TIPS, TRICKS & TECHNIQUES

Modeling RNA Translation with Craft Supplies

NABT BioClub RECOMMENDATION

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Abstract

Students often struggle with the concept of protein synthesis, which incorporates two main processes: transcription and translation. This article describes an activity in which students use craft supplies to physically model the process of translation. The teacher creates the modeling kits, and then students use a worksheet to prepare the kit for a specific amino acid sequence. They practice the process of translation, including the start, tRNAs movement through the ribosome, the amino acid chain building, and the stop. This article describes how to create the model kits and implement the activity in the classroom. We have performed this hands-on activity in college classrooms as large as 170 students. Students appreciate the hands-on approach and find the activity extremely useful in understanding translation. While students model translation, the teaching team identifies and helps students overcome any misconceptions and gaps in their knowledge.

Key Words: *model; pipe cleaners; protein synthesis; tRNA; translation.*

○ Introduction

How genes are used to code for proteins is a complex topic that often causes confusion among students (Smith & Knight, 2012; reviewed in Tibell & Rundgren, 2010). Yet understanding how "genes encode the information for making specific proteins" (National Research Council, 2012, p. 157) is a core idea in biology (LS3: Heredity: Inheritance and Variation of Traits). Protein synthesis consists of two main processes: transcription of DNA to form an mRNA sequence and translation of that mRNA to make protein. Most published activities that engage students in practicing translation have them act out the different parts via role playing (e.g., Ong, 2010; Dunlap & Patrick, 2012; Firooznia, 2015; Voltzow, 2016), which can be difficult to do in large lecture halls with fixed chairs. Given that developing and using models is a scientific practice (National Research Council, 2012) and that manipulating physical models helps students understand complex molecular mechanisms (Tibell & Rundgren, 2010), I created a translation model activity that uses pipe cleaners, paper, and paper clips.

> *"The model shows how mRNA and tRNAs are used in a ribosome to build an amino acid chain."*

○ Context

I use this activity in both introductory biology major courses and nonmajor courses. Enrollment varies between 40 and 170 students. The teaching team consists of the instructor and two undergraduate learning assistants who previously took the course. The courses are "flipped," in that students learn basic content before each class and then apply concepts during class in teams of two to four students. During class time, the teaching team walks around the room, addressing student questions and asking the students questions to further aid in their critical thinking and to check for understanding. This activity occurs about halfway through the semester, so students are familiar with spending most of a class period working in a team and using worksheets.

During a few class periods leading up to this activity, students practice writing out the sequences for DNA, mRNA, and amino acids using an amino acid chart (e.g., Figure 1) and drawing models of transcription. In preparation of this class period, students take a quiz with basic-knowledge questions regarding the following resources:

- Your Genome, "From DNA to protein" (video), https://www.yourgenome.org/video/from-dna-to-protein
- Concord Consortium, "DNA to proteins" (interactive model), http://lab.concord.org/embeddable.html#interactives/sam/DNA-to-proteins/4-mutations.json
- OpenStax, "9.4 Translation" (excerpt from Fowler et al.'s textbook *Concepts of Biology*), https://cnx.org/contents/s8Hh0oOc@14.1:FUH9XUkW@10/9–4-Translation

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FIRST NUCLEOTIDE	SECOND NUCLEOTIDE: U		C		A		G		THIRD NUCLEOTIDE
U	UUU	Phenylalanine (Phe)	UCU	Serine (Ser)	UAU	Tyrosine (Tyr)	UGU	Cysteine (Cys)	U
	UUC		UCC		UAC		UGC		C
	UUA	Leucine (Leu)	UCA		UAA	[stop]	UGA	[stop]	A
	UUG		UCG		UAG		UGG	Tryptophan (Trp)	G
C	CUU	Leucine (Leu)	CCU	Proline (Pro)	CAU	Histidine (His)	CGU	Arginine (Arg)	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Glutamine (Gln)	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Isoleucine (Ile)	ACU	Threonine (Thr)	AAU	Asparagine (Asn)	AGU	Serine (Ser)	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lysine (Lys)	AGA	Arginine (Arg)	A
	AUG	Methionine (Met)	ACG		AAG		AGG		G
G	GUU	Valine (Val)	GCU	Alanine (Ala)	GAU	Aspartic Acid (Asp)	GGU	Glycine (Gly)	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glutamic Acid (Glu)	GGA		A
	GUG		GCG		GAG		GGG		G

Figure 1. Amino acid sequence chart.

Table 1. Molecules modeled and the material in each model kit.

Molecules	Material	Amount
mRNA	11″ × 0.25″ strip of paper	1
tRNA	Full-length pipe cleaner	4
Anti-codon	2″ pieces of pipe cleaner	8 of each color; 4 colors[a]
Amino acid	1″ × 1″ piece of paper	4
Amino acid bond	Paper clip	4
Ribosome	8″ × 8″ piece of paper; optional: cut into shape of ribosome	1
Stop protein	1″ × 4″ piece of paper (optional: print "stop")	1
Kit bag	*Food storage bag*	*1*

[a]Each color represents a different nucleotide; the number of each actually used varies with the mRNA sequence.

- Howard Hughes Medical Institute, BioInteractive, "DNA translation (basic detail)" (animation), https://www.hhmi.org/biointeractive/translation-basic-detail
- Learn.Genetics, Genetic Science Learning Center, "RNA's role in the central dogma," https://learn.genetics.utah.edu/content/basics/centraldogma

○ Translation Model Kit

The model shows how mRNA and tRNAs are used in a ribosome to build an amino acid chain. Students work in teams of two to four, with one model kit per team (Table 1 and Figure 2; see also Supplemental Material Appendix S1, available with the online version of this article). Each tRNA is created by folding each pipe cleaner into a tRNA shape (Figure 3). This is the most time-consuming part of creating the models. Begin by bending the pipe cleaner at 1.5 inches (Figure 4A) – students will use this 1.5-inch space for connecting the pipe cleaner pieces for the tRNA anticodons. Add a bend about one inch from the original end but going the opposite direction (Figure 4B). Create three loops with the remaining pipe cleaner, leaving about an inch of pipe cleaner to wrap around below the loops. Use your finger to create each loop (Figure 4C). Wrap the remaining pipe cleaner below the loops (Figure 4D). For a video showing how to create the tRNAs, see https://youtu.be/Ks0H7_3nYBI.

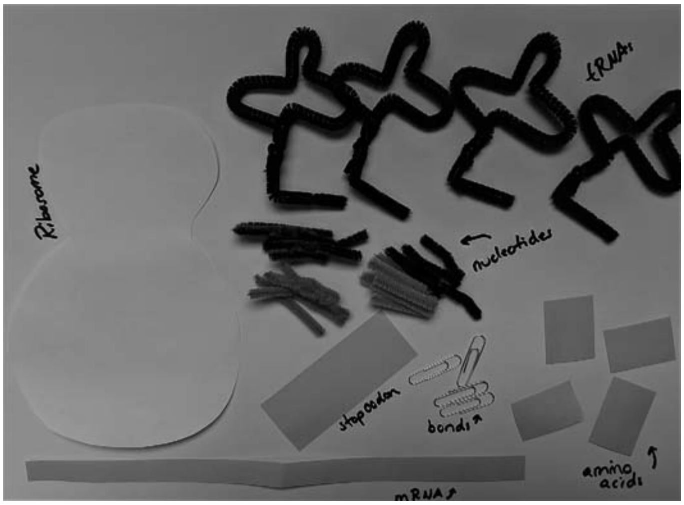

Figure 2. Components for each translation model kit.

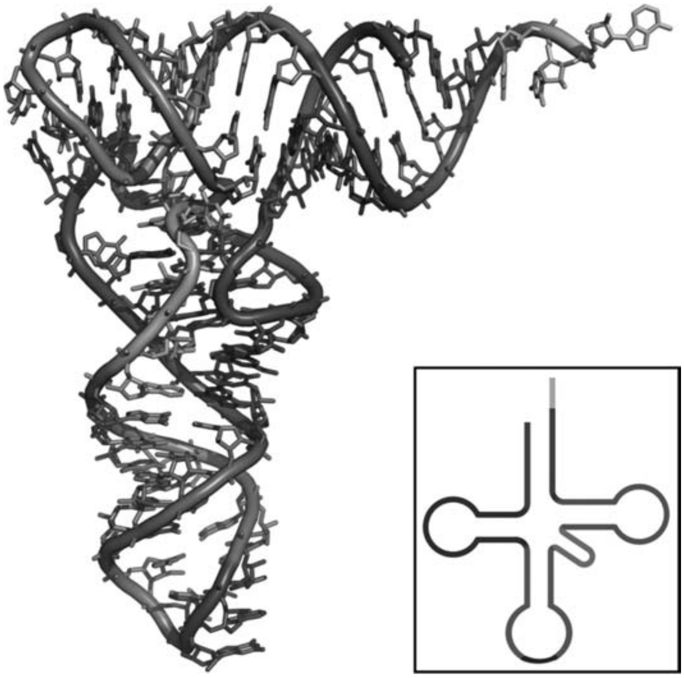

Figure 3. A three-dimensional and a two-dimensional (inset) model of a tRNA. Source: "Tertiary structure of tRNA" by Yikrazuul, 2010, https://commons.wikimedia.org. Licensed under CC BY-SA 3.0.

○ Translation Model Lesson Plan

Pre-model Worksheet

Before starting the physical model, students make up an amino acid sequence consisting of four amino acids and determine the tRNA anticodon and the mRNA sequence, including a stop codon (for the worksheet, see Supplemental Material Appendix S2). When I first taught this activity, the worksheet also included writing the DNA sequence, but this introduced the misconception that DNA molecules are used in translation.

The teaching team checks the sequences as students are working. One common mistake is labeling one of the tRNAs as a stop codon. If students do that, ask them the purpose of the stop codon. Have students look for "stop" in an amino acid chart, where they should discover that the stop codon does not code for an amino acid. Part of the confusion may be that the start codon, unlike the stop codon, serves multiple purposes: it signals the start of translation, and it codes for an amino acid.

Model Materials Prep

Once students have completed their sequences, the instructor identifies the parts of the model kit by using either a document camera or a photograph of the materials (Supplemental Material Appendix S1). One important feature to point out is that both the tRNA bodies and the tRNA anticodons are made of the same material: pipe cleaners. This is purposely done to confirm that the entire tRNA body is made of RNA nucleotides – not just the anticodon. Pass out the tRNA model kits after this instruction.

Students complete the following tasks to prepare the model:

1. Label the stop protein with "stop." (This can also be done by the instructor while creating the model kits.)
2. Record the amino acid names on each amino acid sheet.
3. Connect each amino acid to a tRNA with a paper clip.
4. Using two-inch pieces of pipe cleaner, create the anticodon on each tRNA:
   a Determine which color will represent which base.
   b Wrap the corresponding pipe cleaner pieces to the end of the tRNA, as shown in Figure 5. Note that there will be leftover pipe cleaner pieces.
5. Write the mRNA code on a long, thin strip of paper. Make sure to space out the letters enough so that the tRNA anticodons will line up with the mRNA sequence.

Translation Model

Once students have finished prepping the materials for their models, they model translation. During this time, the teaching team is walking around and observing students practice translation. One of the most common issues is that students do not know how the amino acid chain builds. They will sometimes connect it to the ribosome or they will not connect the amino acids at all and instead just lay them out. If students are required to use the paper clips, then the teaching team can identify if students understand that the chain builds on a tRNA as tRNAs move in and out of the ribosome.

Translation Presentation

Because it is difficult to check every team in large-enrollment courses, it is essential to have a presentation of a functioning translation model – by either the teaching team or a student team. This presentation can be done using a document camera during class. Or, as a homework assignment, students could be required to view a video of the functioning model (e.g., https://youtu.be/vzfEMHozxS4) and write a reflective essay. The essay assignment can have them compare the way translation is modeled in the video to how they originally modeled it and describe any issues they had while learning about the process of translation. The teaching team can also provide students with critical-thinking questions to consider once they have

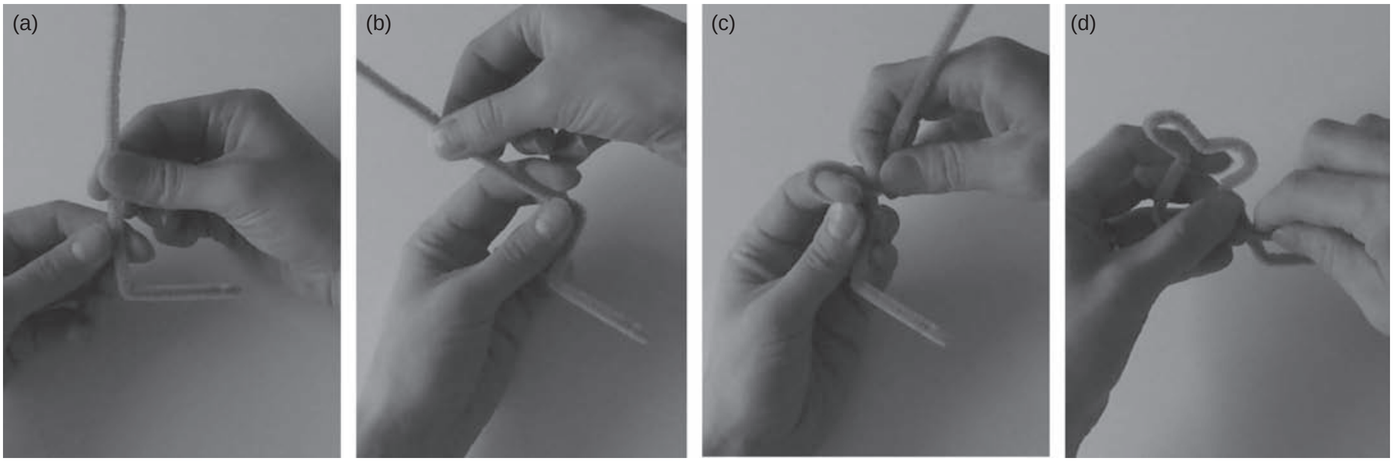

Figure 4. The process for creating a pipe cleaner tRNA.

Figure 5. A tRNA with associated anticodon and amino acid.

mastered the process. For instance, what happens if a substitution point mutation occurs, changing one of the bases in a codon? If students repeatedly test what happens after this type of mutation, they will discover that multiple codons can encode the same amino acid.

○ Conclusion

Before we began using this activity in the class, students would only draw a couple of key translation stages, and they typically just copied a few images from the textbook while changing the sequences to match the activity. After implementing the model activity in class, I discovered that the previous activity had missed several student misconceptions and that the current one leads to more students asking questions, such as how the amino acid chain builds or what the stop codon does. Although these models do require some initial time and monetary investment, the materials are relatively cheap, and the pipe cleaners and "ribosomes" can be reused each semester.

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