

Demonstrations, Skits, and Props in Introductory Biology to Improve Student Understanding and Engagement

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Demonstrations, skits, props, and activities can be used to create a more interactive, engaging environment in Introductory Biology lecture courses. Activities to reinforce the following topics have been developed: specific heat of water, transcription/translation, lipids, and cellular respiration. These activities can be used to clear up student misconceptions and as a platform for teaching study skills in the context of the curriculum. A think-pair-share approach in combination with “clickers” or similar response tools can be paired with these activities to ensure full class engagement and probe the level of understanding of the students.

Keywords: introductory biology, specific heat of water, transcription, translation, lipids, cellular respiration

Link to Supplemental Materials

<http://www.ableweb.org/volumes/vol-36/pattison/supplement.htm>

Introduction

Engaging students in their own learning can be a challenge, particularly in large enrollment lecture courses. Our goal is to move away from the “sage on the stage” model of college teaching to a livelier, more interactive model where students participate and take charge of their own learning. In order to create opportunities for students to take the time to process information and evaluate how well they understand a concept, demonstrations and skits were developed for use in the General (non-majors) and Introductory (majors) Biology I and II courses at the University of Houston. These activities help create a positive classroom environment where students feel valued and part of the classroom community and not just another student ID number on a spreadsheet. These activities are largely used as a review after the material has been presented by the lecturer. The activities break up the monotony of lecture and provide students with another way to “see” the material. We have begun building clicker questions to use in conjunction with our skits and demonstrations so that every single student in the room is actively contributing to the process. As the skits unfold, periodic clicker questions quiz the class on what the students at the front should do next. By asking the class, rather than the students who have volunteered, the students at the front are not put in the uncomfortable position of not knowing what to

do next. With the assistance of the instructor and the clicker questions, the students can demonstrate the process at hand. We use clicker questions for longer demonstrations (cellular respiration and transcription/translation) and simple call and answer from the audience for shorter ones (lipids, specific heat of water). As we work our way through the skits, we take the opportunity to point out common misconceptions, easily confused vocabulary, and places we know students tend to get confused. For example, in cellular respiration, students tend to miscount how many ATP are produced in the citric acid cycle if they fail to check if the question is based on glucose entering the process or if they are starting with acetyl CoA. Locations of processes in cellular respiration are often overlooked by students so the demonstration on cellular respiration provides an opportunity to reinforce where processes are occurring.

In the course of walking through the demonstrations, we try to incorporate study skills and often end the skits by having students sketch the concept or process on paper or write a paragraph to reinforce the material and teach the skill of “self-assessment” or “how much do I really remember when I’m not looking at my notes or book”. Learning skills can be taught effectively in the context of course content rather than separately. The literature indicates that teaching study skills out of context in a special “study skills course”

is largely ineffective (Yuksel, 2006). By incorporating brief lessons on how to tackle studying the discipline of biology, we hope to improve student performance not only in our Introductory Biology courses but in all subsequent courses stu-

dents take. Videos of many of the activities described here are available on our Comprehensive Student Success Program website at the following link: <http://cssphmi.nsm.uh.edu/>

Student Outline

Specific Heat of Water Experiment

Purpose

To illustrate the concept of specific heat of water. Students need to understand this concept to understand why water is such a biologically important molecule. This activity provides students in either a lab or lecture hall setting the opportunity to make a hypothesis, collect data, and analyze and explain the data.

Materials

4 large balloons of the same color, graduated cylinder, water, 4 votive candles, matches or lighter, 4 ring stands and clamps, tape, paper towels, 4 timers, ruler.

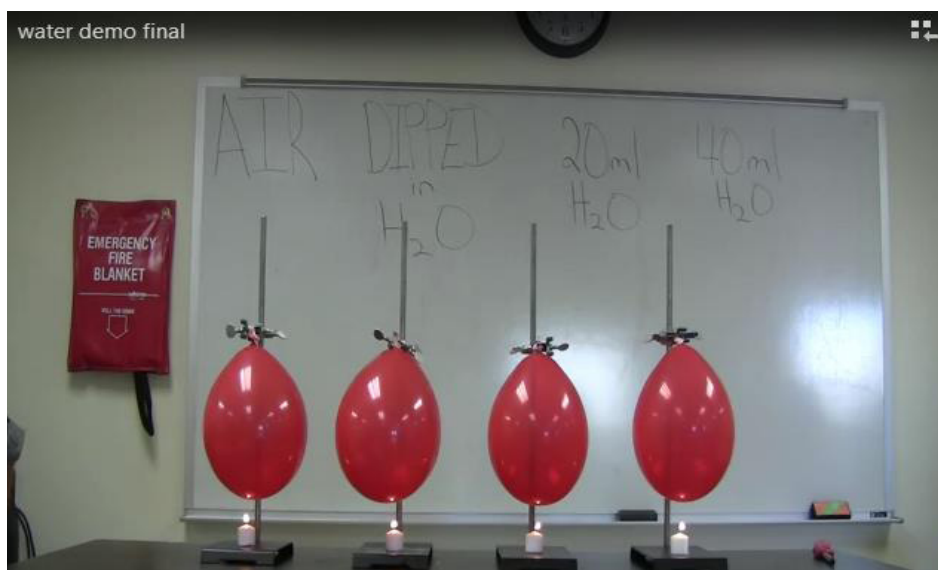


Figure 1. The setup for demonstrating the concept of specific heat of water using balloons filled with air, filled with air and dipped in water, filled with air plus 20 mL water, and filled with air plus 40 mL water from left to right respectively.

Procedure

1. Set-up four ring stands with clamps.
2. Blow up one balloon to slightly below the point where it will pop if you keep adding air. Tie the balloon.
3. Use the first balloon as a guide to estimate the size to blow up the second balloon. Tie the second balloon.
4. Add 20 mL of water to the third balloon. Pouring directly from the graduated cylinder works but you may need an extra pair of hands to help. Blow the third balloon up to the same size as the first balloon. Tie off the balloon.
5. Add 40 mL of water to the third balloon as above. Blow the fourth balloon up to the same size as the first balloon. Tie off the balloon.
6. Use lab tape to attach each balloon to the ring stand clamp. Place the balloons in order (no water, no water, 20 mL water, 40 mL water). Adjust the height of the clamp such that the bottom of each balloon is at the same height and is 1 inch above the votive candle (Fig. 1). Use a ruler to check.
7. Wipe the outside of the bottom of the second balloon with a wet paper towel (or dip in a bucket of water).
8. Have students write down their hypothesis as to the order in which the balloons will pop. They should provide an explanation of their hypothesis. Allow students time to discuss their hypothesis with their neighbors.
9. Hand four students a timer and assign them each a different balloon to time.
10. Rewet the bottom of the second balloon since it will have dried by the time students are done writing down their hypothesis. Light the four votive candles. Have four students place one votive candle beneath each balloon simultaneously and start the timers. Students should stop the timers when their assigned balloon pops.
11. Record the time each balloon pops on the board.

9. Discuss the results.

Transcription/Translation Demonstration

Purpose

To review the principles of transcription and translation and to highlight the differences between the two processes.

Materials

3/4" to 1" diameter PVC pipe (20 pieces cut to 2 feet), 16 PVC couplers, duct tape (red, blue, and yellow), foam board, colored copy paper, large swimming inner tube or hula hoop, brown butcher paper, Velcro with self-adhesive backing, glue sticks, scissors.

To Build the Model

1. Assemble five PVC pieces with four couplers to make the DNA backbone. Wrap with blue duct tape. Do not tape over the joints where the couplers meet the PVC pipe or you will not be able to take the model apart for transport and storage. Assemble a second DNA backbone identical to the first. Assemble the mRNA backbone and wrap the pipe in yellow duct tape. Assemble the protein backbone and wrap the pipe in red duct tape.
2. Attach Velcro™ along the entire length of each of the duct taped pipes. Do not place Velcro™ over the joints where the couplers meet the PVC pipe.
3. Print out letters on colored copy paper for each of the nucleotides (nine copies of A, T, G, and C and three copies of U): Pink=A, Blue =T, Yellow=C, Orange=G, and Green=U.
4. Print out the amino acid codes on colored paper: MET, TYR, ARG, STOP.
5. Use an Exacto™ knife or similar handled razor blade tool to cut foam board into the desired nucleotide shapes and amino acid shapes. Templates for the nucleotides are included in the appendix. Once the nucleotides are cut out, they can be used to help make the template for the amino acids. The bottom of the amino acid should be cut to align with the nucleotides. Any shape can be used for the upper part of the amino acid (see Fig. 2 for a suggestion).
6. Glue the nucleotides and amino acids to the appropriate foam board.
7. Glue Velcro™ to the bottom of nucleotide and amino acid boards (Fig. 2).
8. Print out 5' and 3' signs for each end of the DNA and mRNA models. Tie to the ends of the PVC pipes.
9. Using large sheets of brown butcher paper, cut out a large and small ribosome. Tape the pieces together on the backside. Use marker to draw in the E, P, and A sites (Fig.3).



Figure 2. Nucleotide letters are cut and pasted onto foam board. Velcro™ is added in a strip at the bottom of each nucleotide so that the pieces can be attached to the poles serving as the DNA or RNA backbone.



Figure 3. Students in an introductory biology lecture course participate in a review of the processes of transcription and translation.

Running the Transcription/Translation Demonstration in Class:

1. This demonstration requires a minimum of 17 students. Have your volunteers line up off the side of the front of the class room.
2. Have 2 students hold the 2 blue DNA template poles. It is easiest to have the top pole be oriented in the 3' to 5' direction and the bottom pole oriented in the 5' to 3' direction. Be sure the orientations are correct before you begin. I recommend you set these up on the floor before class starts so that when students pick them up, they are in the correct orientation. The DNA sequence should be set up ahead of time to read ATGTACCGCTAG (so that the amino acid sequence at the end is MET, TYR, ARG, STOP).
3. Ask the class what must be done to make the mRNA template. The DNA can be denatured by lowering the 5' to 3' pole to the floor. Two more students step into the demonstration and pick up the yellow mRNA pole. The pole should be held beneath the 3'-5' pole. Discuss the direction in which mRNA is processed (polymerization always occurs in the 5' to 3' direction).
4. Have 4 students (or as many as you wish) play the role of the polymerase and assemble the mRNA sequence using the DNA template as a guide. Students typically start matching up the nucleotides but they don't add them in a processive 5' to 3' manner. Stop them and ask the class how a polymerase behaves. Add one nucleotide at a time in the 5' to 3' direction. In the pile of nucleotides students have to choose from, you should have some T's. The T's aren't actually needed for mRNA. Uracil is used. There is usually one student that adds a T though. The students observing or in the demonstration usually catch the mistake but if not, you'll need to redirect.
5. Once the mRNA is made, the DNA comes back together. Both poles are dropped to the floor and the DNA pole holders step off the stage.
6. The mRNA is then exported through the nuclear pore which is the swimming inner tube. Discuss the difference between what happens in a prokaryote and a eukaryote if desired.
7. Have 2 students hold up the ribosome.
8. Have 2 students pick up the red protein pole.
9. Align the mRNA with the A site.
10. Have 4 students serve as tRNAs to carry the amino acids to the ribosome. Students in the class should use the provided amino acid chart in their notes or projected on the board to help the tRNA students assemble the appropriate amino acids along the mRNA. The mRNA pole holders should move the growing polypeptide along the ribosome sites as appropriate.
11. The final protein floats away from the ribosome. Ask students whether the protein is in primary, secondary, tertiary, or quaternary structure.

Phospholipid Membrane Demonstration

Purpose

To provide students with a review of the key concepts concerning lipids and membranes and to provide a visual illustration of the fluid mosaic model.



Figure 4. Students participate in a model of lipids, cholesterol, and a transmembrane protein.

Materials

6 giant fuzzy pipe cleaners (available at craft stores) folded into the shape of a phospholipid, 2-3 cholesterol structures printed on card stock.

Procedure

1. Recruit 6 students. Each will hold 1 of the 6 giant fuzzy pipe cleaner lipids.
2. Review the parts of the phospholipid:
 - a. Glycerol-phosphate head (the top loop of the pipe cleaner)
 - b. Fatty acid tails (tails of the pipe cleaner)
3. Review hydrophobic vs hydrophilic.
4. Have students demonstrate how to hide the tails. What conformations are possible?
 - a. Bilayer.
 - b. Micelle (eg: Dish water: soap is both hydrophilic and hydrophobic. Hydrophobic ends mix with oil and hydrophilic ends interact with water forming a micelle with oil in the middle).
 - c. Liposomes (eg: Drug-delivery).
5. Demonstrate the fluid mosaic model.
 - a. Lipids move transversely with neighbors at 1×10^7 times per second. A lipid can traverse the entire length of the cell in 1 second. Have students rearrange themselves.
 - b. Flipping layers occurs rarely and is facilitated by an enzyme called flippase. This process helps balance bilayers, especially when the cell is expanding. Ask students why it is unlikely a phospholipid would spontaneously flip on its own. Use the model to demonstrate the problem of the hydrophilic head passing through the hydrophobic tails.
 - c. Have one student be a transmembrane protein. Pop them in between the students serving as lipids. Discuss movement in the fluid membrane of a protein tethered to the cytoskeleton and untethered to the cytoskeleton.
6. Packing: Saturated vs Unsaturated
 - a. Define saturated vs unsaturated.
 - b. Have students line up the membrane. Have another student come up and put kinks in the membrane. Pack without touching. Look at the space between the lipids.

- c. Stick cholesterol in (two or three more students) with cholesterol molecules on card stock.
- d. Discuss the effect on fluidity. Cholesterol makes the membrane more rigid but also helps prevent packing when the temperature drops.
- e. Discuss the effect of a cold spell on plants. Plants produce more unsaturated lipids in the autumn before freezing temperatures set in. A cold snap without the acclimation period leads to fractured membranes. Cytosol leaks out of the membrane where ice crystals caused ruptures.

Cellular Respiration Activity

Purpose

Students will review cellular respiration from glycolysis through oxidative phosphorylation.

Materials

poster board, glue stick, 8.5" x 11" card stock, yarn, self-adhesive Velcro, approximately 42 feet of thick yellow rope

Assembly Instructions

Make poster boards of the components of the cellular respiration process. You will need boards for the following (Fig. 5).

1. Glycolysis: large poster board. Place two strips of Velcro™ below the word glycolysis so that “glucose” and “pyruvate” sheets can be attached by students in the skit. Punch holes in the bottom of the large poster board (about 10 inches apart). Punch holes in two “ATP” sheets (top and bottom of one sheet and top only of the second “ATP” sheet). Tie the “ATP” sheets to each other and to the glycolysis board such that they hang below the glycolysis board. Attach Velcro™ to the back of the “ATP” sheets and the back of the glycolysis board. The “ATP” sheets can be hidden until needed in the skit by attaching them to the back of the glycolysis board with the Velcro™.
2. Pyruvate oxidation: large poster board. Place two strips of Velcro™ below the words pyruvate oxidation so students can attach the “2 pyruvate” and “2 acetyl CoA” sheets during the skit.
3. Citric Acid Cycle: large poster board. Punch holes in two “ATP” sheets (top and bottom of one sheet and top only of the second “ATP” sheet). Tie the “ATP” sheets to each other and to the Citric Acid Cycle board such that they hang below the Citric Acid Cycle board. Attach Velcro™ to the back of the “ATP” sheets and the back of the Citric Acid Cycle board. The “ATP” sheets can be hidden until needed in the skit by attaching them to the back of the Citric Acid Cycle board with the Velcro™.
4. Electron Transport, Chemiosmosis, Oxidative Phosphorylation: large board. Attach Velcro™ to the back of the board. Attach Velcro™ to the back of a board with the “many ATP” sheet (alternatively, attached as many ATPs as you can fit). Punch holes in the bottom of the Electron Transport board and the top of the “ATP” sheet. Tie them together with yarn. The “ATP” sheet can be hidden until needed in the skit and then flipped down.
5. Print the “glucose”; “2 pyruvate”; “2 acetyl CoA”; “6 NADH and 2 FADH₂”; “2 CO₂”; “4 CO₂”; and “many ATP” sheets. Print two “2 NADH sheets. Print four “ATP” sheets. Print all on a laser printer on 8.5" x 11" colored tag board.

Procedure

1. Place an oval on the floor to represent the mitochondria.
2. Invite 11 volunteers to the front of the room. Hand each student a board. Have the students stand off to the side.
3. Explain to students that it is important that they understand what the key inputs and outputs are for each major stage of cellular respiration.
4. Have the class direct the students at the front of the room to line up the process (Fig. 6). The first step is glycolysis. Ask where it occurs (inside or outside of the mitochondria). Stick the “glucose” sheet to the glycolysis board. The “pyruvate” sheet will be velcroed to the glycolysis board next. Students should step off the stage area once their board is attached.
5. Ask what other “outputs” result from glycolysis. Two ATPs are formed and two NADHs are formed. Have the student holding the glycolysis board flip down the “ATP” sheets attached to the back of the board. Have one of the “2 NADH” students stand next to the glycolysis board. Stress the fact that NADH is an electron carrier. The important part is the electrons because we need those further down in the respiration process. Add a “2 CO₂”. Have the student “float off”.
6. Pyruvate oxidation comes next. Ask the class if the student holding the board should be inside or outside of the mitochondria and in the membrane or the matrix. Have a student move the pyruvate board from the glycolysis board to the pyruvate

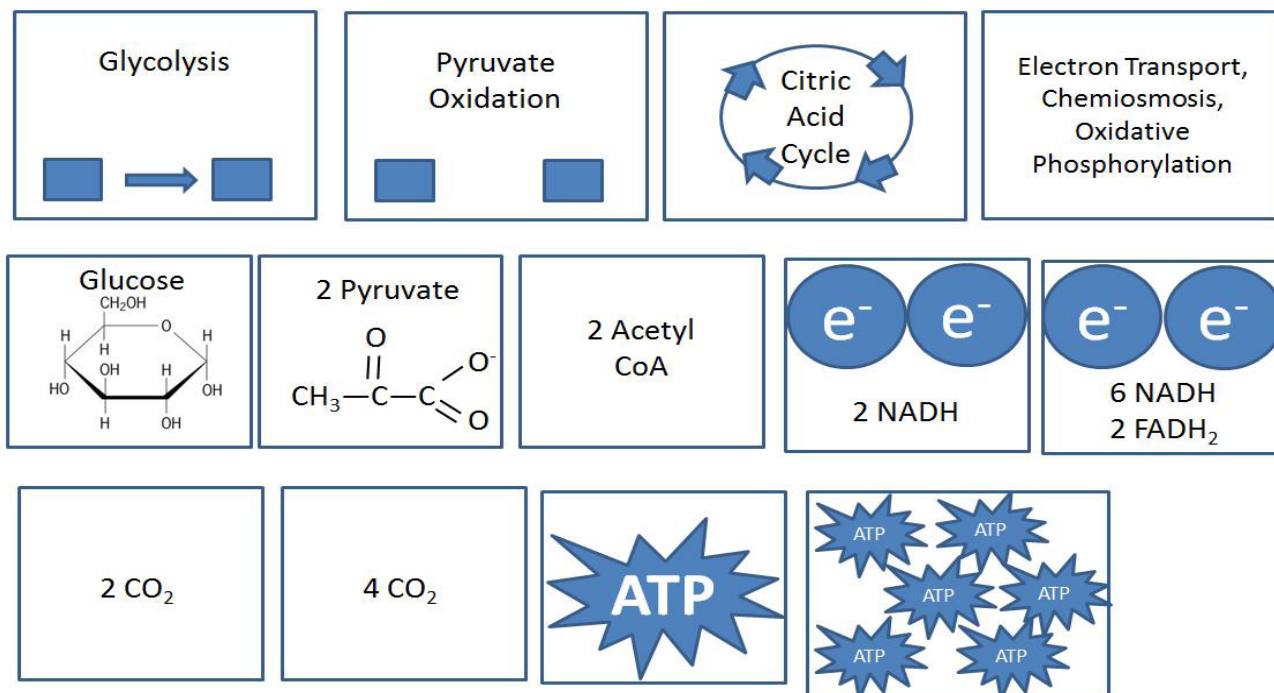


Figure 5. The boards illustrated above need to be created for the demonstration.



Figure 6. Students participate in a review of cellular respiration.

oxidation board (attach with the Velcro™). The “2 Acetyl CoA” board should be added next. Have the second “2 NADH” student stand next to the pyruvate oxidation board.

7. The Citric Acid Cycle is added next. Again, ask students whether the citric acid cycle occurs in the membrane or the matrix of the mitochondria. Ask what is produced by the Citric Acid Cycle. The student holding the Citric Acid Cycle board can flip down the “ATP” sheets attached to the back. The student holding the “6 NADH and 2 FADH₂” sheet should come stand next to the Citric Acid Cycle board.

8. The Electron transport, chemiosmosis, oxidative phosphorylation board comes next. Ask students what is needed to drive this process. Ask the students whether electron transport occurs in the mitochondrial matrix or the membrane. Have the student with the board stand on the rope to represent occurrence in the membrane. Have the “NADH and FADH₂” students deliver their electrons to the electron transport chain. They should stand behind the student with the electron transport board. Ask students where the electrons end up. Stress the fact that oxygen is the terminal electron acceptor. This is why we breathe and must have oxygen to survive. Ask what is produced by oxidative phosphorylation. The student holding the electron transport board can flip down the “many ATP” sheet attached on the back.

9. Have the students take out a piece of paper and without looking at their notes, sketch the process. Remind them that if they cannot do this from memory, they are not yet ready for the test! Understanding a process is not the same as being able to

recall and answer questions about a process on an exam.

“Where in the Mitochondria?” Activity

Purpose

Students will review cellular respiration and understand where in the mitochondria each step occurs.

Materials

Laminator sheets, acetate sheets, 8.5” x 11” card stock

Assembly Instructions

1. Print out all the components except the electron transport chain onto white card stock (see the appendix for template). Laminate the sheets. Cut the pieces.
2. Print the electron transport chain components on clear acetate (overhead projector) sheets.
3. Assemble kits for student teams in gallon size zipper bags. Use the laminated mitochondria and place the labels and components in the correct place.

Procedure

1. Have students place the labels and components in the correct locations in the mitochondria on the laminated mitochondrial mat. Students should sketch the model in their notes.
2. Have students answer the questions below.
 - a. Where does the TCA cycle occur?
 - b. What is the input in the TCA cycle? Where does this molecule come from?
 - c. What is the output in the TCA cycle?
 - d. How many ATPs per molecule of glucose are produced in the TCA cycle?
 - e. What is the main purpose of the TCA cycle?
 - f. What is another name for the citric acid (TCA) cycle?
 - g. Where is the electron transport chain found?
 - h. What goes into the electron transport chain and where does it come from?
 - i. A gradient is very important in electron transport and oxidative phosphorylation. What molecule composes the gradient and how is the gradient established?
 - j. What is chemiosmosis?
 - k. How many molecules of ATP does the cell gain from the electron transport chain per molecule of glucose? What is the name of the process?
 - l. What role does oxygen play in the electron transport chain?

Materials

Specific Heat of Water Experiment

Four large balloons of the same color; a graduated cylinder; water; four votive candles or matches or a lighter; four ring stands and clamps; tape; paper towels; four timers; a ruler.

Transcription/Translation Demonstration

Three quarters to 1 inch diameter PVC pipe (20 pieces cut to 2 feet); 16 PVC couplers; duct tape (red, blue, and yellow); a foam board; colored copy paper; a large swimming inner tube or hula hoop; brown butcher paper; Velcro™ with self-adhesive backing; glue sticks; scissors.

Phospholipid Membrane Demonstration

Six giant fuzzy pipe cleaners (available at craft stores) folded into the shape of a phospholipid; two to three cholesterol structures printed on card stock.

Cellular Respiration Activity

Poster board; a glue stick; 8.5" x 11" card stock; yarn; self-adhesive Velcro™; approximately 42 feet of thick yellow rope.

“Where in the Mitochondria?” Activity

Laminator sheets; acetate sheets; 8.5" x 11" card stock.

Notes for the Instructor

Specific Heat of Water Experiment

1. This demo does not work well in a draft. If you place the set up beneath air conditioning vents, the current will blow the balloons around and blow your candles out.

2. You will need to mop up the water from the popped balloons at the end.

3. While it is highly unlikely that you will start a major fire doing this activity (the water puts the candle out when the balloon pops), it is recommended you have a fire extinguisher handy (in case you accidentally flambé your class notes).

4. This demonstration takes approximately 10 minutes. The first balloon pops around 22 seconds. The second balloon pops at 24 seconds. With 20 mL of water, the balloon pops at 1 minute and 44 seconds. If you do a 40 mL water balloon, the balloon will actually start dripping water before it pops (although sometimes it extinguishes the candle when it drips so it never pops). The 40 mL balloon pops at 7 minutes and 57 seconds. The amount of water in the balloon can be reduced to reduce the time this activity takes to complete.

5. This activity has been adapted from “The Fireproof Balloon” by David A. Katz; <http://www.chymist.com/The%20fireproof%20balloon.pdf>.

Transcription/Translation Demonstration

1. This demonstration requires a minimum of 17 students. Have your volunteers line up off the side of the front of the class room.

2. Have two students hold the two blue DNA template poles. It is easiest to have the top pole be oriented in the 3' to 5' direction and the bottom pole oriented in the 5' to 3' direction. Be sure the orientations are correct before you begin. I recommend you set these up on the floor before class starts so that when students pick them up, they are in the correct orientation. The DNA sequence should be set up ahead of time to read ATGTACCGCTAG (so that the amino acid sequence at the end is MET, TYR, ARG, STOP).

3. Ask the class what must be done to make the mRNA template. The DNA can be denatured by lowering the 5' to 3' pole to the floor. Two more students step into the demonstration and pick up the yellow mRNA pole. The pole should be held beneath the 3' to 5' pole. Discuss the direction in which mRNA is processed (polymerization always occurs in the 5' to 3' direction).

4. Have four students (or as many as you wish) play the role of the polymerase and assemble the mRNA sequence using the DNA template as a guide. Students typically start matching up the nucleotides but they do not add them in a progressive 5' to 3' manner. Stop them and ask the class how a polymerase behaves. Add one nucleotide at a time in the 5' to 3' direction. You should have some T's in the pile of nucleotides from which students have to choose. The T's aren't actually needed; uracil is used. There is usually one student that adds a T though. The students observing or in the demonstration usually catch the mistake but if not, you'll need to redirect.

5. Once the mRNA is made, the DNA comes back together. Both poles are dropped to the floor and the DNA pole holders step off the stage.

6. The mRNA is then exported through the nuclear pore which is the swimming inner tube. Discuss the difference between what happens in a prokaryote and a eukaryote if desired.

7. Have two students hold up the ribosome.

8. Have two students pick up the red protein pole.

9. Align the mRNA with the A site.

10. Have four students serve as tRNAs to carry the amino acids to the ribosome. Students in the class should use the provided amino acid chart in their notes or projected on the board to help the tRNA students assemble the appropriate amino acids along the mRNA. The mRNA pole holders should move the growing polypeptide along the ribosome sites as appropriate.

11. The final protein floats away from the ribosome. Ask students whether the protein is in primary, secondary, tertiary, or quaternary structure.

Phospholipid Membrane Demonstration

1. The lipid demonstration takes approximately 5 minutes.
2. The cholesterol molecules can be printed on card stock and laminated for repeated use.

Cellular Respiration Activity

1. This activity takes approximately 15 minutes.
2. Laminating the pieces helps keep them in good condition so you don't have to keep remaking the parts. Large poster boards can be taken to a copy center for lamination. For the sheets, we use a Scotch Thermal Laminator (Model TL901)TM and 8.5" x 11" Thermal Laminating PouchesTM.

"Where in the Mitochondria?" Activity

1. This activity takes approximately 30 minutes.
2. Laminating the pieces helps keep them in good condition so you don't have to keep remaking the parts. For smaller pieces, we use a Scotch Thermal Laminator (Model TL901)TM and 8.5" x 11" Thermal Laminating PouchesTM.
3. The exercise can be extended to include glycolysis if desired.
4. The same type of activity can be used for photosynthesis to cover the light reactions and the Calvin cycle.
5. Answer key to questions a-l.
 - a. Mitochondrial matrix.
 - b. Two acetyl-CoA from the oxidation of pyruvate.
 - c. One ATP, one FADH₂, three NADH, two CO₂ per acetyl-coA entering the TCA cycle.
 - d. Two.
 - e. To provide electrons for the electron transport chain.
 - f. Tricarboxylic acid cycle.
 - g. Inner mitochondrial membrane.
 - h. NADH and FADH₂ from the citric acid cycle.
 - i. H⁺; protons are pumped from the mitochondrial matrix to the intermembrane space by complex I, III, and IV as electrons are shuttled from NADH and FADH₂ into the transport chain.
 - j. Chemiosmosis couples the proton motive force of the proton gradient to the production of ATP.
 - k. Twenty-six to twenty-eight ATP molecules; oxidative phosphorylation.
 - l. Oxygen serves as the terminal electron acceptor in the electron transport chain.

Acknowledgements

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