Science Activities, 47:22–28, 2010

ISSN: 0036-8121 print / 1940-1302 online
DOI: 10.1080/00368120903274035

Routledge
Taylor & Francis Group

Trail Mix Genetics: Protein Synthesis in Two Acts

Meena M. Balgopal
Colorado State University,
Fort Collins, CO

ABSTRACT Protein synthesis can be a difficult concept to learn because the processes are difficult to visualize. As an alternative to relying only on textbook drawings, the author presents a role-playing activity that can help reinforce the processes of transcription and translation. Students play the roles of cell organelles and subunits and work cooperatively to synthesize the brazzein protein. This lesson is useful for both teacher and student self-assessment of understanding of content standard C of the *National Science Education Standards*: the molecular basis of heredity (National Research Council 1996). A general outline of the activity is described in this article, and student modifications are encouraged to make the role-playing more meaningful. This activity is engaging for students as a review of other inquiry laboratory activities. Because this activity involves eating, teachers should make sure to conduct it in a classroom or commons area where food is allowed.

KEYWORDS brazzein, protein synthesis, role playing

The roles of DNA and RNA in protein synthesis confuse many science students (Krebs 1999; Rode 1995). It has been suggested that microscopic processes are difficult for students to understand because they cannot be visualized (Lawson et al. 2000). Teachers often rely on textbook diagrams and cartoons to help students see microscopic processes. Some science teachers then use question-and-answer games to review these concepts (Hickman 1990). These games tend to focus on recalling terms, but I found that my high school students were struggling with creating a mental image of cellular processes. I wanted to give my students an involved, fun way to review the central dogma of biology while identifying their own areas of confusion.

In this activity, students must get up and move around the classroom and work as a team in order to re-enact protein synthesis through two dramatic acts: transcription and translation. Transcription is the process during which DNA is copied and a complementary mRNA strand is created. Translation is a subsequent occurrence during which the mRNA strand is decoded into chains of amino acids that form proteins. Teachers can help students address misconceptions or confusion about the processes of transcription and translation because the final outcome of the processes relies on everyone's participation. Most students enjoy interacting with one another and being able to (literally) eat the fruits of their labor, so I developed an activity that centers on assembling trail mix through role-playing.

Address correspondence to Meena M. Balgopal, Colorado State University, School of Education, Campus Delivery 1588, Fort Collins, CO 80523. E-mail: Meena.Balgopal@colostate.edu

Role-playing is an engaging and interactive instructional strategy (Cherif and Somerville 1995; Joyce and Weill 2004). Cherif and Somerville (1995), in their review of role-playing in science classrooms, suggest using the following format when using this teaching model:

1. Identify the problem.
2. Identify the characters, the individuals featured in the role-playing exercise.
3. Identify the roles to be played.
4. Determine what information is needed before beginning.
5. Describe what procedures will be adapted as the play is acted.

Although Cherif and Somerville (1995) discuss social, political, and controversial topics, I posit that role-playing abstract intracellular processes can be just as instructional. At first, some of my students seemed hesitant to act out a play in front of their peers in science class, but I found that, after some encouragement, the students enjoyed this nontraditional review of protein synthesis.

As students are made responsible for determining more of the five traits of role-playing a scene, the more challenging the lesson becomes. I suggest having students participate in acting out the scene with a large amount of teacher input the first time. If students are unsure what to do, the teacher can outline the actions each character does. Each subsequent time, students can help construct more details for the protein synthesis play, making the process more challenging. The main learning objective of the lesson is for students to be able to distinguish between transcription and translation. This overarching objective meets content standard C—the molecular basis of heredity—of the *National Science Education Standards* (National Research Council 1996) and also reinforces sequencing skills. As part of this larger objective, students learn to identify the products of transcription and translation. Students describe the role of each of the main players involved in these processes. Students also explain what the genetic code is and how protein sequences are described by scientists. The activity is designed for a middle or high school introductory biology course and can be run through once in one class period.

Brazzein is a protein that induces a sweet taste. It was identified in the mid-1990s in the pulp made from berries collected from the west African plant *Pentadiplandra brazzeana* (Hellekant and Danilova 2005). The brazzein protein is unique because it is one of the smallest and sweetest proteins that has been studied. Because of these properties, it is currently being investigated as a dietary sweetener (Hellekant and Danilova). The amino acid sequence for brazzein is as follows: *QDKCKKVYEN YPVSKCQLAN* QCNYDCKLDK HARSGECFYD EKRNLQCICD YCEY. The letters are the conventional representations of amino acids, and the sequence can be found on the Web site of the National Center for Biotechnology Information, a database for protein sequences (http://www.ncbi.nlm.nih.gov / entrez/viewer.fcgi?db_protein&id+3287738). I chose this protein because it is actively being studied, may appear in our diet in the near future, and has a relatively small sequence. The described activity requires that students transcribe and translate the only first twenty amino acids of the protein.

PREPARATION

Decide what specific organelles and players will be represented in the lesson. I chose DNA, mRNA, tRNA, ribosome, and Golgi apparatus (see Table 1). Make name tags for each role on color-coordinated construction paper (e.g., all DNA tags are green, all mRNA are red, and so on) and laminate the tags so they can be reused. Tie off a corner of the room with a jump rope. This space represents the nucleus of the cell, or classroom. Print recipe cards on colored paper with the following recipe to be transcribed by mRNA inside the nucleus:

TAC GTT CTA TTT ACA TTT TTC CAG ATG CTC TTG ATG GCG CAG TCA TTC ACA GTT GAA CGA TTA ATT.

Put the correct answer—the mRNA strand sequence—on the bottom of the card for the teacher:

AUG CAA GAU AAA UGU AAG GUC UAC CGC GUC AGU AAG UGU CAA CUU GCU AAU UAA.

I made the original recipe cards on colored paper for DNA students to hold and gave blank white index cards to the mRNA students to hold.

Before class, purchase and prepare trail mix ingredients, plastic wrap, long celery sticks, and containers to hold the trail mix items. The ingredients needed to transcribe and translate the brazzein protein include the following: butterscotch chips, banana chips,

TABLE 1 **Role of the Players, Suggested Number of Students, Their Place in the Room, and Their Actions**

Role	Suggested Number of Students	Place in the Room	Action
DNA	Four	Behind the jump-rope barricade in the nucleus	Give a copy of the recipe to mRNA
mRNA	Four	Between nucleus and ribosome	Retrieve the recipe copy and deliver it to ribosome
tRNA	At least one per type of amino acid used	Between the bowls of amino acids and ribosome	Bring ingredients to ribosomes
Ribosome	Six	Along desks labeled "RER"	Read recipe, request ingredients, and stir trail mix
Golgi apparatus	Three	Back of the room but near ribosomes	Transfer trail mix to baggies

cheerios, Chex cereal, chocolate candy, coconut, dried cranberries, dried apricot, mini marshmallows, pumpkin seeds, raisins, sunflower seeds, and raisins (see Figure 1). Avoid nuts unless you are sure that there are no allergies. If students have other food restrictions (such as gluten intolerance), remind them to refrain from eating restricted foods. Pour each food item into a separate container. Place these containers around the room and label each one with the letter that corresponds to the specific amino acid the contents represent (see Figure 2). To help ribosome students construct the protein, give them a stick of celery on which they can sequentially add their amino acids. The celery stalk allows students to maintain amino acids in order, so it must be long enough to contain the entire protein. To reduce the chance of dropping the protein, I suggest using a paper plate as a base for the celery stalk.

Finally, Golgi apparatus students will need plastic wrap to package and transport the trail mix (i.e., to completely wrap the celery with the trail mix sequence intact). To maintain a hygienic work environment, ribosome and Golgi apparatus students, who handle the food, should wear gloves. To ease the role-playing activity, label the nucleus, rough endoplasmic reticulum (RER), and Golgi apparatus areas of the room (see Figure 3).

FIGURE 1 **Some possible ingredients that can be used to make trailmix and name tags. Do not use nuts, if you know that there are students with nut allergies.**

First Base (5' end)	Second Base: U				Second Base: C				Second Base: A				Second Base: G				Third Base (3' End)
U	UUU	Phenylalanine Phe	F	peanut	UCU	Serine Ser	S	sun-flower seed	UAU	Tyrosine Tyr	Y	cheerio	UGU	Cysteine Cys	C	candy	U
	UUC				UCC				UAC				UGC				C
	UUA	Leucine Leu	L	butter scotch chips	UCA				UAA	Stop	*		UGA	Stop	*		A
	UUG				UCG				UAG	Stop	*		UGG	Tryptophan Trp	W	wheat germ	G
C	CUU	Leucine Leu	L	butter-scotch chip	CCU	Proline Pro	P	pump-kin seed	CAU	Histidine His	H	dried apple	CGU	Arginine Arg	R	prune	U
	CUC				CCC				CAC				CGC				C
	CUA				CCA				CAA	Glutamine Gln	Q	raisin	CGA				A
	CUG				CCG				CAG				CGG				G
A	AUU	Isoleucine Ile	I	walnut	ACU	Threonine Thr	T	Brazil nut	AAU	Asparigine Asn	N	coconut	AGU	Serine Ser	S	nutmeg	U
	AUC				ACC				AAC				AGC				C
	AUA				ACA				AAA	Lysine Lys	K	banana chip	AGA	Arginine Arg	R	cinna-mon	A
	AUG	Methionine Met (START)	M		ACG				AAG				AGG				G
G	GUU	Valine Val	V	cran-berry	GCU	Alanine Ala	A	dry apricot	GAU	Aspartate Asp	D	marsh-mallow	GGU	Glycine Gly	G	choco-late chips	U
	GUC				GCC				GAC				GGC				C
	GUA				GCA				GAA	Glutamate Glu	E	chex	GGA				A
	GUG				GCG				GAG				GGG				G

FIGURE 2 Genetic code dictionary with corresponding amino acid letters and trail mix items.

REHEARSAL

Start the lesson by asking students to take a pretest on one side of a piece of paper. Ask the following questions:

1. Why can't the DNA go directly to the ribosomes?
2. What must happen to the mRNA before it can leave the nucleus?
3. How do the roles of tRNA and mRNA differ?

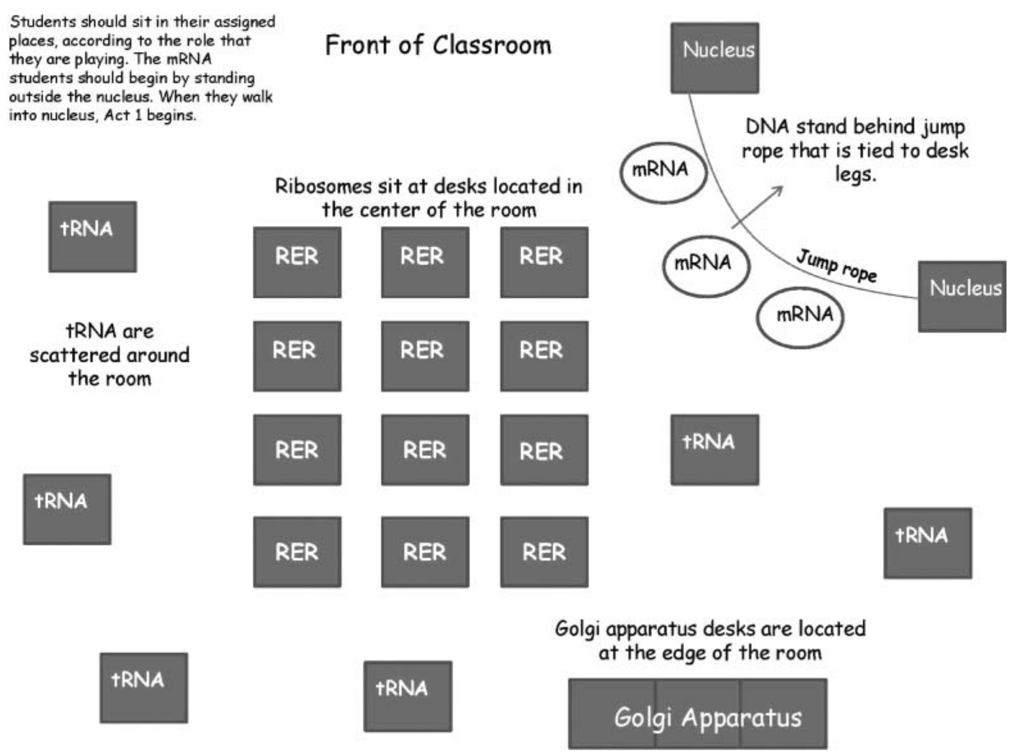

FIGURE 3 Positions of players around a classroom. The first act (transcription) begins when the mRNA students enter the nucleus.

4. Why can't ribosomes retrieve amino acids themselves?
5. How are anticodons transferred to the ribosomes by rRNA (not part of our role-playing exercise)?
6. **Posttest only:** Describe some limitations to this role-playing activity and how they might be addressed.

Have students save the back of the paper to use for a posttest at the end of the lesson so they can see if and how their answers have changed.

Ask students to pick a card randomly and attach it to the front of their shirt using masking tape. Point out where the nucleus, RER, and Golgi apparatus are located. Then, tell students that they will be acting out the making of a protein, that there are many players involved in this process, and that each one has a specific role. Invite students to help each other remember their roles.

Ask students to imagine that the classroom is a cell, and encourage them to take their places within it. A diagram might help students visualize where they will be starting the activity (see Figure 3). This diagram can be projected as an overhead to help students find their places. If a student is not sure where to stand, ask the class to help. For example, ask, "Where is DNA found?" DNA students should walk over to the barricaded nucleus and step over the rope. Ask the class why DNA cannot leave this organelle (it is double-stranded and too large to move through the nuclear membrane pores) and what the rope represents (the nuclear membrane). By staying in the nucleus, DNA is more protected than it would be if it traveled back and forth in and out of the cytoplasm. Alternatively, mRNA, which is assembled in the nucleus and undergoes protective modification before it is able to exit, is able to carry the recipe into the cytoplasm. Give each mRNA student a clipboard, an index card, and a pencil and explain that the message that they write down represents mRNA. Remind students that proteins are made up of chains of amino acids, which will be represented by different food items. As the students collect amino acids collectively and sequentially, they will make a protein (i.e., trail mix).

In addition, remind students that, even though each student plays a particular role, all students must pay attention when the teacher stops the class to inquire about a particular role and activity. From my experience, if the teacher is able to engage the entire class in asking and answering questions, then it does not matter that some students do not participate in every part of the role-playing activity (e.g., the DNA students are not part of the translation act). I also recommend having students switch roles so they can experience transcription and translation from different perspectives.

ACT 1: TRANSCRIPTION

1. The genetic code should be projected in the front of the room either as a slide or an overhead, so all students can see it throughout the lesson.
2. DNA students hold up their recipe card printed on colored paper.
3. mRNA students approach the nucleus and cross over. Each mRNA student pairs up with a DNA student and transcribes the recipe onto a blank index card. To do this, students must remember that the mRNA strand is a complimentary strand of each DNA template strand. (This step might take some time, so tell mRNA and DNA students to work together.) Remind students that A, C, G, T on the DNA strand would be transcribed as U, G, C, A on the mRNA strand. I usually ask students to stop and recall out loud which nucleotides pair with one another and write these on the board as we begin the activity.
4. mRNA must be altered in order to be able to leave the nucleus and re-enter the cytoplasm: the 5-ft end of mRNA is capped with a modified guanine nucleotide. To represent this, the student can be given a baseball cap to wear or a "G" sticker can be capped on the end of the recipe sequence. Likewise, a 3-ft poly-A (adenine) tail is added either by pinning or tying a piece of ribbon to the back of the student or by putting an "A" sticker on the end of the sequence. When this is occurring, remind students that the cap and tail help protect the mRNA from degradation as it leaves the nucleus, as well as helping it bind to ribosomes for translation.
5. Each mRNA student can leave the nucleus after the teacher has proofread the sequence and given the student a cap and tail.

ACT 2: TRANSLATION

Make a dramatic point that students are now in act 2, and ask students if they would be able to follow a recipe if they had not written it down first. The second act is about making sense of, or translating, the information from mRNA. The DNA students will not be a part of the translation act, so I would suggest that they use the projected code and try to translate the message (recipe).

1. The mRNA students will leave the nucleus and walk to the RER desks, where ribosome students should be seated. Each ribosome will have a plate with celery stalks, the actual site of protein synthesis (i.e., trail mix synthesis). The mRNA should stay close (bound) to the ribosome in order to translate the recipe. You may wish to print a copy of the code (Figure 2) for each of the mRNA students, in addition to having it projected in the front of the room.
2. In the mean time, tRNA students will be spread around the classroom near bowls of mock amino acids. They should fill small paper cups about 1/4 full and transport them to the ribosome plates. Note that you will need as many tRNA students as you have different amino acids. Pose the question, "What is the importance of tRNA, and why can't ribosomes retrieve amino acids?" Discuss with students that each tRNA recognizes particular amino acids, and ribosomes (either freely floating or attached to the endoplasmic reticulum) are the physical site of protein synthesis.
3. The mRNA students should alert the different tRNA students if their partnering ribosomes need an additional ingredient, ensuring that all of the components are added to each mixing plate. It may get a bit loud as mRNAs call out to tRNAs to deliver their amino acids. Each tRNA student is in charge of only one type of amino acid. Because amino acids will be placed on the celery stalks, there will not be room for the full quarter cup of each type of amino acid to be added. tRNA students can take a pinch of their ingredient and place it on the celery stalk. The plate is to catch any spilled trail mix items; it does not necessarily represent any intracellular organelle.
4. When a complete recipe has been made, the ribosome will hand the plate with the filled celery stalk back to a Golgi apparatus student (these students sit behind the RER with boxes of plastic wrap). The Golgi apparatus students wrap the filled celery stalks using the plastic wrap. The process will continue until there are enough proteins for each student in the class.
5. Once there are enough stalks of trail mix for every student, ask the students to return to their desks, turn their pretests over, and take a posttest on the back without peeking at their first set of answers. Collect these tests after a class discussion of the answers.

CONCLUSION

Role-playing activities often simplify actual biological processes. Although this activity can be modified to reflect more details involved in transcription and translation, there are limitations. Whenever using any type of model, it is important for teachers to engage students in follow-up discussions of any elements that are not quite accurate in the model. I have found that this discussion is often fruitful because the students have a shared experience to which they can all refer. After completing the posttest I also ask students to compare their pretest and posttest answers. When students can examine their preconceptions, it is easier to generate discussion. This is when I talk about the limitations of analogies. For example, ribosomes do not actually hand proteins to the Golgi apparatus. In addition, many proteins that are synthesized are regulatory and do not have extracellular functions. Some proteins stay in the cell and are never processed for export. Depending on the amount of detail that you cover in your class, this hands-on activity has potential to address concepts of protein synthesis in the middle to high school science curriculum.

When students replay the protein synthesis process, use the limitations to challenge them. Ask them to integrate more details about the chronology, form and function, and cell organelles involved. Cherif and Somervill (1995) suggest that, with each subsequent role-playing event, students should solve the role-playing problem with less guidance from the instructor in order to analyze the process more independently. In one of my classes, students explained that codons and anticodons needed to connect to one another, so they suggested that tRNA students have triplet codes on their backs to which anticodons could attach. In this case, tRNA students would have to wear the anticodon (pieces of paper attached with tape) that correspond to their amino acid. As an extension for students, teachers may want to have their students return to the NIH protein sequence database Web site, write a paper about the limitations of the trail mix recipe analogy, or write a paper on ways to extend the role-playing activity to more accurately reflect the processes of transcription and translation (as some of my students described).

In order for the protein synthesis process to be acted out, students need to work as a team to synthesize the final product, just as the cell functions as a system. In the end, students get to have a treat as they review how to resolve their confusion about cell processes. I have found students to be very enthusiastic about being able to remember the difference between transcription and translation after this role-playing review. Instead of just memorizing terms such as transcription and translation, my students linked the words with the processes and functions. Likewise, my peer teachers were excited to use a review of an abstract process that is fun and engaging. I received many positive comments from students about this activity, especially students who struggled with understanding the written or drawn explanations in their textbooks.

ACKNOWLEDGMENT

Support was provided by the GraSUS-II Project through a grant funded to the North Dakota State University from NSF (DGE-0338128, 2004-09, D. Comez, PI). I thank S. Forness, C. Bondy, and M. Malott for their useful suggestions.

REFERENCES

Cherif, A. H., and C. H. Somervill. 1995. Maximizing learning: Using role playing in the classroom. *American Biology Teacher* 57: 28–33.

Hellekant, G., and V. Danilova. 2005. Brazzein, a small, sweet protein: Discovery and physiological overview. *Chemical Senses* 30(suppl. 1): i88–i89.

Hickman, D. 1990. Designer genes. *Science Activities* 27(2): 36–37.

Joyce, B. R., and M. Weil. 2004. *Models of teaching*. 7th ed. Boston: Pearson Education, Inc.

Krebs, R. E. 1999. *Scientific development and misconceptions through the ages*. Westport, CT: Greenwood Press.

Lawson, A. E., S. Alkhoury, R. Benford, B. R. Clark, and K. A. Falconer. 2000. What kinds of scientific concepts exist? Concept construction and intellectual development in college biology. *Journal of Research in Science Teaching* 37: 996–1018.

National Research Council. 1996. *National science education standards*. Washington, DC: National Academies Press.

Rode, G. A. 1995. Protein synthesis using a simulation. *American Biology Teacher* 57: 50–52.