How-To-Do-It

Protein Synthesis—An Interactive Game

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The intimate relationship between DNA, RNA and proteins is seen in all life forms. Working together, these molecules determine structure and function at the organismal level and are the raw material of evolutionary change. Understanding this relationship is therefore vital to understanding biology. Students, however, cannot see these molecules, how they interact and how they affect one another. The problem is further aggravated by the typical textbook and lecture format presentation. Even colorful diagrams or animated video sequences fail to provide an understanding of the process. Protein synthesis therefore becomes very abstract, static and 'boring'. Getting students actively involved in biology deepens their understanding, their appreciation and their retention of complex biological events. We have devised an interactive game to help students see and understand the dynamic relationship between DNA, RNA and proteins. This game has been tested for three years (eight semesters) with tremendous results.

Materials

- 3 × 5 index cards—several hundred

  DNA cards—(Figure 1A) Mark cards with 3′ and 5′ designations and use all 61 DNA triplets (stop triplets are excluded). Make enough DNA cards for each group of students to have 15–20 triplet cards. For a class of 24 students (6 groups), you will need a minimum of 120 cards (or two of each triplet).

  mRNA cards—(Figure 1B) Each group will have its own full set of mRNA cards. This set will be complementary to the complete DNA card set.

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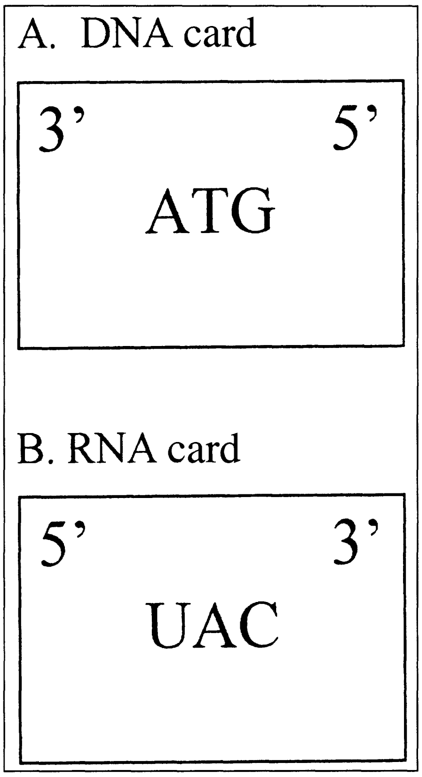

Figure 1. (A) Example of a DNA triplet card, 3 × 5 index card. (B) Example of an RNA codon card, 3 × 5 index card. We recommend using different colored ink for the different sets of RNA codon cards given to each group.

- Pony beads (large, colored, plastic craft beads with a large center hole, available at discount and craft stores)—several hundred in 20 different colors (amino acids). It is more realistic to have some rare amino acids in very low supply in the metabolic pool.
- Bead/amino acid conversion chart (Figure 2)—To correlate amino acid names with bead color; can be done with poster board, beads, and a hot glue gun or craft wire.
- Shoestrings—one per group, represents peptide backbone.
- Codon Chart (Table 1)—one per group.
- Active metabolic pool—a bowl or box containing the amino acids immediately available for protein synthesis.
- Reserve metabolic pool—container with additional amino acids for supplementing the active metabolic pool.

The Game

This is a game to be played by two to six teams. Each team is made up of three or four players. (Although more teams and players per team can be accommodated, this size group seems to work best.) The game is played in two parts, transcription and translation, and takes approximately 45–60 minutes. (Each BINGO game takes an additional five minutes.) This makes this activity amenable to either a class or a laboratory setting and time frame. In the transcription portion of the game, all players are RNA polymerases. During translation, one player is designated as the ribosome and is in charge of the process of protein synthesis. The remaining players are tRNAs and are responsible for getting the amino acids to link together into a protein.

Typically, we have found success by first introducing the students to the subject material in a standard lecture format that is then reinforced by the activity, either in lab the same week or in the following class period.

PART 1—Transcription

The first phase of the game starts when the team receives its DNA template (Figure 1A, 3′ to 5′ direction, 15–20 triplet cards). The strand consists of several cards, each bearing the three letter designations of the nucleotides in that coding region. Each team is dealt cards in the 3′ to 5′ direction. All teams are dealt the same number of cards. The team then must transcribe the strand into an RNA sequence. This is done by matching the appropriate

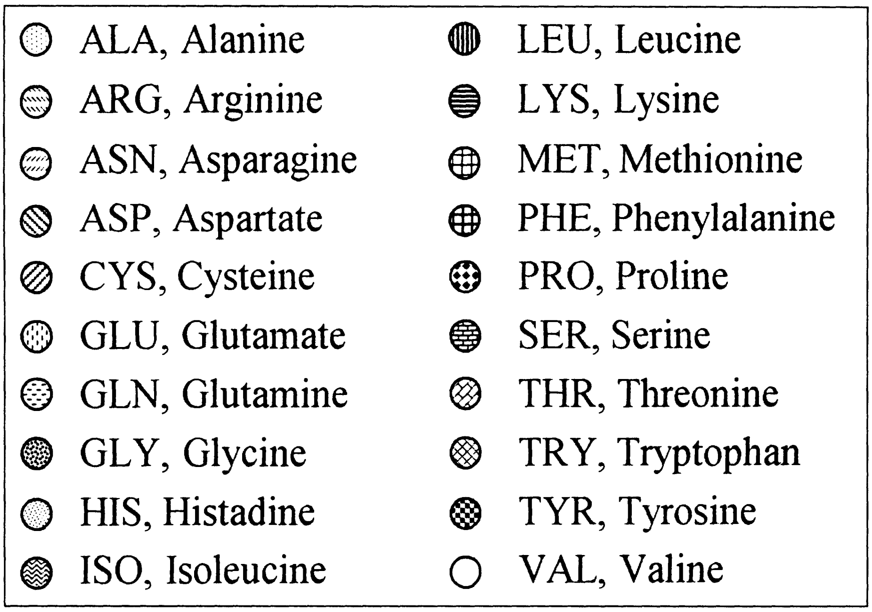

Figure 2. An example of the bead/amino acid conversion chart. Glue or tie down pony beads onto a piece of poster board and label with the appropriate amino acids.

RNA codon cards (Figure 1B) with the DNA cards. When the first team has completed transcription, they yell "STOP," and their sequence is checked. If there is a mistake in transcription, an RNAse (the instructor) destroys from the 5′ end to the error, and all teams resume transcription. Transcription must be completed by all teams before the next phase of the game can start. Points are awarded to groups in the order they finish.

PART II—Translation

Translation, or the synthesis of a protein from the RNA strand, requires the ribosome player to decipher the RNA code using the Codon Chart provided (Table 1). The ribosome player then instructs the tRNA player to pick up the appropriate amino acid (colored bead, Figure 2) from the metabolic pool (accessible to all of the teams). The tRNA returns to the ribosome with the appropriate amino acid. The ribosome then adds it to the peptide backbone by stringing the bead onto the shoestring. Another tRNA molecule is sent to gather the second amino acid. Only one tRNA molecule from each ribosome may be at the metabolic pool at a time, and each tRNA molecule may only take one amino acid at a time. The first team to finish yells "STOP," and their sequence is checked. If there is a mistake, a protease (the instructor) destroys their protein to the point of the error, and they must resume synthesis from the point of their mistake. The remaining teams are allowed to continue synthesis. Points are awarded to teams in the order they finish.

Since not all amino acids are always available for protein synthesis, there are two parts to the metabolic pool, reserve and active. Amino acids are constantly cycled between these two pools by the instructor within an appropriate metabolic context (i.e., fasting, just ate a juicy hamburger, going on a diet). The tRNAs may only obtain amino acids from the active metabolic pool; tRNAs whose amino acids are not available within the active metabolic pool must wait for it to become available from the reserve pool. The rate of transfer of amino acids from the reserve to the active pool is controlled by the instructor or by the variations listed below. For a large class, you may want to have two metabolic pools.

Table 1. Codon Chart

	2nd base				
1st	*U*	*C*	*A*	*G*	*3rd*
	PHE	SER	TYR	CYS	U
	PHE	SER	TYR	CYS	C
	LEU	SER	STOP	STOP	A
U	LEU	SER	STOP	TRY	G
	LEU	PRO	HIS	ARG	U
	LEU	PRO	HIS	ARG	C
	LEU	PRO	GLN	ARG	A
C	LEU	PRO	GLN	ARG	G
	ISO	THR	ASN	SER	U
	ISO	THR	ASN	SER	C
	ISO	THR	LYS	ARG	A
A	MET	THR	LYS	ARG	G
	VAL	ALA	ASP	GLY	U
	VAL	ALA	ASP	GLY	C
	VAL	ALA	GLU	GLY	A
G	VAL	ALA	GLU	GLY	G

Variations

1. New amino acids will be added to the metabolic pool at a rate determined by the roll of a die at the start of the game. The initial metabolic pool is made up of 20 random amino acids. The number rolled on the dice indicates the number of amino acids added to the pool per minute.
2. At set intervals (once every 10 minutes), all teams will pause as a chance card is drawn. Chance cards are divided into two categories, corresponding to the two parts of the game: 1) Transcription Chance and 2) Translation Chance. Transcription Chance cards may introduce mutations (insertions, deletions and changes) into the DNA strands. Translation Chance cards may change the rate of supply of amino acids to the metabolic pool or remove amino acids from the metabolic pool. Additional points may be awarded to teams if they can explain the biological/biochemical cause or reason for the change in conditions.
3. Timed synthesis—each team will race the clock to synthesize the same protein in the smallest amount of time. No restrictions on supply of amino acids are made. Points are awarded only to the

BINGO—SAMPLE CARD*

isoleucine	serine	histidine	alanine
lysine	stop	arginine	glycine
methionine	leucine	proline	valine
asparagine	phenylalanine	leucine	glutamic acid

*The same card can be used for all three versions of the game.

winning team. (We use this to break ties.)

4. BINGO
   - *mRNA BINGO*—Groups or individual students have a random 4 × 4 or 5 × 5 grid of amino acids. The caller reads an mRNA codon. Students must translate to the amino acid, using the Codon Chart. They put a marker on the appropriate amino acid square within the grid. Once an individual student or group has a vertical, horizontal or diagonal row, it yells "BINGO" and its card is checked.
   - *DNA BINGO*—Same as mRNA BINGO, only the caller reads a DNA triplet sequence. Students must determine the complementary mRNA codon and translate to the amino acid.
   - *tRNA BINGO*—Same as above, only the caller reads a tRNA anti-codon sequence. Students must determine the complementary mRNA codon and translate to the amino acid.

For mRNA BINGO *Caller says "UGC." Students look for UGC on the Codon Chart.* **Cysteine** is the match.

For DNA BINGO *Caller says "TAA." Students look for AUU on the Codon Chart.* **Isoleucine** is the match.

For tRNA BINGO *Caller says "CUC." Students look for GAG on the Codon Chart.* **Glutamate** is the match.

Conclusion

We have played this game with students for several years with tremendous response. Students not only enjoy playing the game, they really understand the process: the order in which different processes occur and why they occur in that particular order; the dynamic nature of the metabolic pool; and the detrimental effects of a mutation (especially if they are in the lead). This is evidenced, in our experience, by improved performance on exam questions pertaining to protein synthesis. In particular, a question that asks students to transcribe and translate a DNA sequence, given the Codon Chart, has been correctly completed by approximately 80% of the students over the three years this activity has been incorporated into our curriculum. Additionally, the game has been demonstrated several times to high school teachers with enthusiastic responses.

This game helps students realize that biology can be fun and not always scary or hard and demonstrates to students how dynamic, intricate and elegant biology is. By being an active part of the process, they can't help but learn and better retain the complex issues of protein synthesis.

Acknowledgments

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