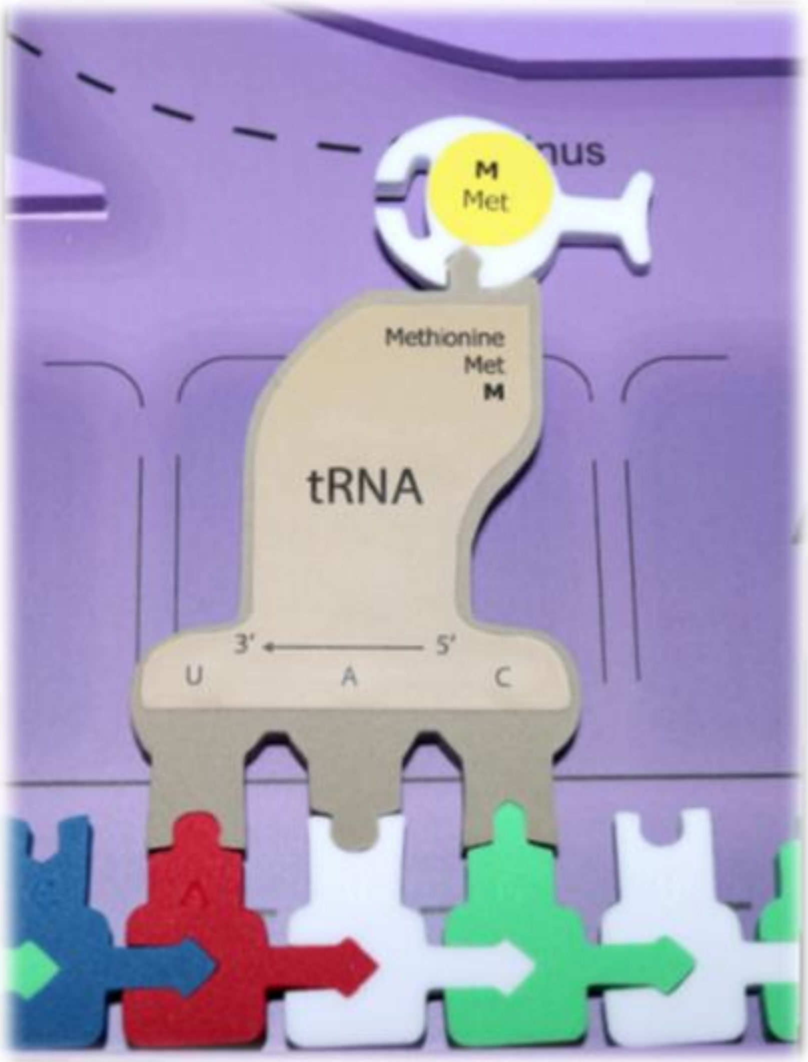
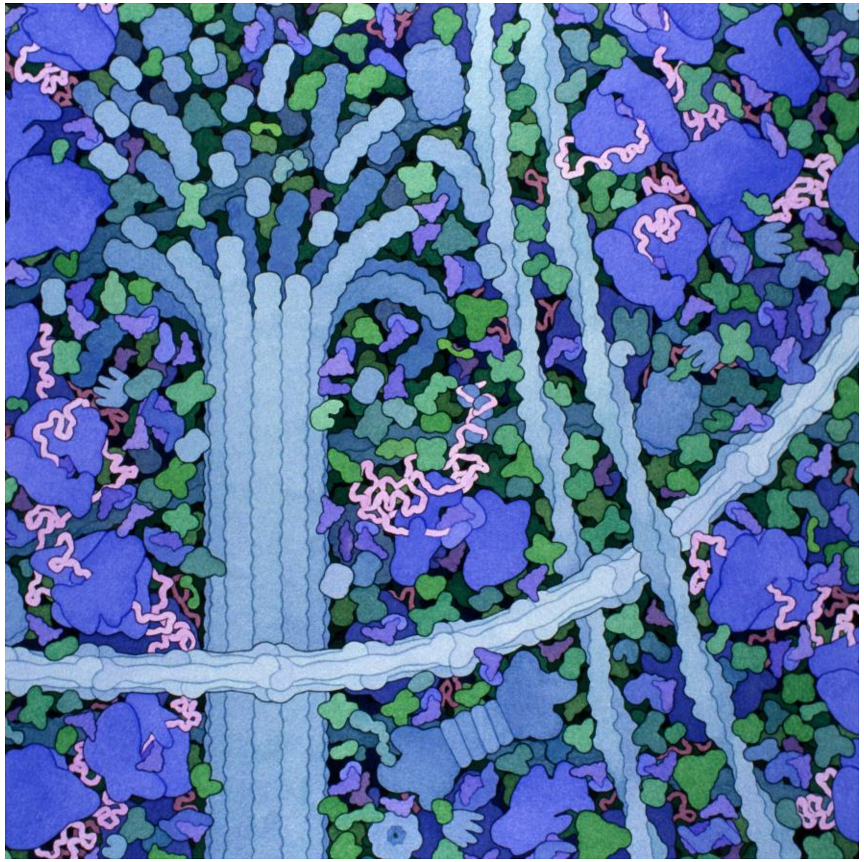


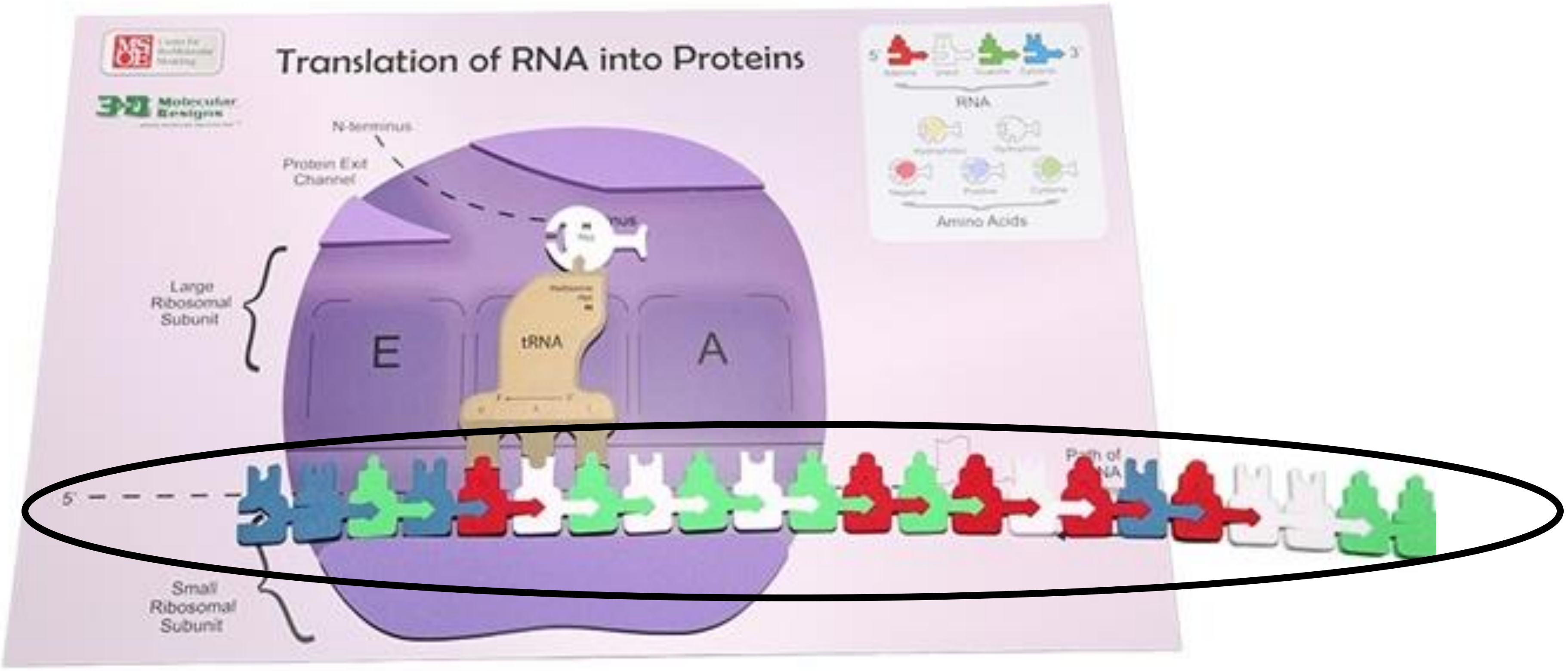
Translation





Acknowledgement: Illustration by David S. Goodsell. doi: 10.2210/rcsb_pdb/goodsell-gallery-006

Messenger RNA—It’s not limp spaghetti.



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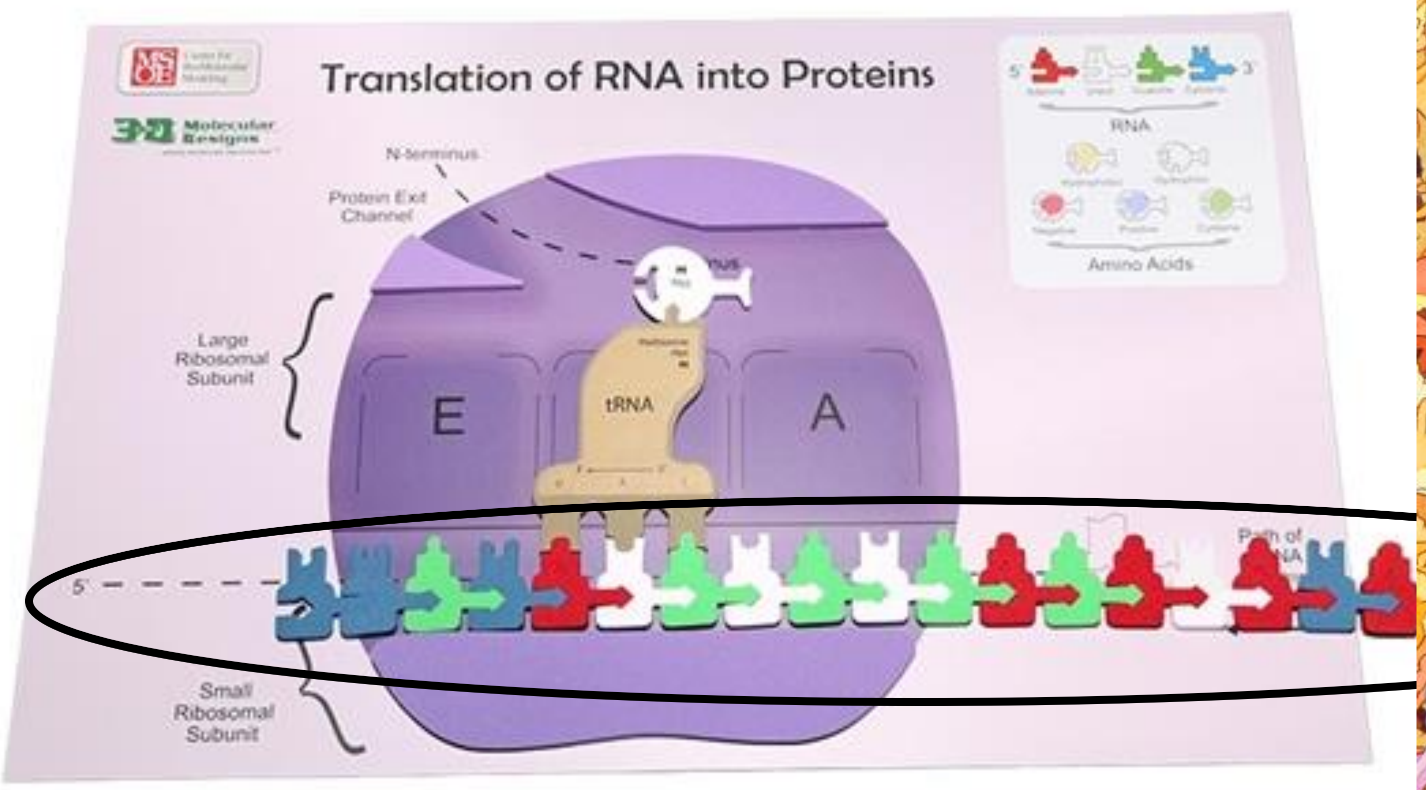
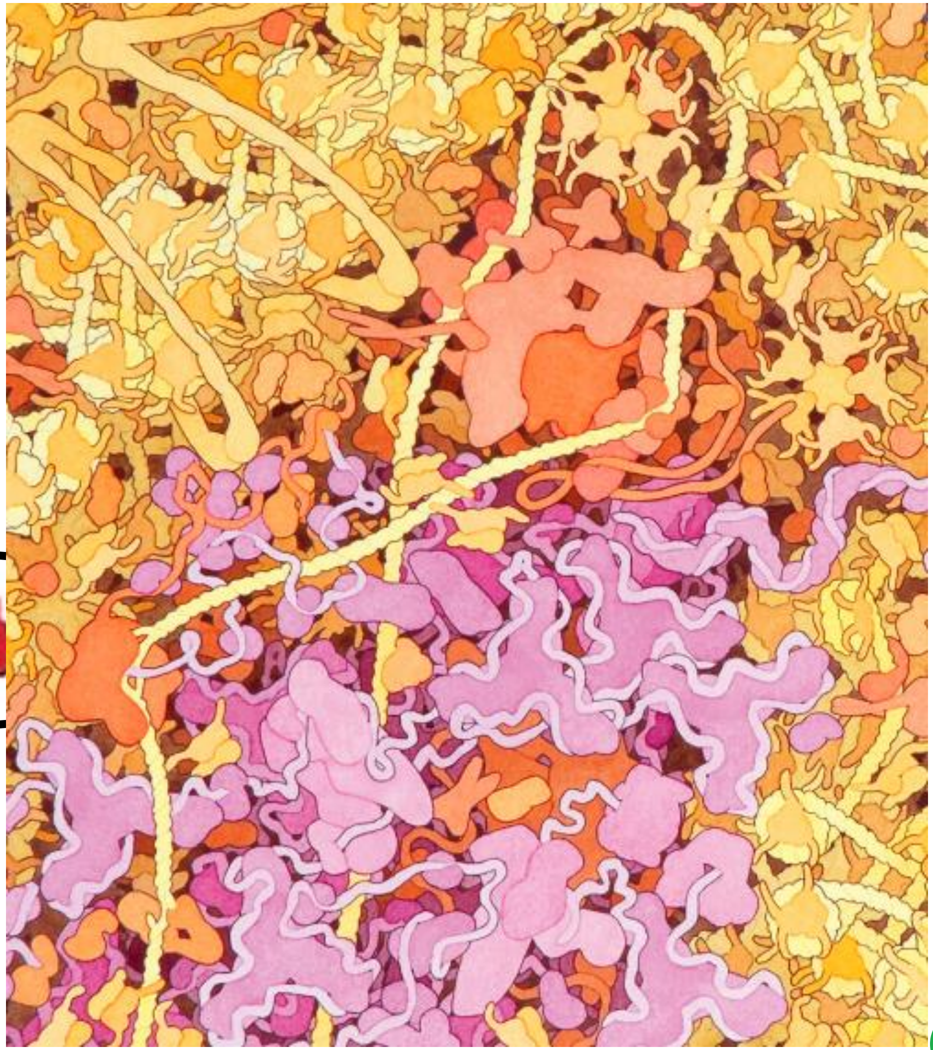




mRNA—Is this unstructured?

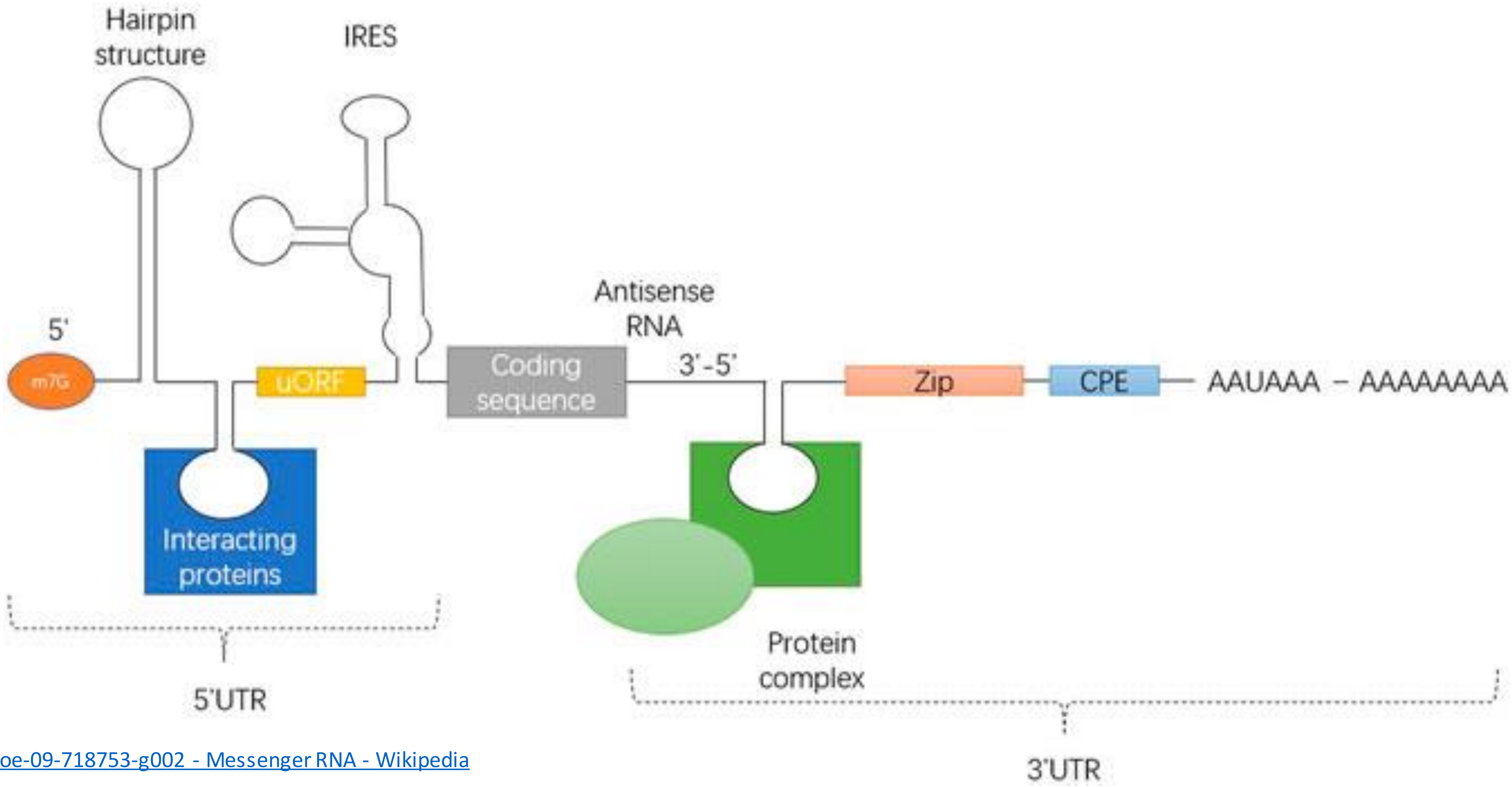
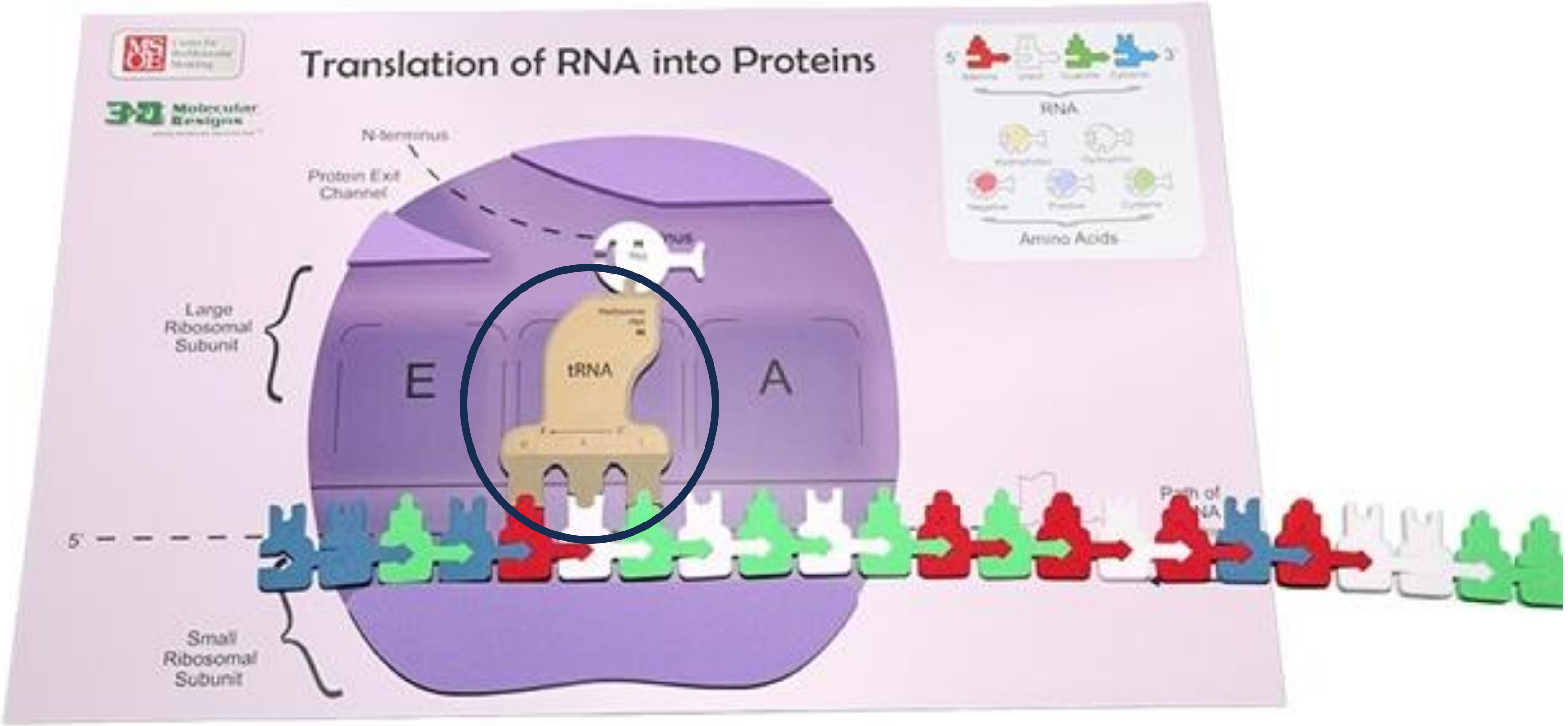
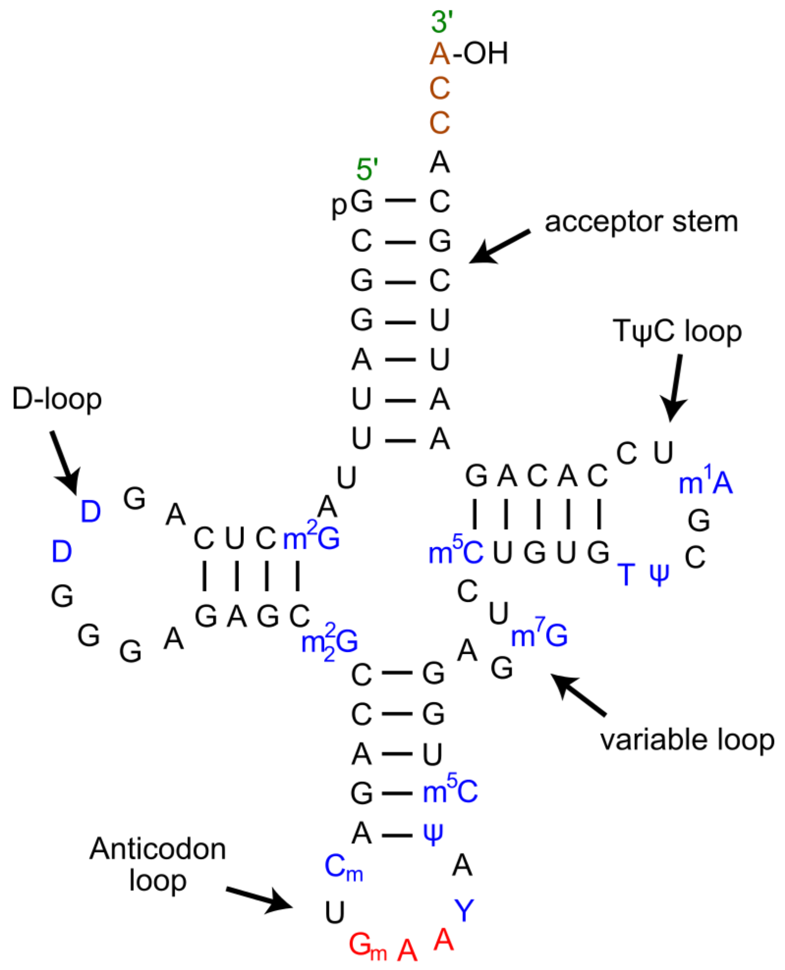


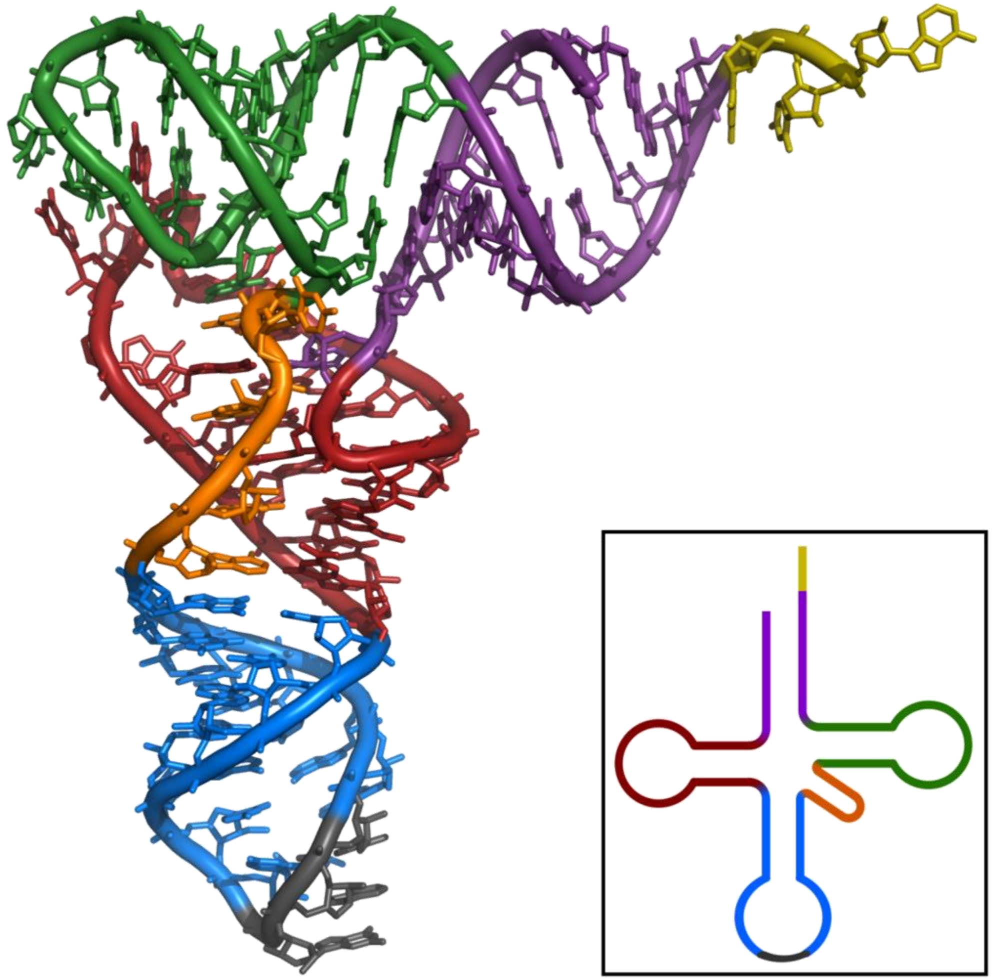
Image credit: Fbioe-09-718753-g002 - Messenger RNA - Wikipedia

Transfer RNA



Comparing tRNA models





[Image credit: TRNA-Phe yeast 1ehz - Transfer RNA - Wikipedia](#) [Image credit: TRNA-Phe yeast 1ehz - Transfer RNA - Wikipedia](#)

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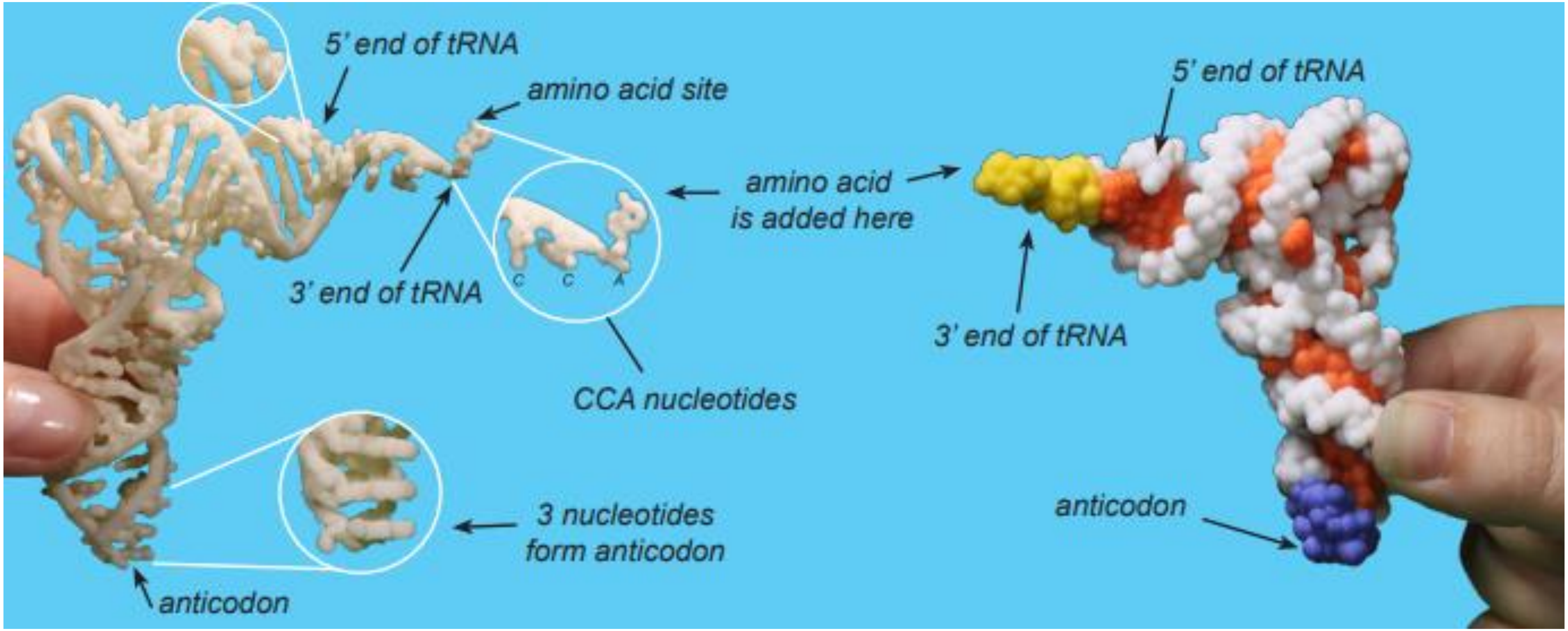
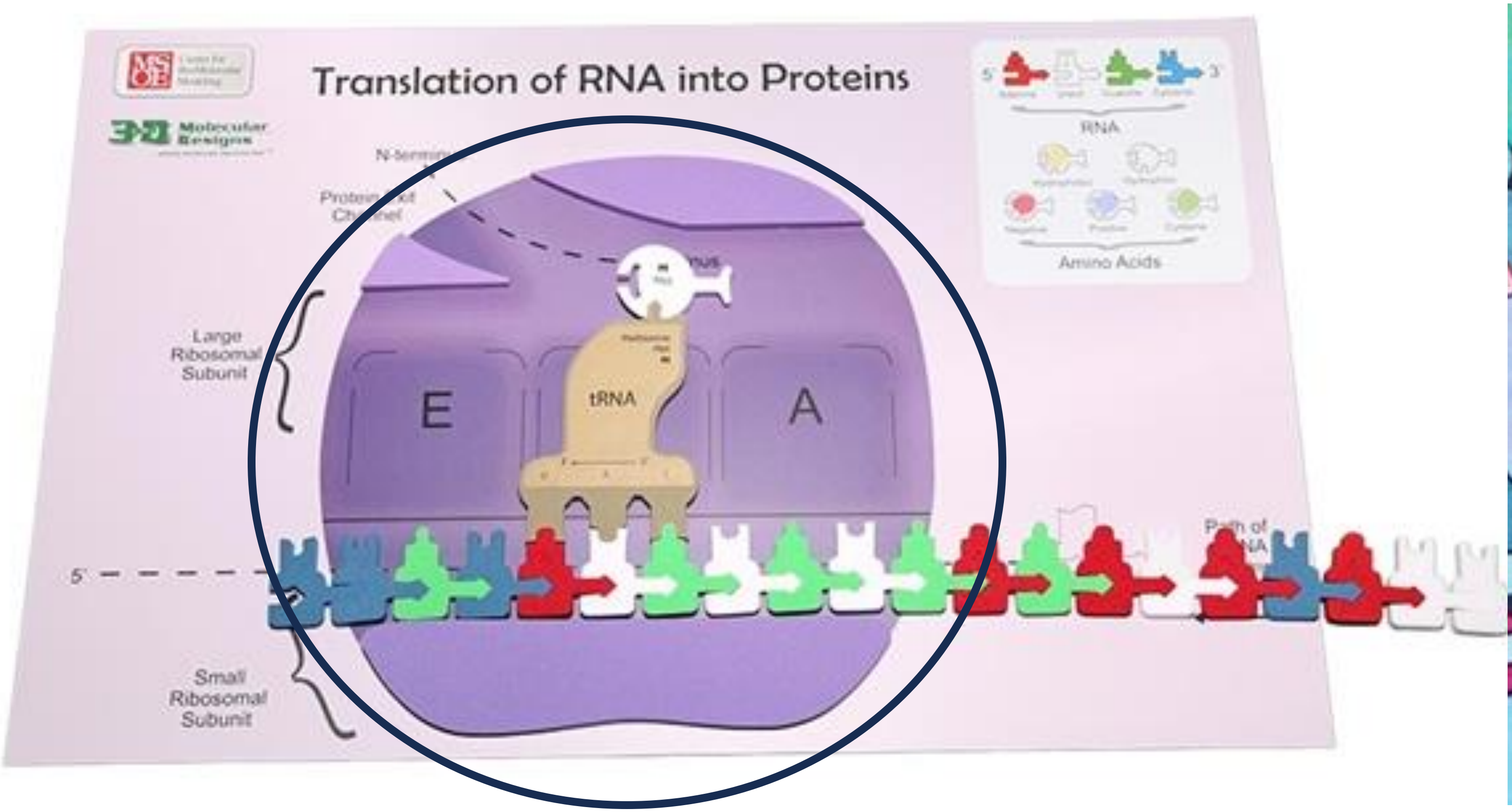
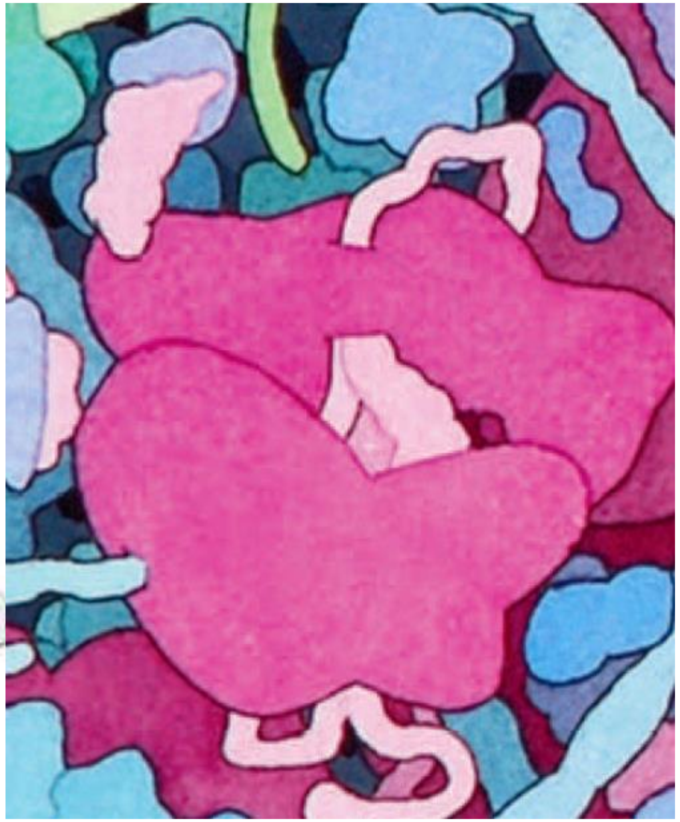


Ribosome-Ribosomal RNA and protein biological machine





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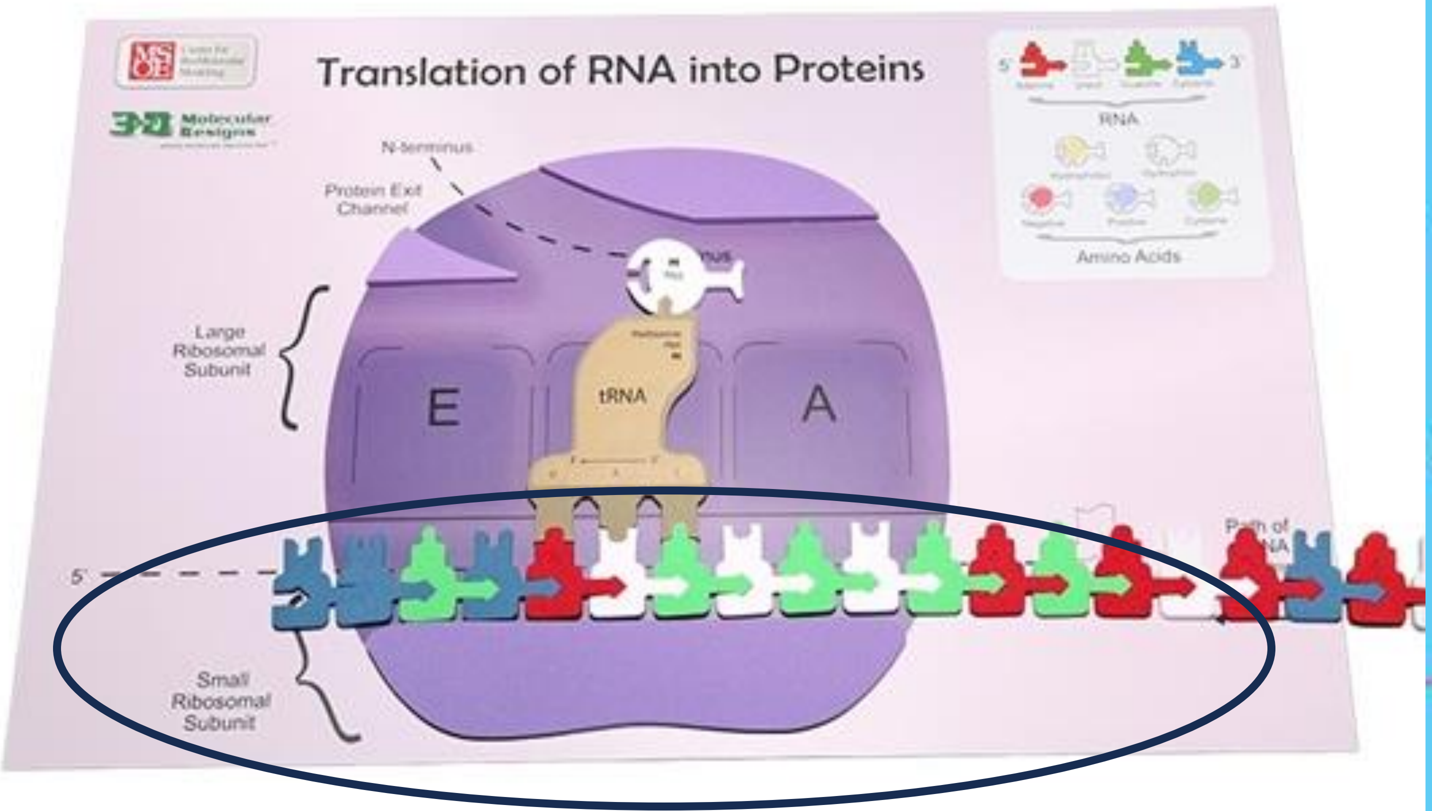

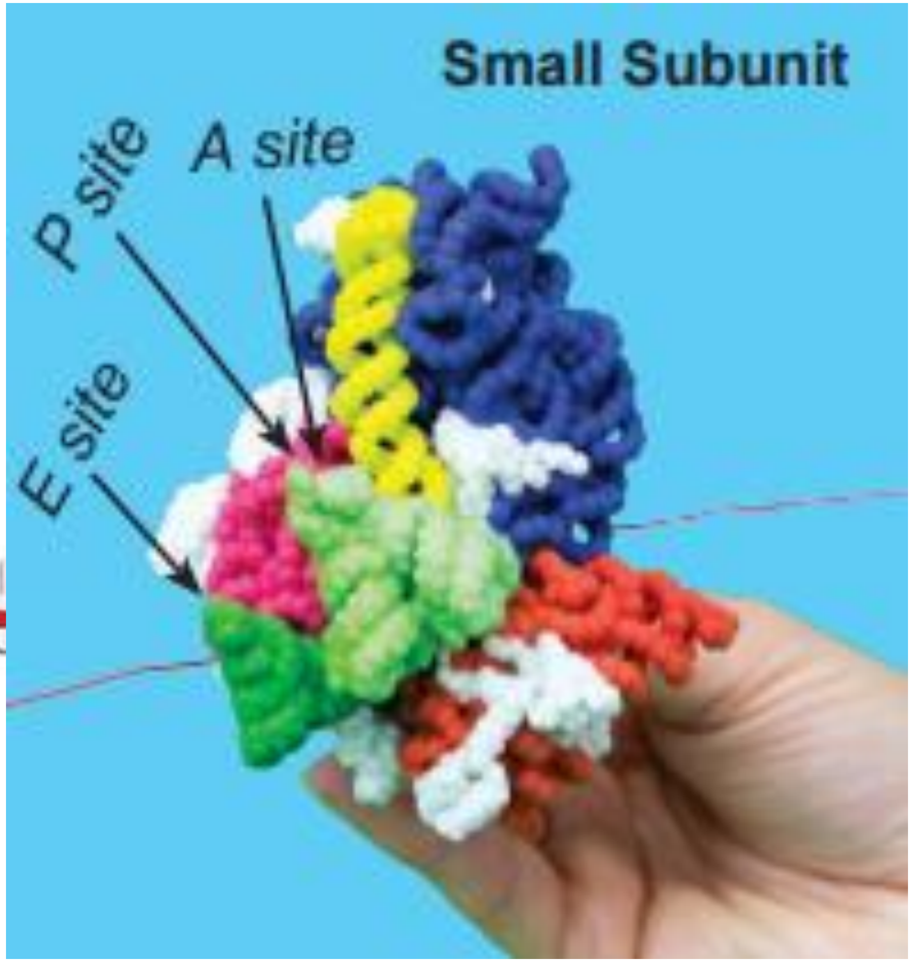

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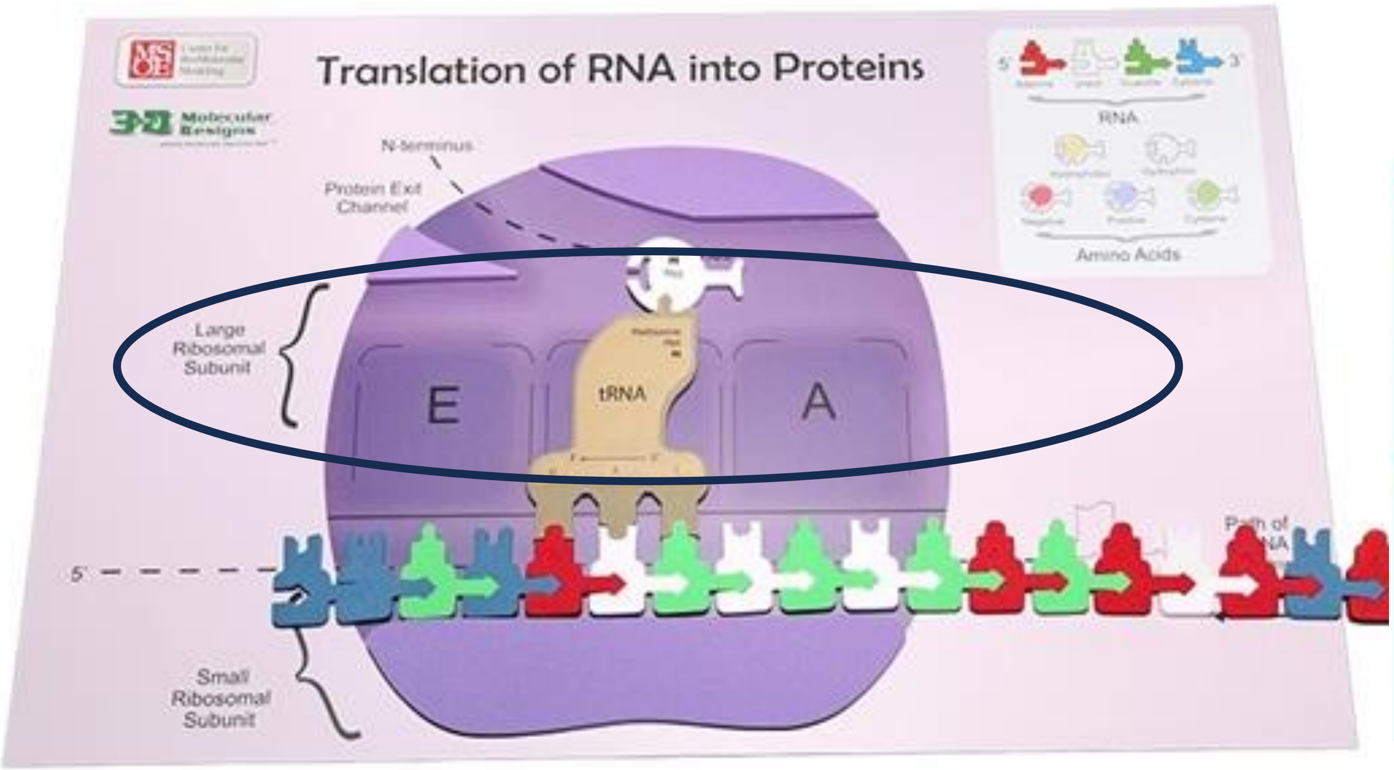

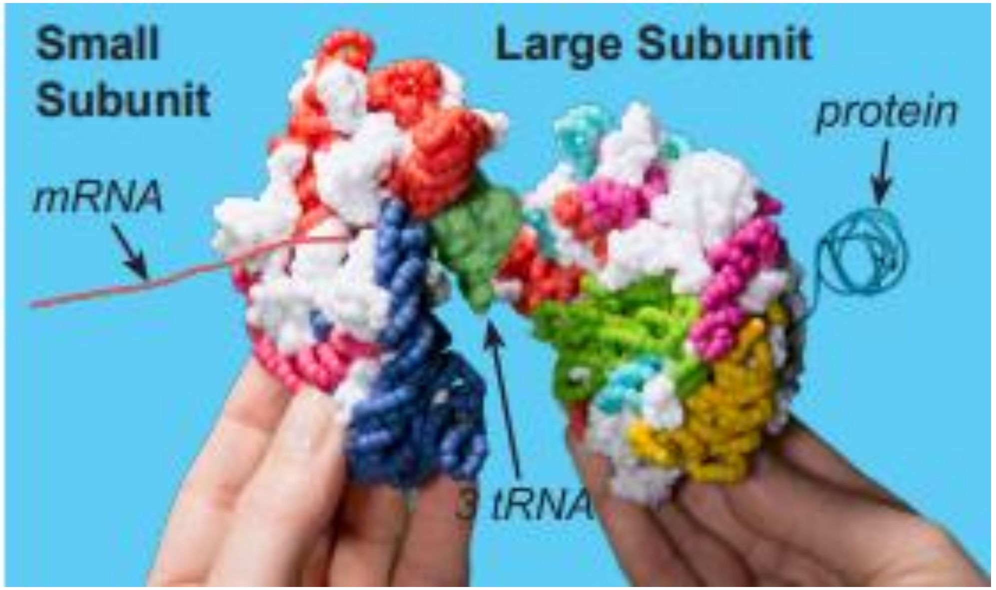

The Genetic Codon Chart®

	U	C	A	G	
U	UUU → Phe F	UCU → Ser S	UAU → Tyr Y	UGU → Cys C	U
U	UUC → Phe F	UCC → Ser S	UAC → Tyr Y	UGC → Cys C	C
U	UUA → Leu L	UCA → Ser S	UAA → Stop	UGA → Stop	A
U	UUG → Leu L	UCG → Ser S	UAG → Stop	UGG → Trp W	G
C	CUU → Leu L	CCU → Pro P	CAU → His H	CGU → Arg R	U
C	CUC → Leu L	CCC → Pro P	CAC → His H	CGC → Arg R	C
C	CUA → Leu L	CCA → Pro P	CAA → Gln Q	CGA → Arg R	A
C	CUG → Leu L	CCG → Pro P	CAG → Gln Q	CGG → Arg R	G
A	AUU → Ile I	ACU → Thr T	AAU → Asn N	AGU → Ser S	U
A	AUC → Ile I	ACC → Thr T	AAC → Asn N	AGC → Ser S	C
A	AUA → Ile I	ACA → Thr T	AAA → Lys K	AGA → Arg R	A
A	AUG → Met M	ACG → Thr T	AAG → Lys K	AGG → Arg R	G
G	GUU → Val V	GCU → Ala A	GAU → Asp D	GGU → Gly G	U
G	GUC → Val V	GCC → Ala A	GAC → Asp D	GGC → Gly G	C
G	GUA → Val V	GCA → Ala A	GAA → Glu E	GGA → Gly G	A
G	GUG → Val V	GCG → Ala A	GAG → Glu E	GGG → Gly G	G

Amino Acid Properties

- Translation Start Codon
- Translation Stop Codon
- Hydrophobic / Non-polar
- Hydrophilic / Polar
- Negative Charge
- Positive Charge
- Cysteine

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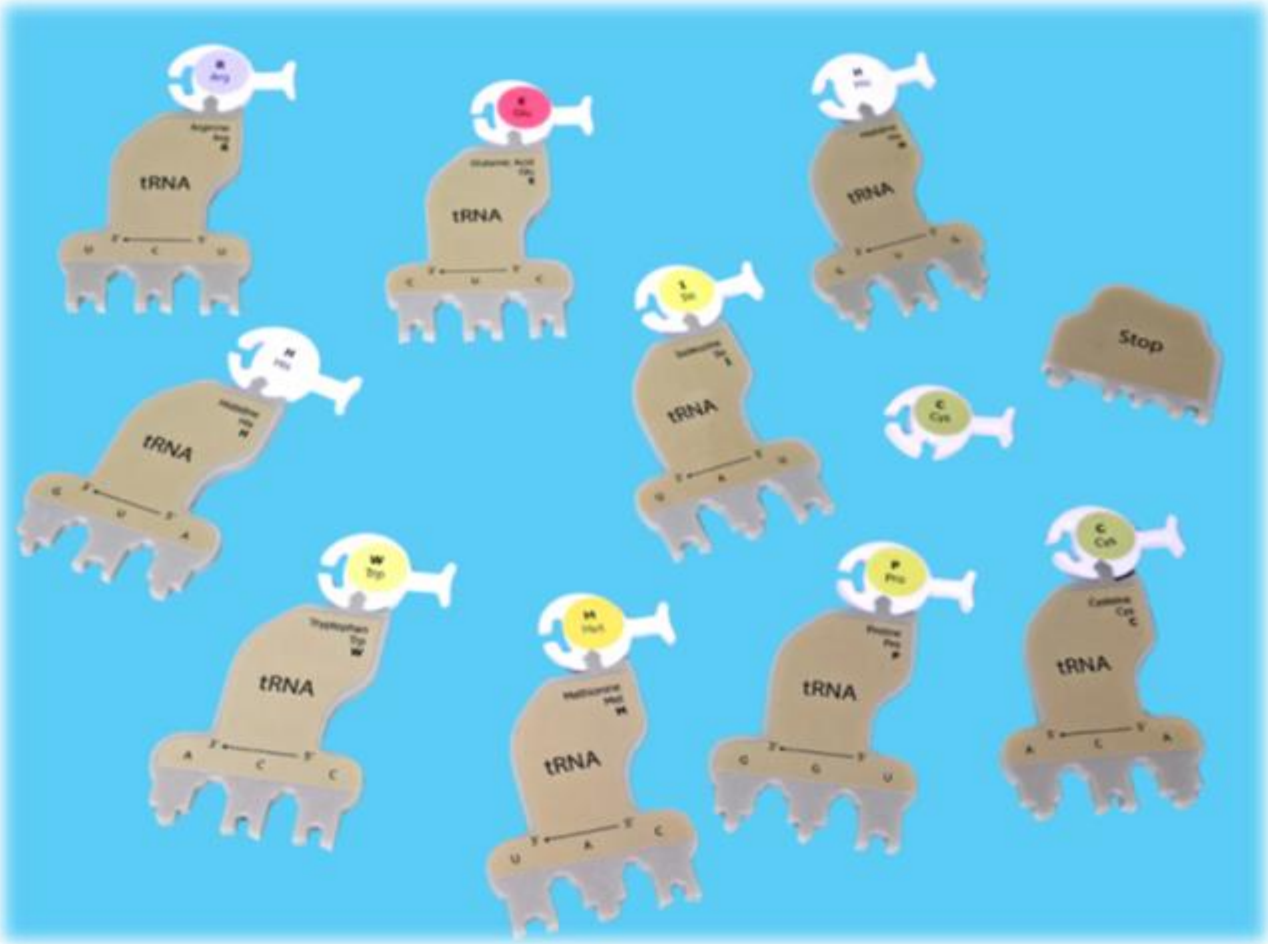
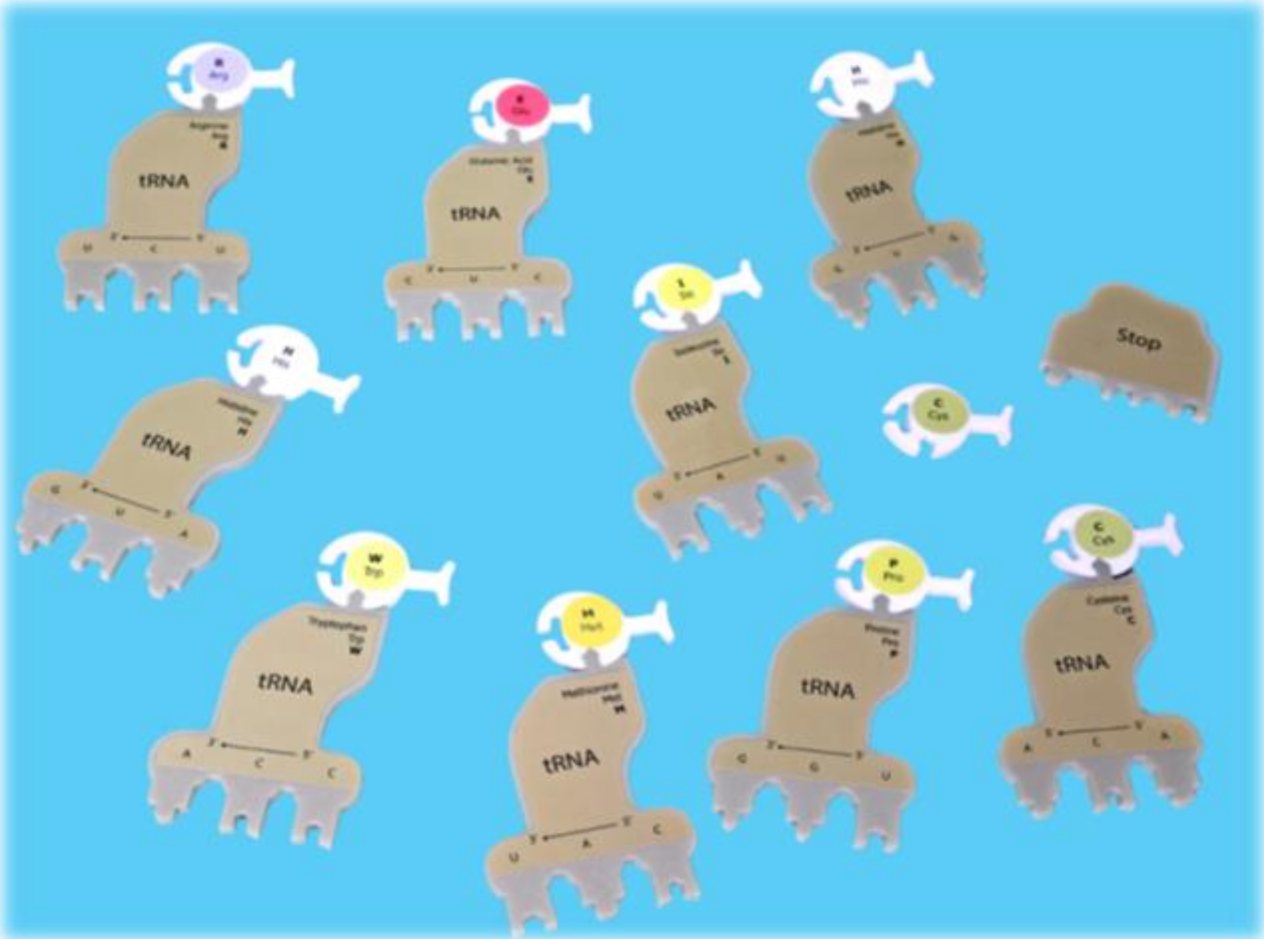
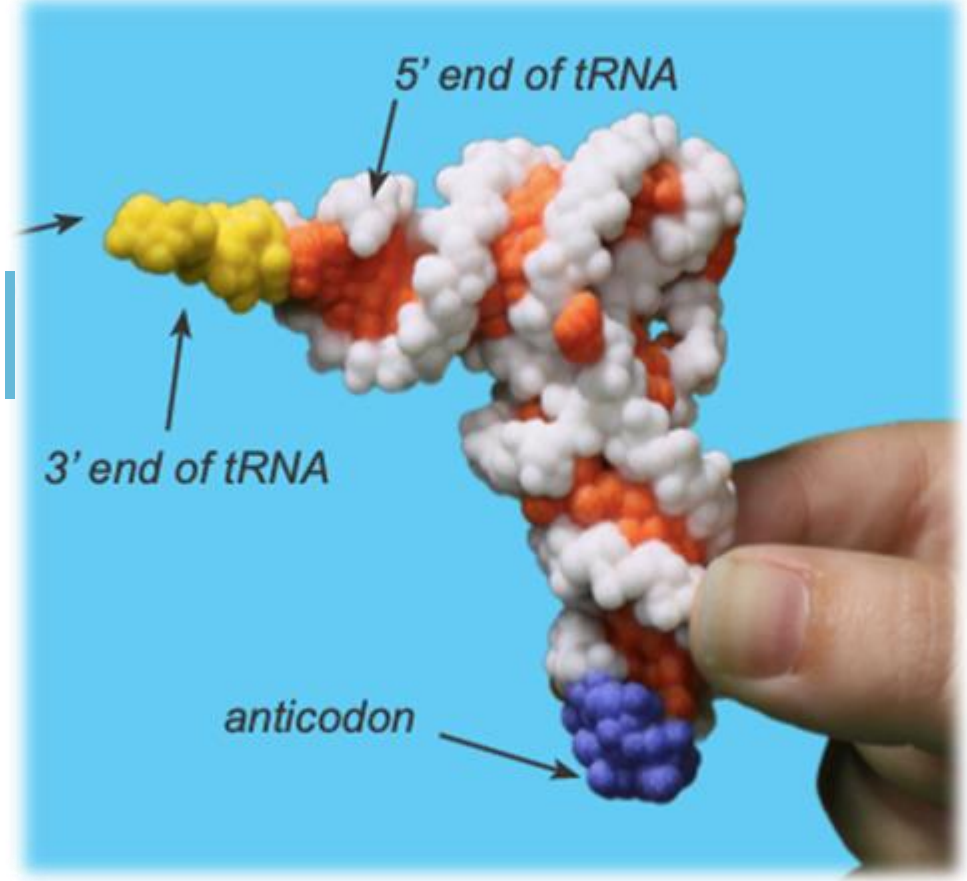
Pair the tRNA with the amino acids

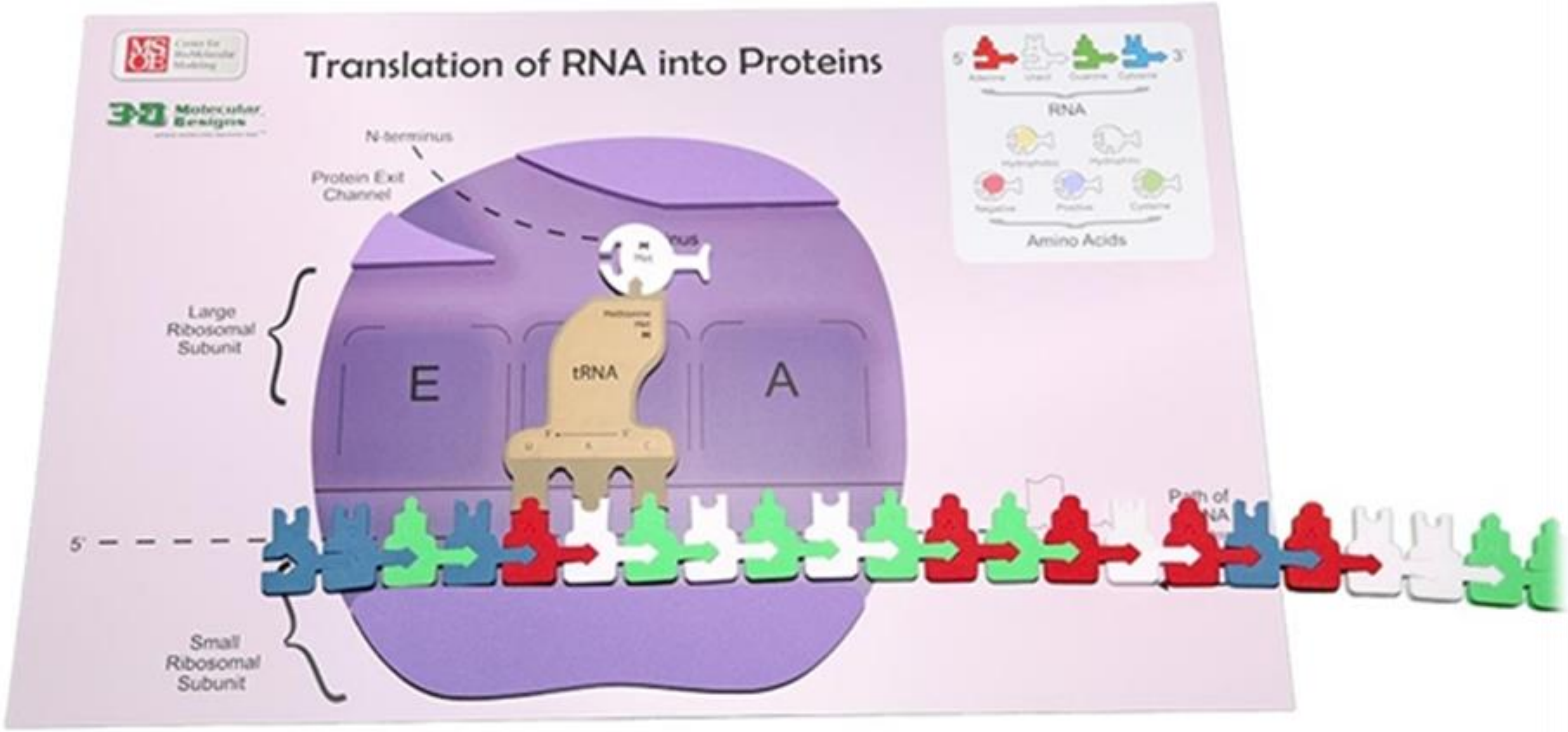


A closer look at tRNAs





Translation: Initiation



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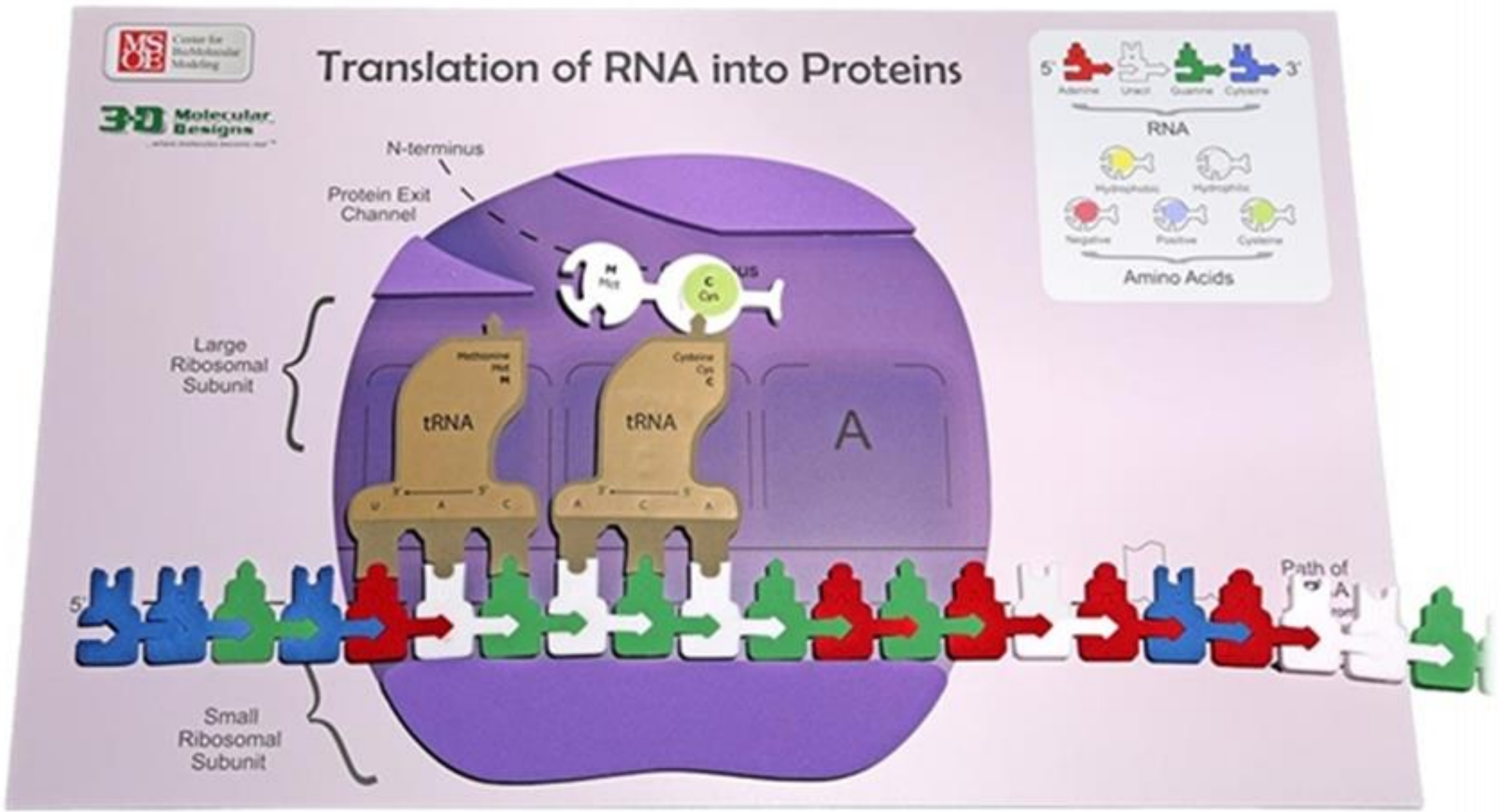

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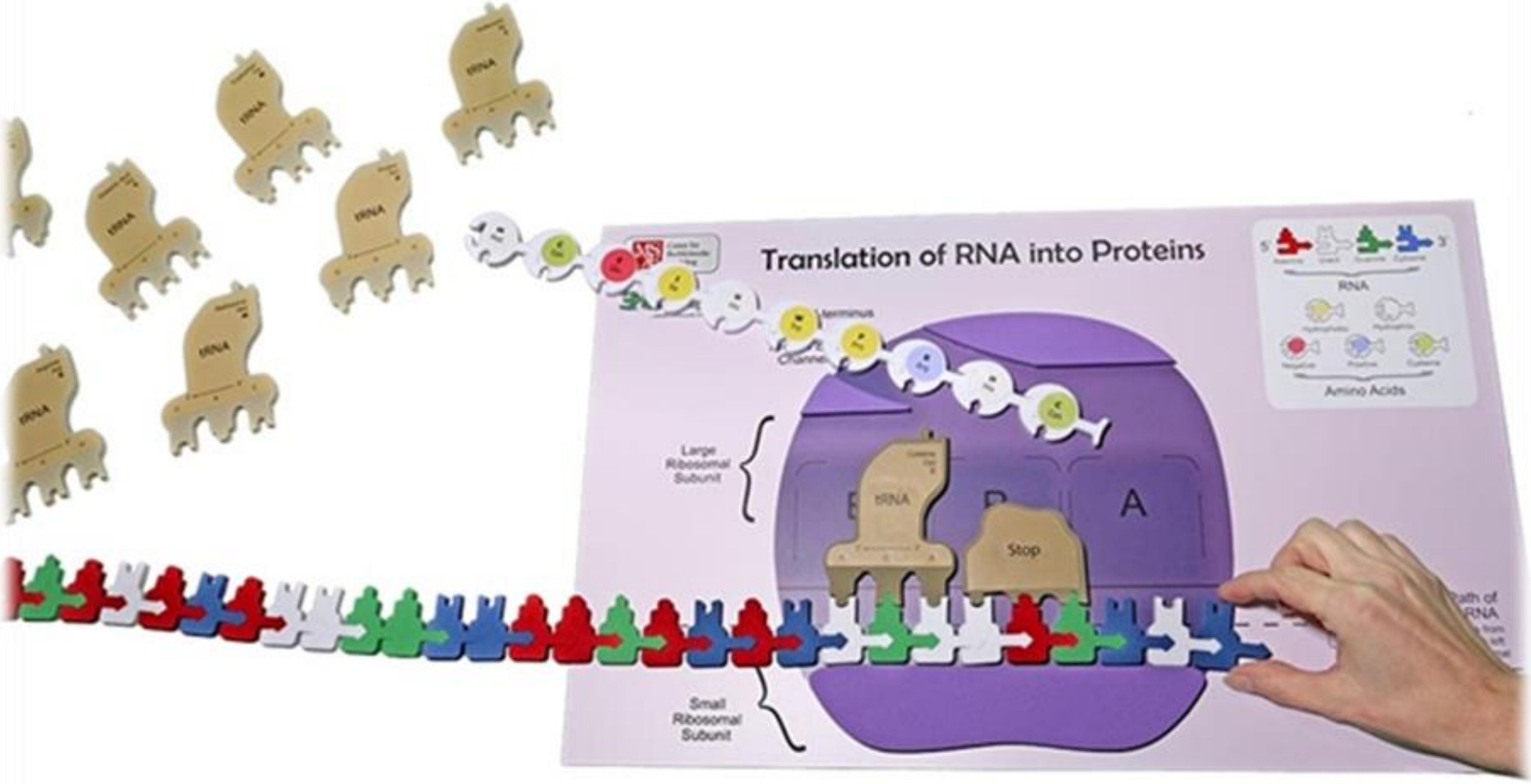

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G	GUU → Val V	GCU → Ala A	GAU → Asp D	GGU → Gly G	U
	GUC → Val V	GCC → Ala A	GAC → Asp D	GGC → Gly G	C
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- Cysteine

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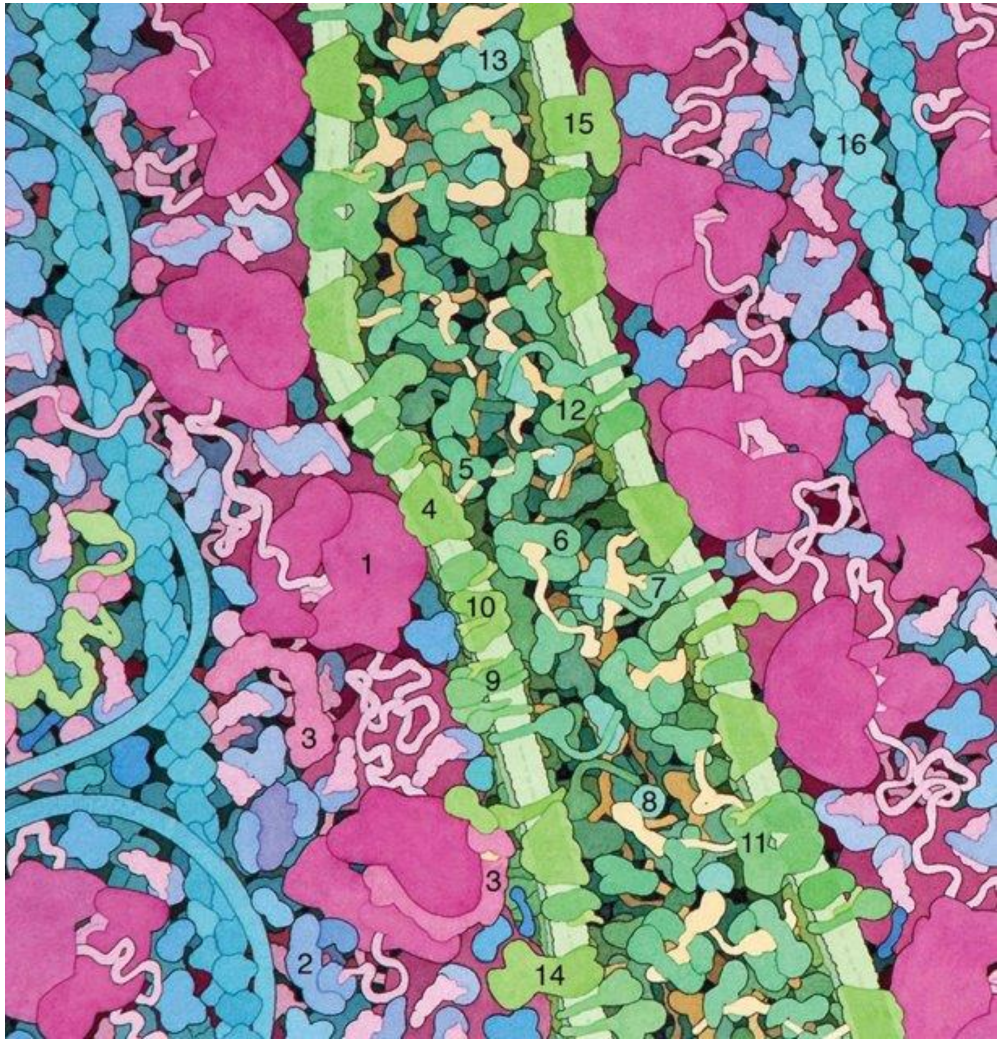
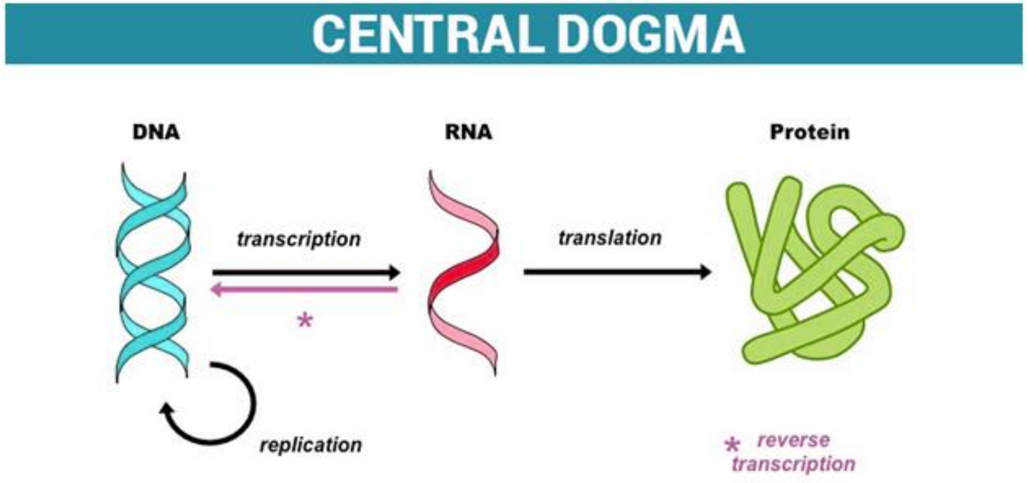
Revisit the panorama

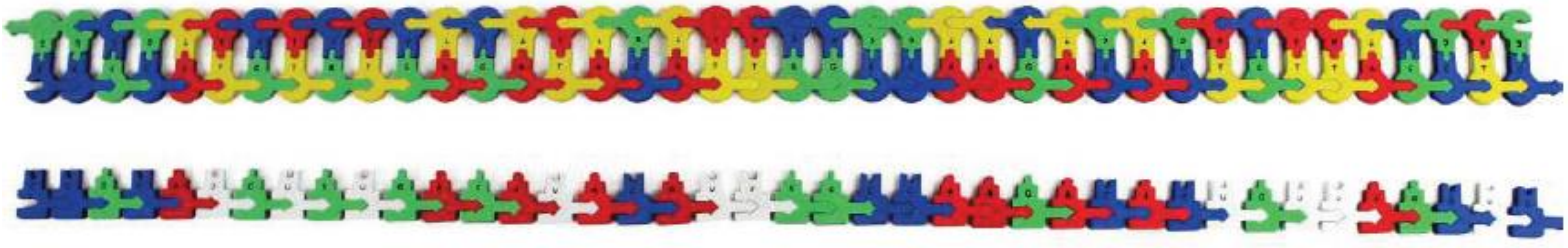


Let’s review

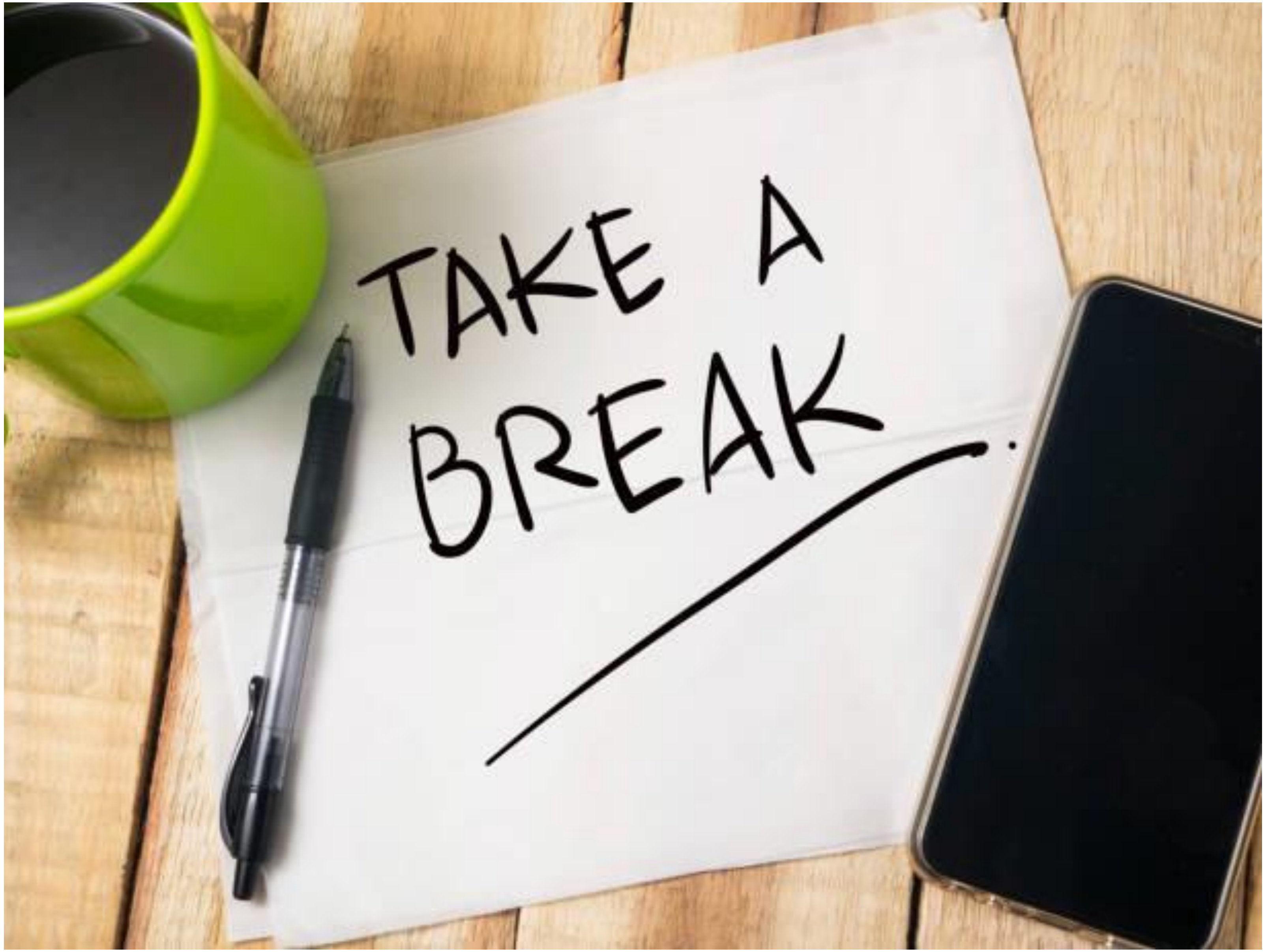
DNA Base	RNA Base
T	*A*
G	*C*
C	*G*
A	*U*
C	*G*
A	*U*



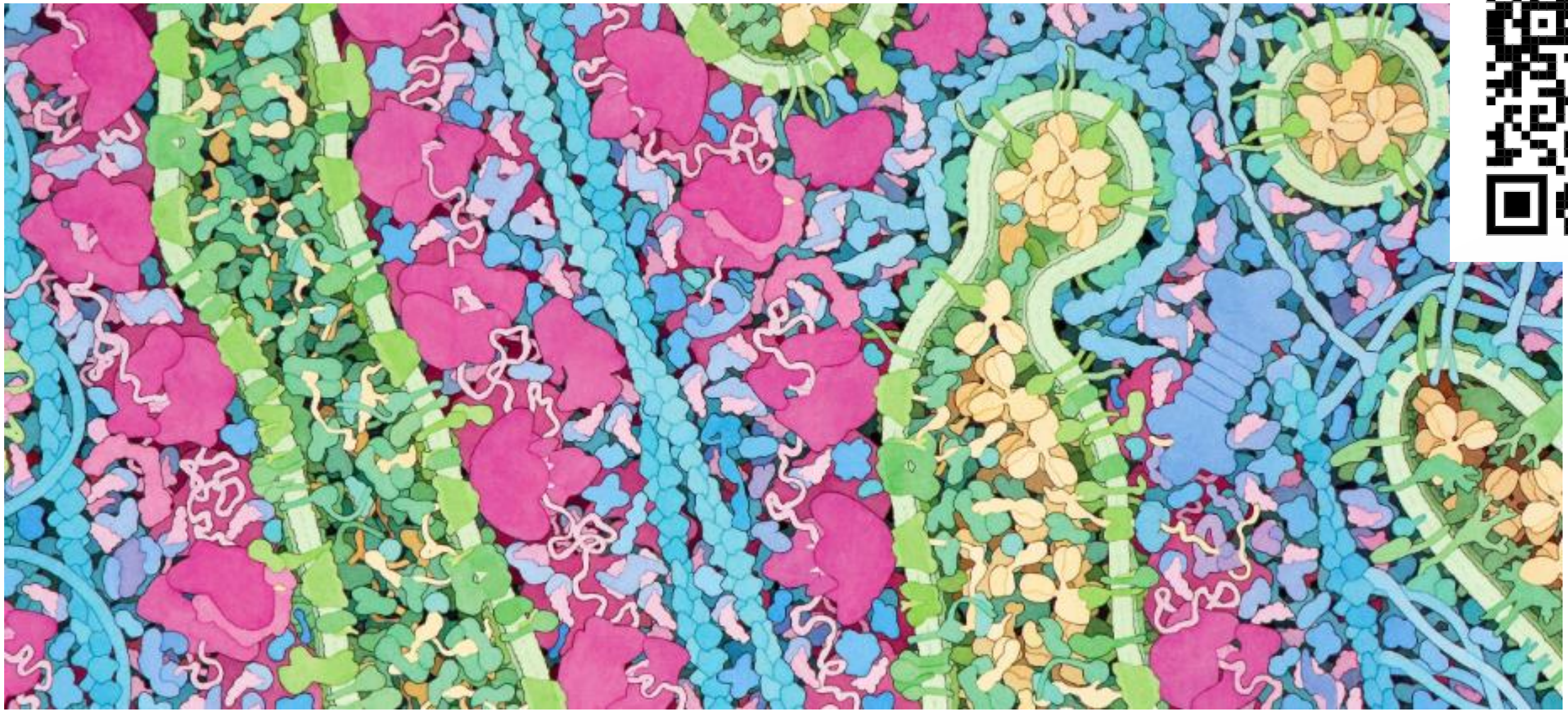
DNA and RNA

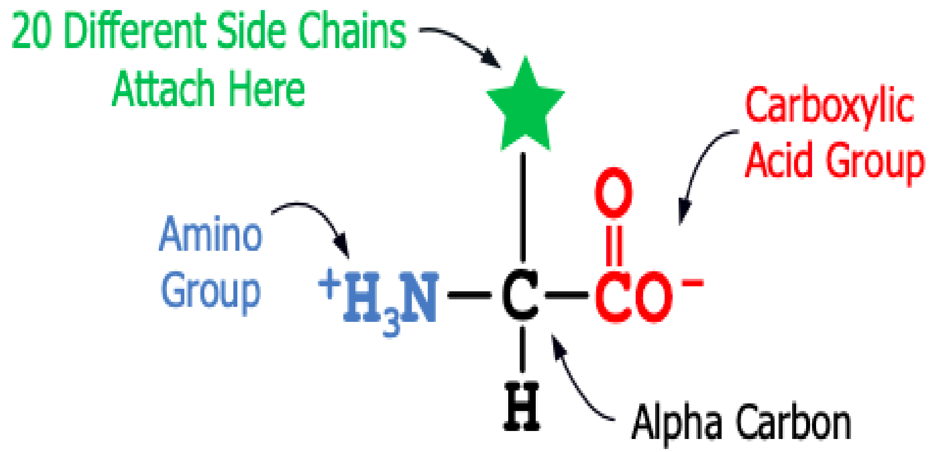


See you back in five minutes.



Revisit the panorama




20 Different Side Chains
Attach Here
Carboxylic
Acid Group
Amino
Group
$^{+}H_3N-C-CO^{-}$
H
O
Alpha Carbon

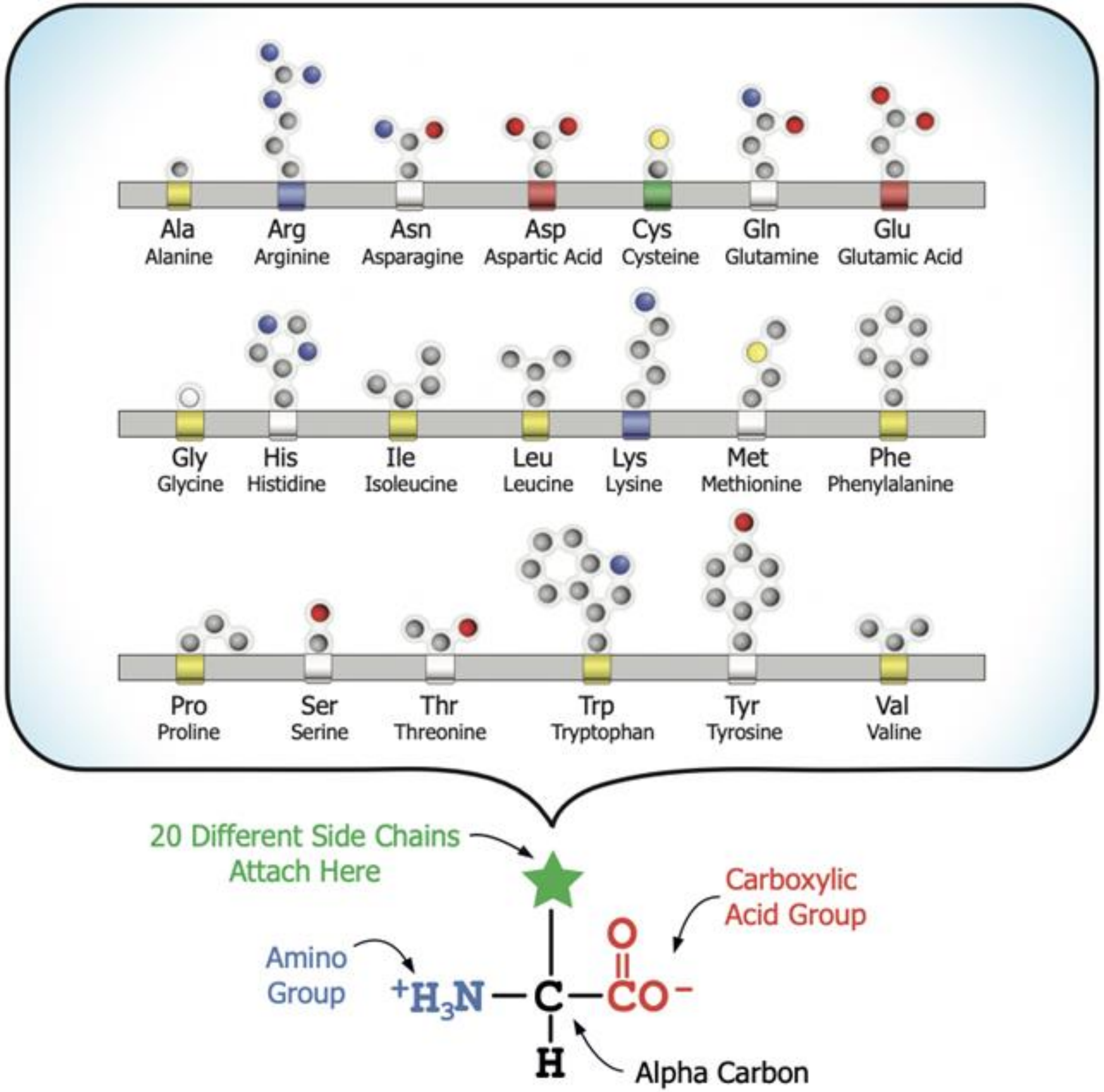
Protein Folding Activity

I notice	I wonder

I notice	I wonder

WHAT PATTERNS DO YOU SEE AMONG THE SIDE CHAINS?

WHAT QUESTIONS DO YOU HAVE?



Ala
Alanine
Arg
Arginine
Asn
Asparagine
Asp
Aspartic Acid
Cys
Cysteine
Gln
Glutamine
Glu
Glutamic Acid
Gly
Glycine
His
Histidine
Ile
Isoleucine
Leu
Leucine
Lys
Lysine
Met
Methionine
Phe
Phenylalanine
Pro
Proline
Ser
Serine
Thr
Threonine
Trp
Tryptophan
Tyr
Tyrosine
Val
Valine
20 Different Side Chains
Attach Here
Carboxylic
Acid Group
Amino
Group
$^{+}H_3N-C-CO^{-}$
O
H
Alpha Carbon

What causes proteins to fold into their 3-D shapes?

Make a prediction.

KEY

Hydrophobic Side Chains are Yellow

Hydrophilic Side Chains are White

Acidic Side Chains are Red

Basic Side Chains are Blue

Cysteine Side Chains are Green

KEY

Hydrophobic Side Chains are Yellow

Hydrophilic Side Chains are White

Acidic Side Chains are Red

Basic Side Chains are Blue

Cysteine Side Chains are Green

SIX HYDROPHOBIC

THREE HYDROPHILIC

TWO ACIDIC

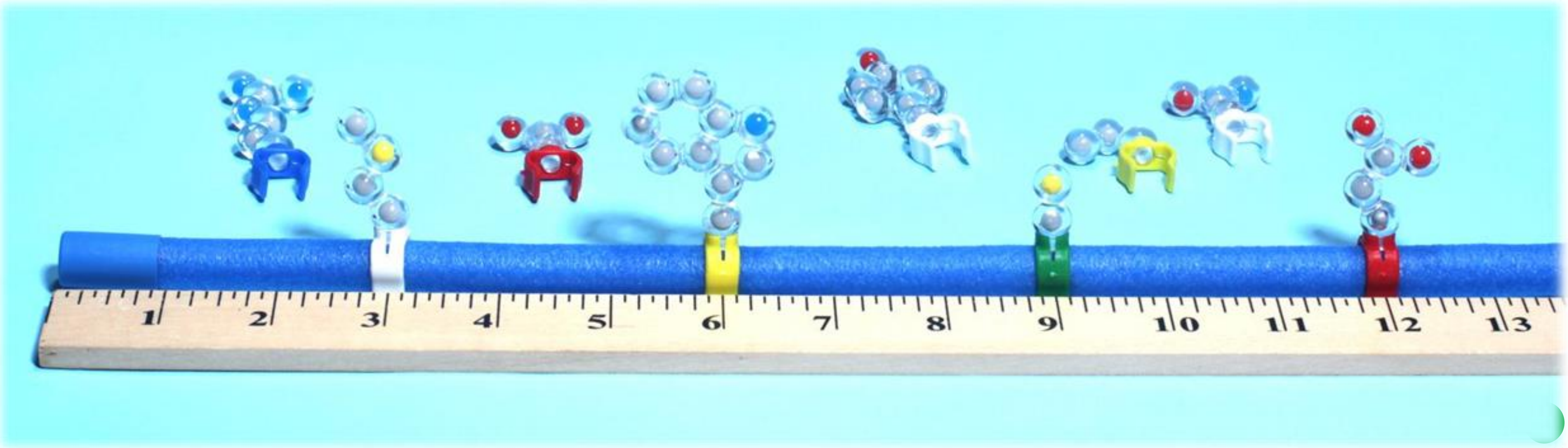
TWO BASIC

TWO CYSTEINE

A TOTAL OF FIFTEEN SIDE CHAINS

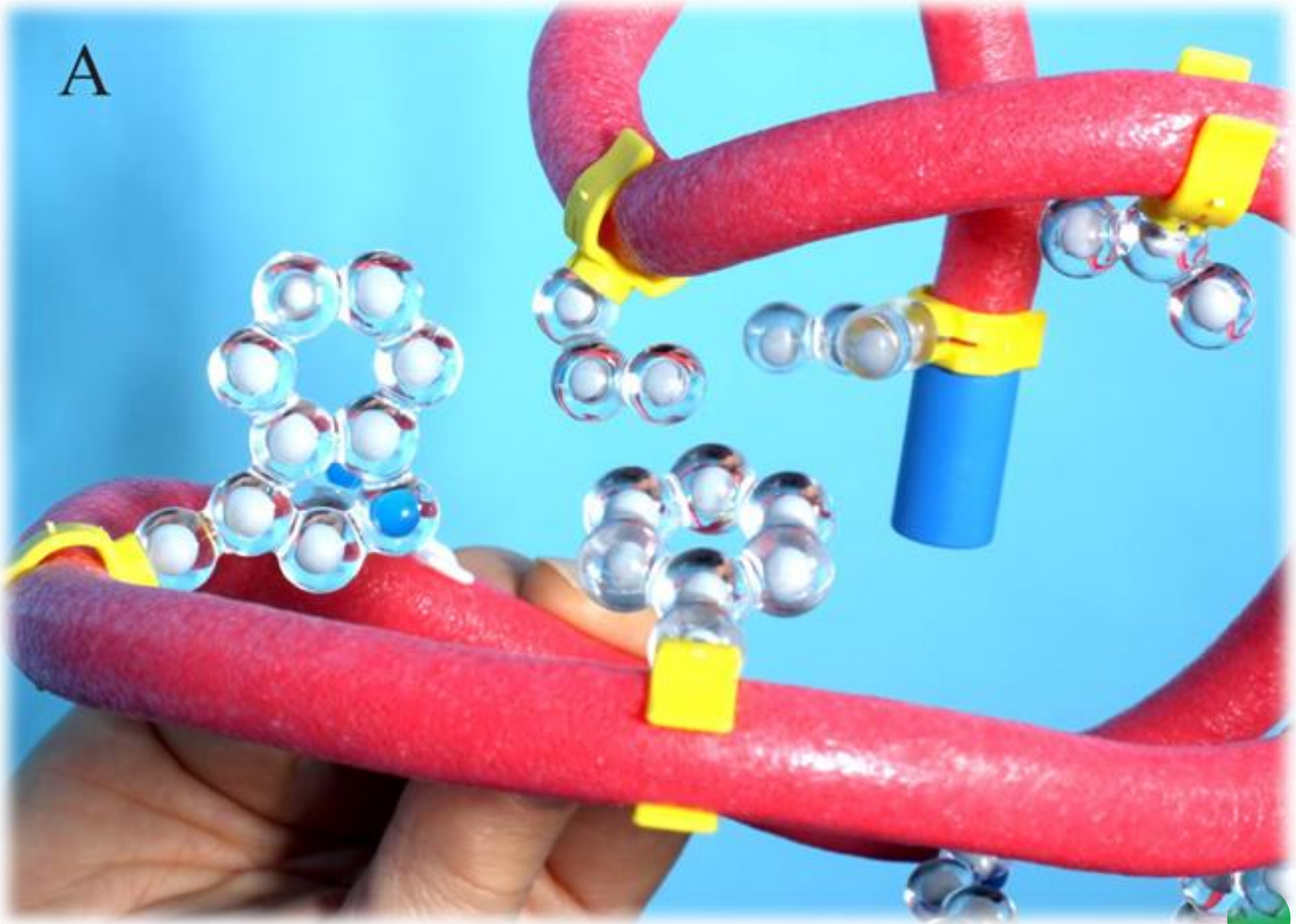
In any order arrange your amino acids equidistant from each other.

You have made a polypeptide.



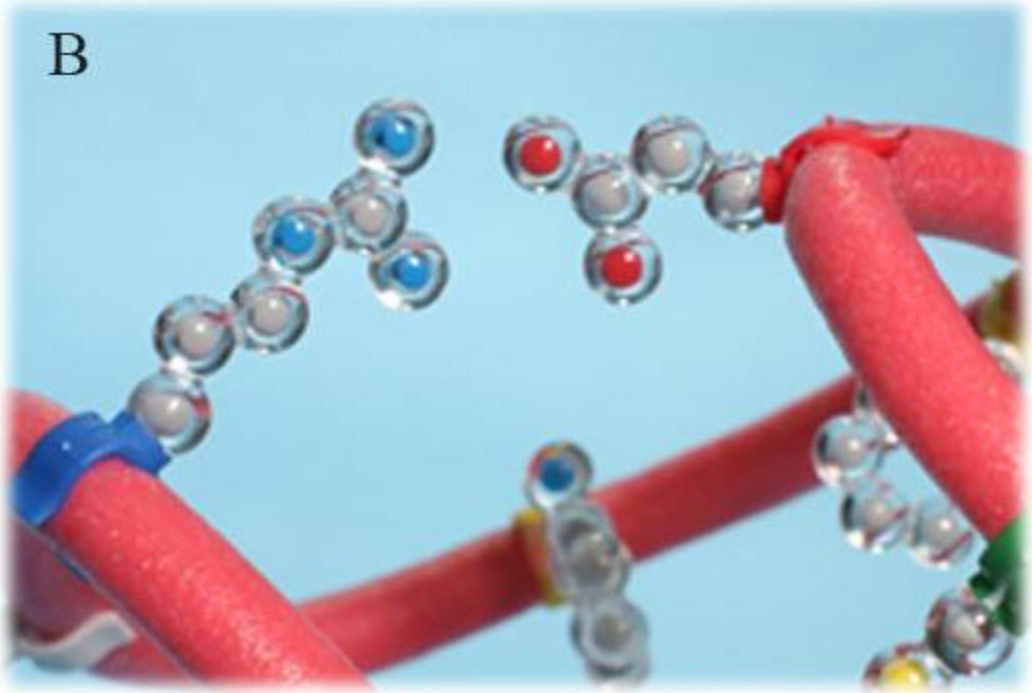
Let's "FOLD" it into a Protein

Rotate the hydrophobic amino acids to the inside.



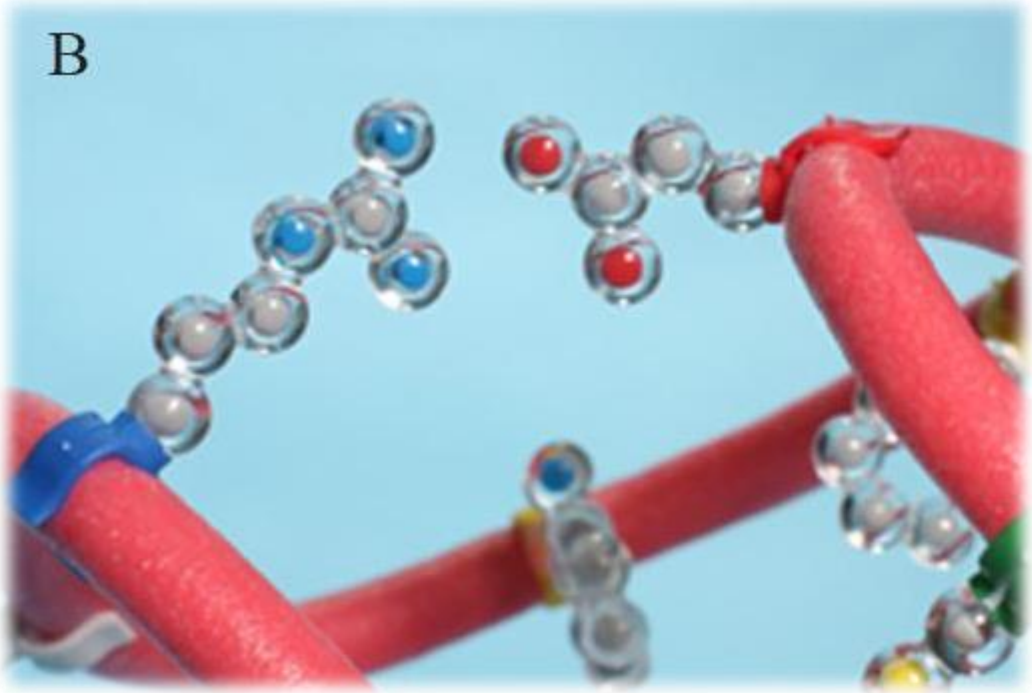
Continue “FOLDING”

Bring the acidic and basic side chains together until they are two cm from each other.



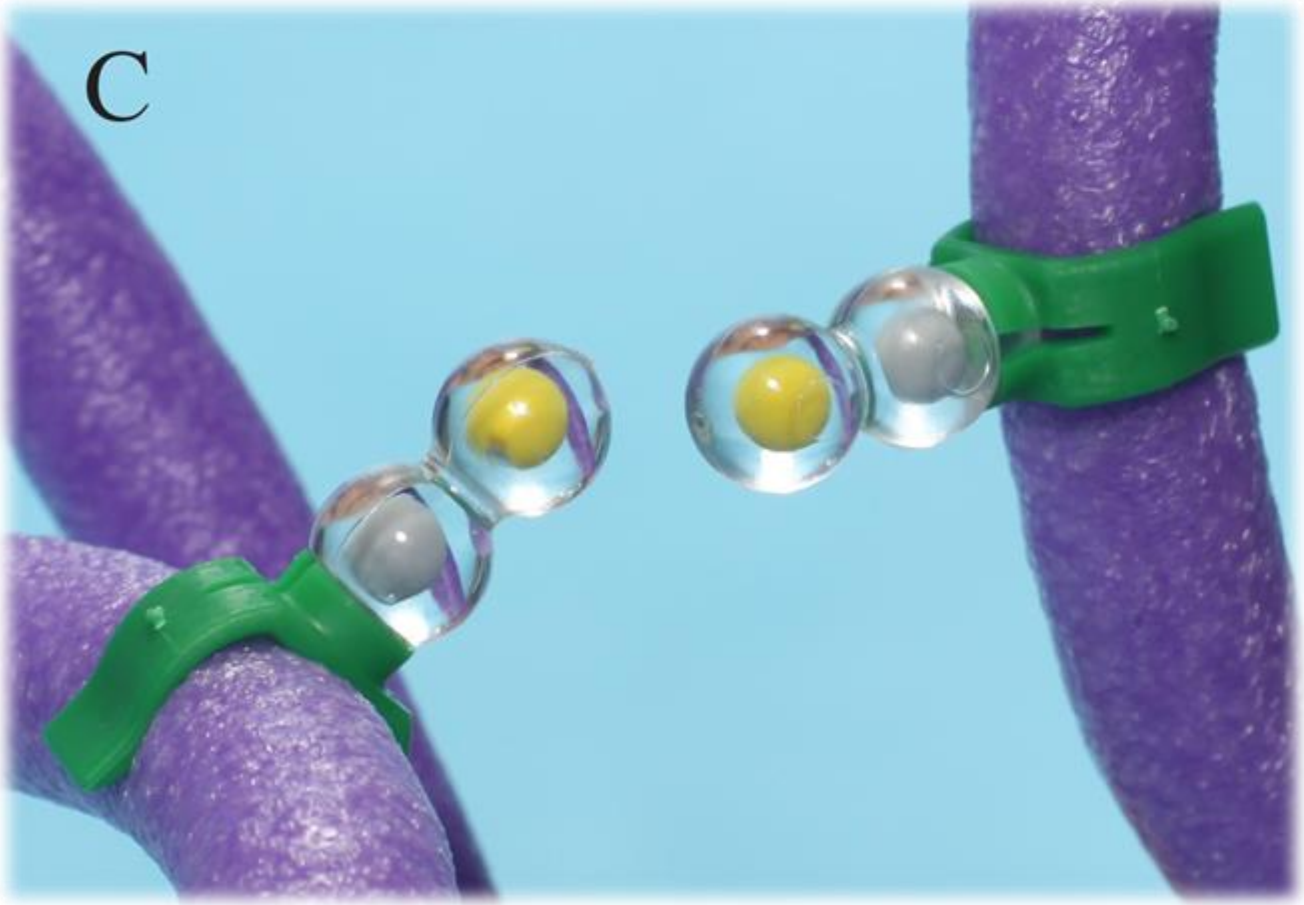
Make sure that you also rotate any hydrophobic side chains that move out of place.

Throughout this whole activity find a shape in which all the properties apply.



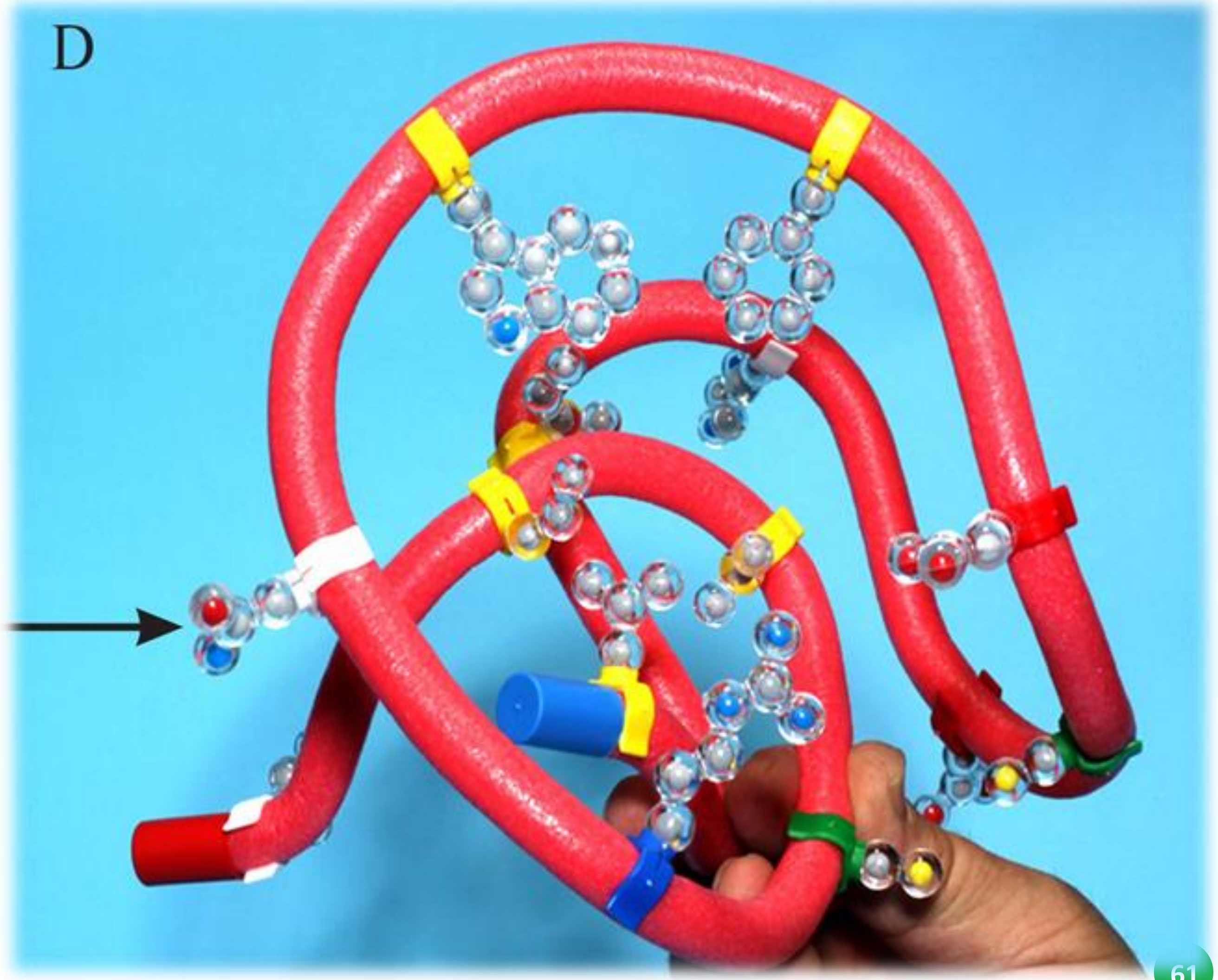
Continue “FOLDING”

Position the cysteines so they are opposite each other.



Continue “FOLDING”

Finally, rotate the hydrophilic side chains so they are on the outer surface.

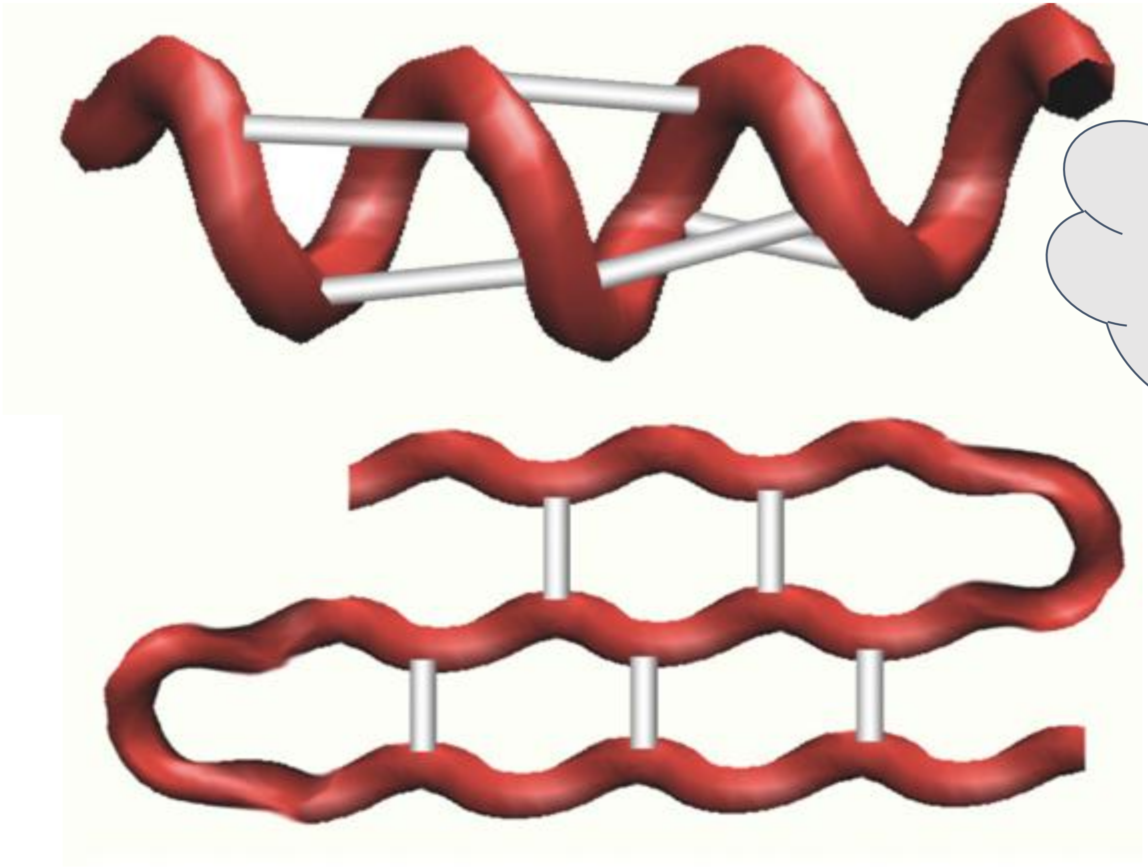


Why didn’t your proteins all look the same?

The Importance of Secondary Structure

Alpha Helix

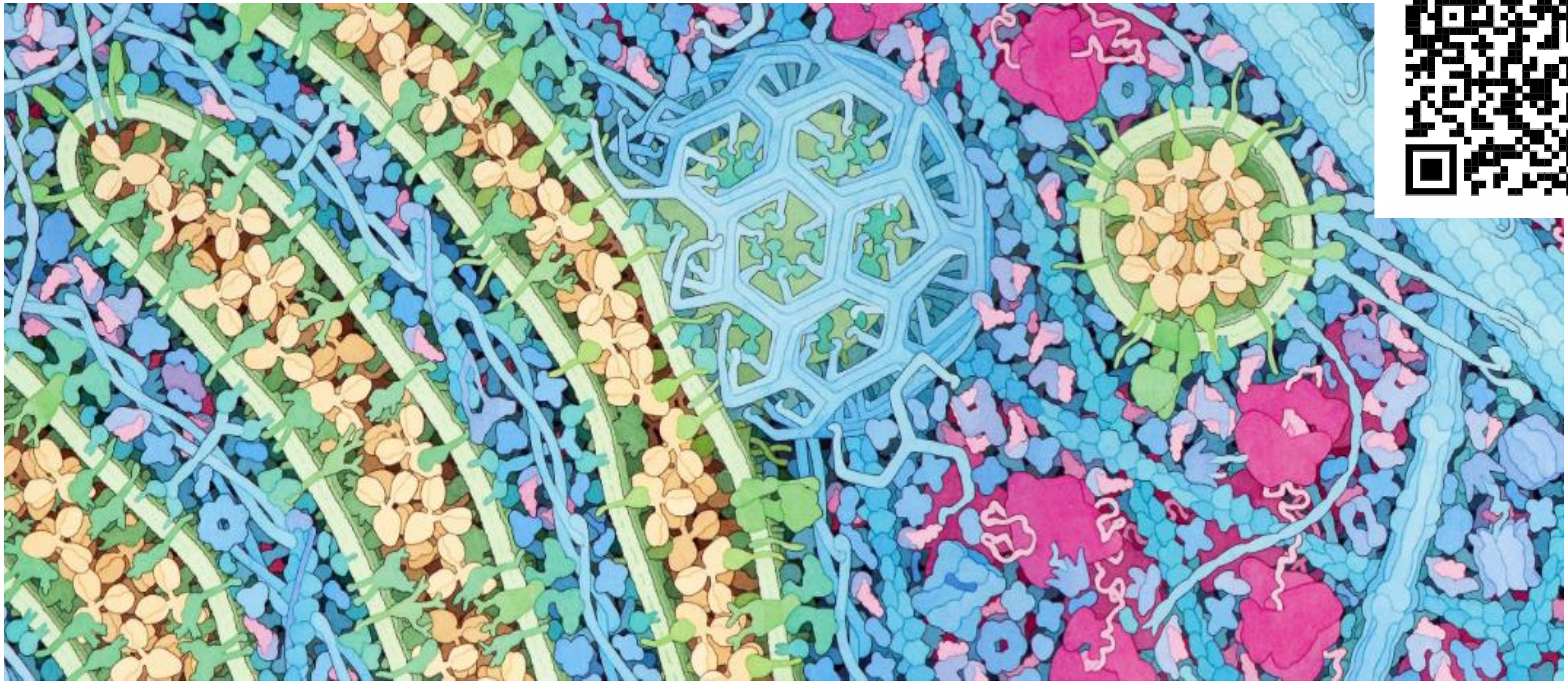
Beta Sheet



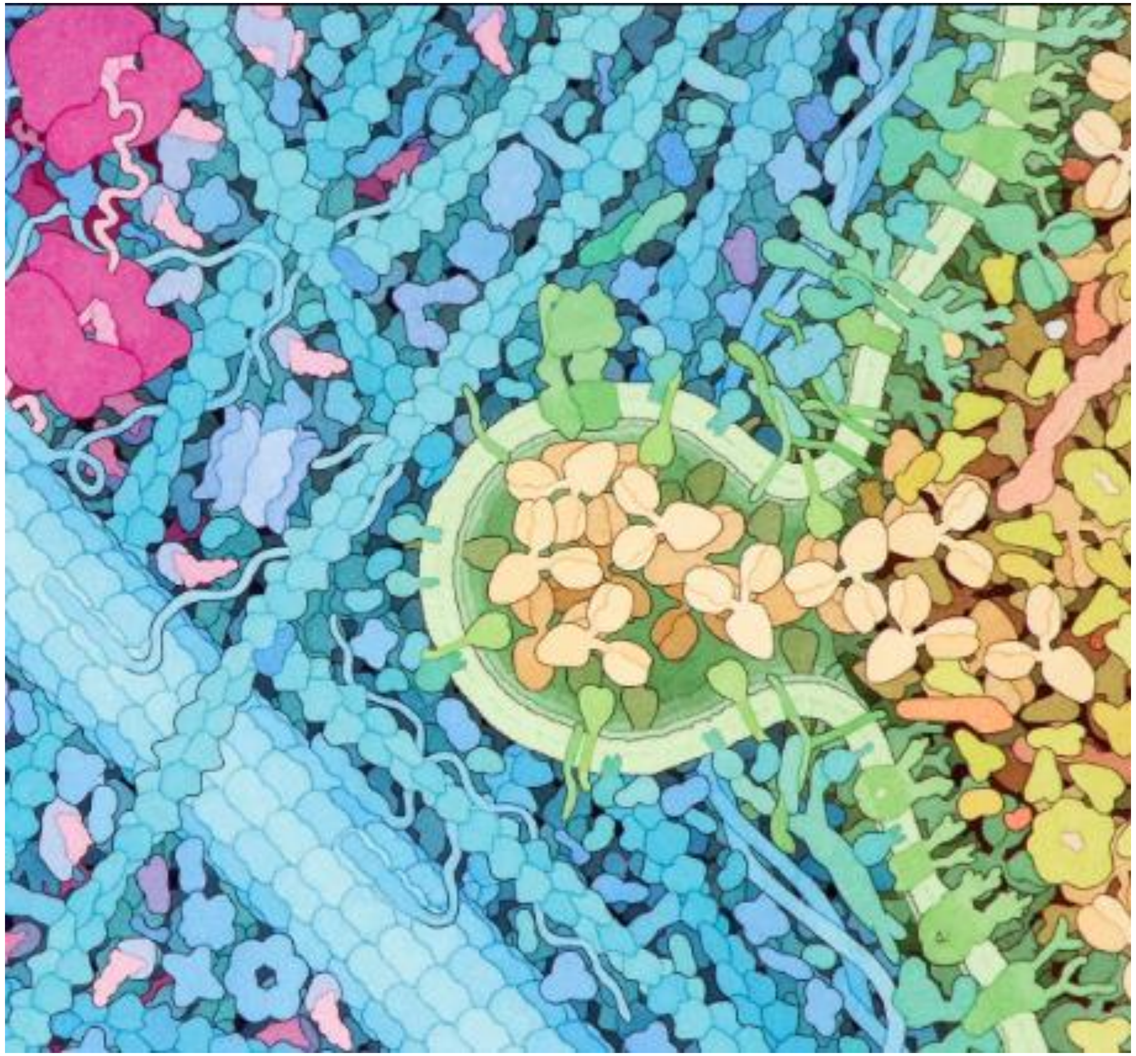
HOW DO SECONDARY STRUCTURES STABILIZE A PROTEIN?

WHAT ABOUT QUATERNARY STRUCTURE?

Revisit the panorama



Revisit the panorama



Helpful resources

- Tracking the Resolution of Student Misconceptions about the Central Dogma of Molecular Biology - PubMed (nih.gov)
- DNA → RNA: What Do Students Think the Arrow Means? - PMC (nih.gov)
- What's in a cell? — young people's understanding of the genetic relationship between cells, within an individual: Journal of Biological Education: Vol 34, No 3 (tandfonline.com)
- Teaching More by Lecturing Less | CBE—Life Sciences Education (lifescied.org)

Additional Resources

- Quentin Vicens and Jeffrey S. Kieft. 2022. PNAS. Thoughts on how to think (and talk) about RNA structure.

- Anna Marie Pyle (Yale U./HHMI) Part 1: RNA Structure – YouTube.

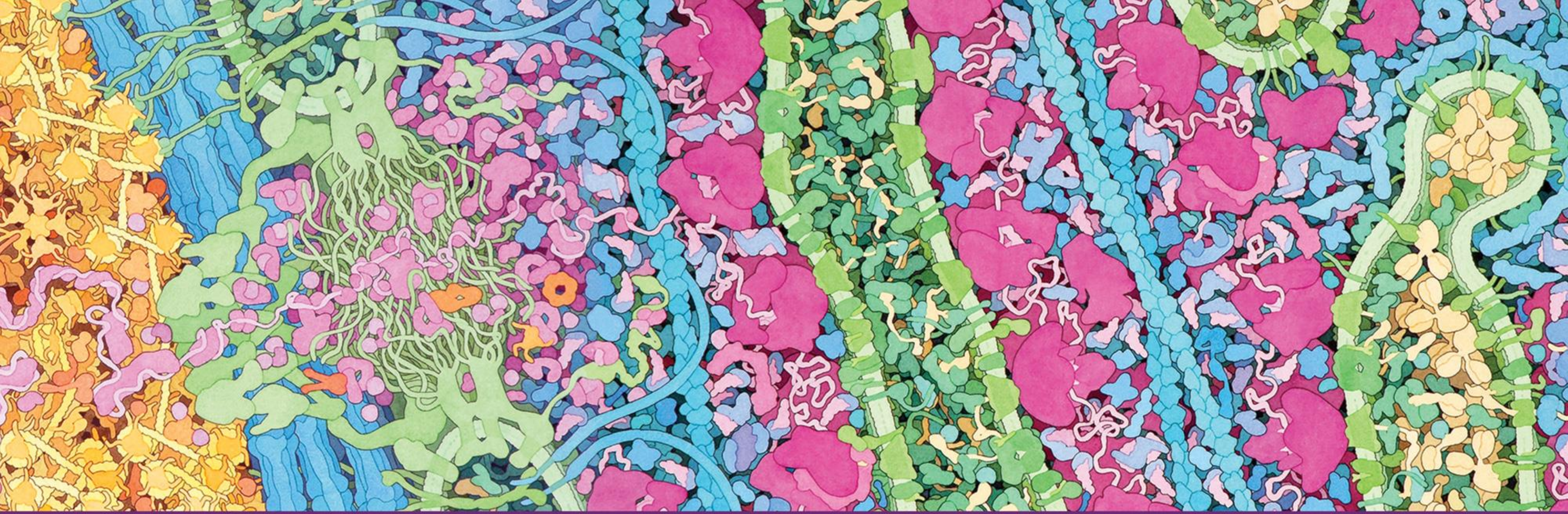
- Eukaryotic cell panorama - Goodsell - 2011 - Biochemistry and Molecular Biology Education - Wiley Online Library

Workshop NGSS Connections

SEPs	CCCs	DCIs
Using Mathematics and Computational Thinking	**Scale, Proportion, and Quantity**	**5-PS1-2**
Developing and Using Models	**Patterns**	**MS-PS1-1**
Planning and Carrying Out Investigations		**HS-PS1-3**

We value your opinion! Let us know what you think.

Scan the QR Code and complete this short survey.



3d molecular designs

Transforming Science Learning