

Role-Playing Activity to Demonstrate the Electron Transport Chain

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ATP
H₂O

Electron

ABSTRACT

The role of the electron transport chain, its associated proteins, and carrier molecules can be difficult for introductory biology students to understand. Role-playing activities provide a simple, active, cost-effective method for demonstrating and comprehending complex biological processes. This role-playing activity was designed to help introductory biology students learn the role of the electron transport chain in the synthesis of ATP. The activity can be completed within a single class period and, when combined with a post-activity writing assignment, can enhance student understanding of how the electron transport chain functions.

Key Words: classroom activity; role-playing; cellular respiration; electron transport chain.

○ Introduction

Cellular respiration can be a difficult concept for introductory biology students to understand (Rice, 2013). While all of the stages of cellular respiration can be complicated for students (Svec, 2017), how the electron transport chain (ETC) generates ATP can be the most challenging to visualize (Romero & Choun, 2014). Role-playing activities are a simple, cost-effective method for students to actively learn and understand complex biological processes (Elliott, 2010; Harrison, 2018) while developing cooperative social skills (Chinnici et al., 2009). This role-playing activity was designed for a general biology course for STEM majors to explain how the ETC generates ATP and produces water. This activity differs from other strategies for teaching the ETC by incorporating kinesthetic learning to stimulate motor neurons and enhance retention (see example in Wagner, 2014).

○ Activity Description

Procedure

Four white cards are each labeled “electron,” five yellow cards “ATP,” and one blue card “H₂O.” Seven student volunteers are selected from the class. One acts as ATP synthase while the other six act as electron

carrier complexes and proteins in the ETC: Complexes I, II, III, IV, ubiquinone, and cytochrome C. The remaining students act as the protons derived from NADH and FADH₂ (both played by the instructor). The students are arranged into groups of three or four students with similar roles. Each group is given 10 minutes to research and discuss what their assigned molecule or ion does as part of the ETC. After the research period, the seven volunteers form a line that splits the classroom in two and represents the inner mitochondrial membrane. “ATP synthase” stands further away from the line and holds all the ATP cards (Figure 1). The portion of the classroom to the left of the ETC is designated as the mitochondrial matrix, while the portion to the right is the intermembrane space. The “protons” are divided so that the intermembrane space has at least one more student than the mitochondrial matrix (nine and eight students for a 24-person class, respectively), thus establishing a concentration gradient. The instructor states that NADH donates two electrons to Complex I, hands two electron cards to Complex I, and instructs the students to pass the two cards together down the ETC to ubiquinone, Complex III, cytochrome C, and Complex IV, respectively. As the electrons are passed from one student to another, the protons walk between the ETC proteins from the mitochondrial matrix into the intermembrane space until all the protons have moved over (solid arrows in Figure 1). The instructor states that pumping the protons into the intermembrane space against their concentration gradient requires energy (active transport) that is provided by passing the electron between the complexes. For classes of 28 or more, the electrons can be passed individually and five protons should move into the intermembrane space for each electron card that is passed down the ETC, resulting in 10 protons moving into the intermembrane space. The instructor then states that 10 protons will follow their concentration gradient and move back into the mitochondrial matrix through ATP synthase – which provides the only opening – and that every time four protons pass by ATP synthase, one ATP molecule is generated (Urry et al., 2014). The ATP synthase student spins around whenever four protons move past and then hands the instructor an ATP card, thus demonstrating

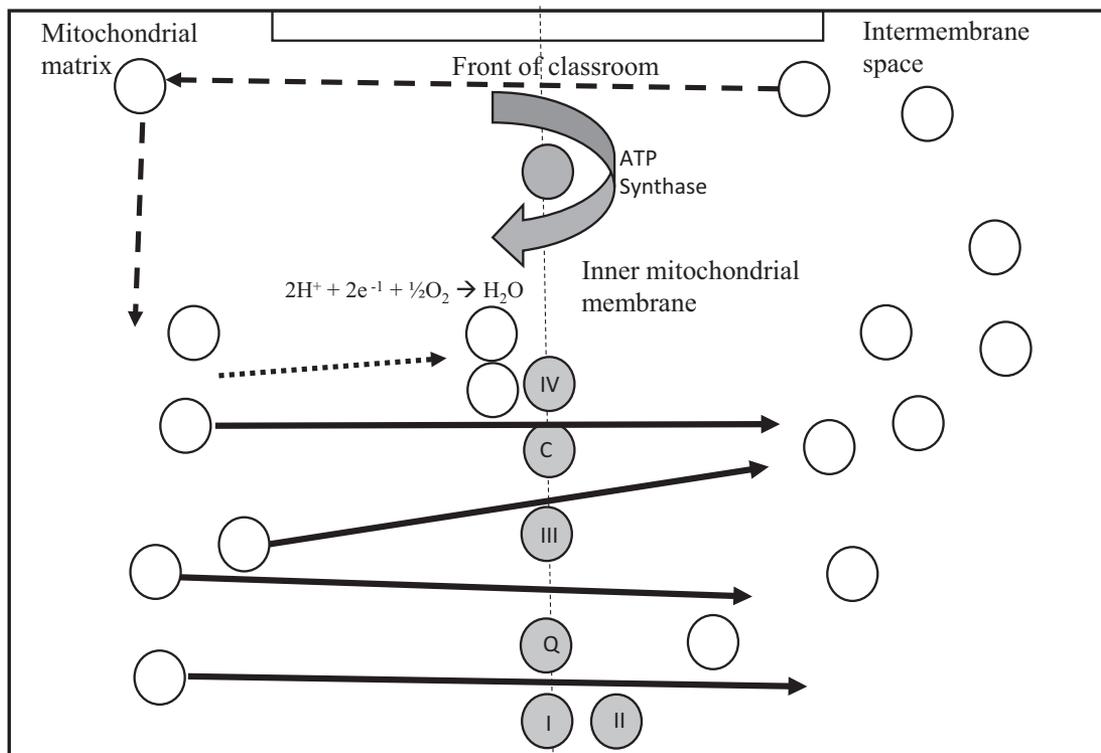


Figure 1. Diagram showing the arrangement of students. White circles represent students acting as protons; gray circles represent students acting as ATP synthase and the electron carrier complexes: Complex I, Complex II, ubiquinone (Q), Complex III, cytochrome C (C), and Complex IV. To demonstrate water formation by Complex IV, two protons move to that complex (dotted line) and they hand the water card to the instructor.

how the diffusion of protons along their concentration gradient causes ATP synthase to spin and generate ATP. The instructor explains that each NADH molecule leads to the formation of 2.5 ATP molecules that were represented by three ATP cards. This part of the activity ends after 10 protons move back into the matrix and ATP synthase hands the instructor three ATP cards.

The protons are then “reset,” with eight in the mitochondrial matrix and nine in the intermembrane space to simulate the ETC, starting with FADH₂ donating its electrons. The instructor states that FADH₂ donates two electrons to the ETC (but this time to Complex II), fewer protons are moved across the membrane, and only 1.5 ATP molecules are generated. The instructor hands two electron cards to Complex II and instructs the students to repeat the passing of electrons down the ETC but skipping Complex III. As the electrons are passed down the ETC, protons move into the intermembrane space against their concentration gradient. The instructor states that six protons will diffuse into the mitochondrial matrix through ATP synthase. ATP synthase spins whenever four protons move past and then hands the instructor an ATP card. The instructor explains that each FADH₂ molecule leads to the formation of 1.5 ATP molecules that were rounded up to two ATP cards. This part of the simulation ends after six protons move into the matrix and ATP synthase hands the instructor two ATP cards.

Water Production

To avoid confusion, I demonstrated the production of water by Complex IV separately, but I stressed that it happens simultaneously with the ETC using oxygen from the lungs, electrons passed down

the ETC, and protons that diffused back into the mitochondrial matrix through ATP synthase. Two protons that were in the mitochondrial matrix move to Complex IV, where they combine with oxygen and two electrons – that Complex IV is holding – to produce a molecule of water (dotted arrow in Figure 1). Complex IV then hands the H₂O card to the instructor. It is important that the instructor remind the students that the protons and electrons in the ETC are used to produce water and are not reused.

Wrap-up

This activity should be repeated in class if time permits, the first time with the instructor narrating every step and then with the students narrating the second time. After the activity is completed, each student writes a brief description of the roles of NADH, FADH₂, the electrons, carrier complexes, protons, ATP synthase, and oxygen in the ETC, and annotates a blank diagram of the ETC in action. The students are given a graded quiz about the ETC during the next class period.

Conclusion

This role-playing activity is an effective, fun way of demonstrating a complex cellular process to introductory biology students. While quantitative assessment of the method’s effectiveness is not included in this publication, students enjoyed the activity and were able to accurately answer quiz and exam questions about the ETC after completing the activity. This activity was designed for a

24-student classroom but is scalable for much larger class sizes by dividing the class into groups of about 28 students and having the groups perform the activity simultaneously. This activity may not work for classes smaller than 17 students because they will run out of “protons.” We completed the activity during a 75-minute class period. For shorter classes, it can be divided into two activities, with the ETC and water formation steps done during separate class periods. To avoid confusion while arranging the students for the activity, I stated the objectives for the activity at the beginning of the class period, showed the students a map of the activity (Figure 1 without arrows), and narrated every step.

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