Replication Rhumba & Translation Tango: Active Learning Exercises for Introductory Biology

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Abstract

Active learning exercises can help students understand and remember complex, three-dimensional processes. By modeling molecular processes with their bodies, students gain an appreciation for the three-dimensional nature of these processes and the physical sequence of events that constitute them. The exercises presented here focus on DNA replication and the translation of mRNA into amino acid sequences, multistep processes that require specific series of events. The exercises help students appreciate the spatial and temporal frameworks of these essential cellular functions. They can be incorporated into classes when these concepts are introduced or used as review exercises for exams.

Keywords: *DNA; RNA; biochemistry; molecular biology; kinesthetic learning activities.*

○ Introduction

One of the many challenges facing students in introductory biology classes is to appreciate the three-dimensional nature of molecular processes. My experience teaching college students indicates that many students continue to view replication and translation as occurring in two-dimensional space, despite enhanced textbook figures and videos. To help students appreciate the three-dimensional nature of these processes, I have developed active learning exercises in which the students themselves become the molecules they are studying, physically moving their bodies through these fundamental processes of molecular biology.

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Active learning involves students in discussions and/or activities and encourages students to take a dynamic role in the learning process, in contrast to passive learning in which students listen as an expert (usually the course professor) provides information via a lecture. It is an integral part of the shift in focus "from faculty-centered teaching to student-centered learning" encouraged by AAAS (2011). In a recent meta-analysis of 225 studies that compared the outcomes of active versus passive learning techniques, Freeman et al. (2014) found that examination scores increased by ~6% in classes that incorporated some active learning techniques. The proportion of students who failed a course (defined as those who received grades of D or F or who withdrew from the course) was ~1.5× higher in traditional lecture-style courses. Freeman et al. (2014) found that the benefits of active learning held across all STEM disciplines and class sizes, although the benefit was greatest in smaller classes.

I use active learning to reinforce textbook and class presentations on replication and translation in my introductory biology courses. These are especially important yet challenging processes for students to understand. Student responses on exams and surveys indicate that these exercises are highlights of the semester and help students remember these processes when they encounter them in their upper-level biology courses.

○ The Replication Rhumba

The replication of DNA involves the enzyme helicase unwinding regions of the DNA double helix at origins of replication, which separates parental strands of DNA to form a replication fork (Reece et al., 2014). Once RNA primers have been attached by the enzyme primase, the complementary DNA nucleotides can be added continuously on the leading strand. A series of primers are required to serve as the starting point for the addition of the complementary nucleotides to the lagging strand. These steps require numerous additional enzymes, including DNA polymerases.

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After we have reviewed the basic steps of DNA replication in class, a group of 12–18 students are asked to go to the front of the room to serve as nucleotides. They are told that their left hands represent their 5' phosphate groups, their left shoulders represent their 3' hydroxyl groups, and their right hands represent the nitrogenous bases that will be involved in forming the hydrogen bonds between the antiparallel strands of nucleotides. They are then asked to align themselves as a small region of a DNA molecule. With help from the rest of the class, they form two lines facing in opposite directions, with each student's left hand on the left shoulder of the student in front of them and with their right hand joined to a student in the opposite strand (Figure 1). This helps students understand the antiparallel nature of the nucleotide strands, the 5& to 3& polarity of the strands, and the role of the hydrogen bonds to link the opposing strands.

A volunteer is then asked to play the role of helicase to separate the parental DNA strands. Usually, half the class instructs the helicase to begin at one end of the strand and the other instructs that student to begin at the other end. The ensuing discussion results in the students' appreciation that the strand is three-dimensional and that the two ends of the strand are equivalent. The student-helicase then begins breaking the hydrogen bonds at one end of the strand.

Figure 1. A group of students illustrating the antiparallel nature of the DNA strand. Each student represents a DNA nucleotide, with the left hand serving as the 5' phosphate group and the left shoulder as the 3' hydroxyl group. The students' right hands are joined to form the hydrogen bonds that connect the complementary bases of the DNA strands.

A few more students are asked to serve as RNA primases, who direct additional students who serve as RNA nucleotides. These students need to insert themselves in the proper orientation and at appropriate spots along the separated strands to build the RNA primers. With the help of their peers, they eventually form hydrogen bonds with students on either side of the DNA molecule, providing the beginning of the complementary DNA strands. The students are then asked to determine which is the leading strand and which is the lagging strand. After some additional debate they appreciate the three-dimensional reality of the differences between these two and why they occur.

This exercise can be embellished in several ways. For example, students could be assigned to be specific DNA and RNA nucleotides, other students could be assigned the roles of enzymes, including specific DNA polymerases, and the resulting Okazaki fragments of the lagging strand could be fused. Each student could be provided with a simple label or sandwich board identifying the particular nucleotide or enzyme they represent. Students could be asked to explain their roles to their classmates. These modifications would require more students and time than the essential steps outlined above.

○ The Translation Tango

The process of translating a strand of messenger RNA (mRNA) into a polypeptide strand involves a sequence of steps that require site-specific positioning of mRNA and transfer RNA (tRNA) on a ribosome (Reece et al., 2014). Before class, I distribute a set of helium-filled balloons labeled with the three-letter abbreviations for a diversity of amino acids so that they are floating above the heads of the students. I tie strings to each balloon so students can reach them. After a review of the translation process, I label three chairs facing the class at the front of the room as the E, P, and A sites of a ribosome. A roll of paper with a codon sequence represents the mRNA ribbon. Six to eight students are assigned the roles of specific tRNAs. Each student is given a sheet of paper with their particular anticodon. Using the codon table for mRNA projected at the front of the room, the students must locate the balloon for the amino acid they should transport to the ribosome. This helps the students understand the relationship between codons and anticodons and the specificity of the tRNA–amino acid complex. Two students are asked to support the paper mRNA ribbon. These students and the student-tRNA with methionine (Met) initiate the translation process by positioning themselves with the start codon and tRNA–Met complex occupying the P site of the ribosome. Once that site is occupied, the class reads the next codon, identifies the tRNA-student with the appropriate anticodon and amino acid, and helps them position themselves at the A site. The tRNA-student with the Met balloon ties their balloon to the string of the tRNA-student occupying the A site, which models the elongation of the polypeptide through peptide bond formation. The tRNA students at the P and A sites then shift their positions to the E and P sites, respectively, and the students in charge of the mRNA roll shift the mRNA ribbon with them. The student occupying the P site leaves, and a new tRNA-student with the amino acid that matches the next codon occupies the A site. Once again, the growing strand of balloons is tied to the balloon at the A site and all the players shift positions. After five codons, the mRNA ribbon has a STOP codon. The students disassemble and the polypeptide chain of helium balloons is released. Not all the available tRNA–amino acids are used, which helps students gain an appreciation for the dynamic nature of the multiple translation processes occurring in the cell at any given time.

○ Conclusion

Students are enthusiastic about these exercises and say they profoundly help them understand the spatial organization of the cell. Actively involving students in the learning process strengthens their engagement with the material and leads them to ask questions about the coordination and control of the processes of replication and translation within the cell.

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