Cellular Processes: Energy and Communication

Big Idea 2

Biological systems utilize free energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis. Organisms have evolved various strategies to capture, use, and store free energy and other vital resources; for example, autotrophic cells capture free energy through photosynthesis and chemosynthesis, whereas fermentation and cellular respiration harvest free energy from sugars to produce free energy carriers, such as ATP, that drive metabolic pathways in cells. Because deficiencies in free energy are detrimental to organisms, several questions emerge about these processes, including *What factors affect the rate of photosynthesis and cellular respiration?* and *How can these changes be measured?*

In addition to free energy, cells and organisms must exchange matter with the environment; for example, carbon moves from the environment to organisms, where it is incorporated into the sugars produced in photosynthesis. Membranes not only allow cells to maintain internal environments that differ from external environments, but the selectively permeable structure of cell membranes regulates the movement of molecules across them. The processes of osmosis, diffusion, and active transport help cells maintain dynamic homeostasis. Because cells must constantly exchange molecules with their environment, key questions include *What factors affect the rate of diffusion and osmosis? How can these be tested? Why does a plant wilt when deprived of water?* and *Why can a plant recover from water loss when other organisms die from dehydration?*

The suite of inquiry-based investigations in big idea 2 provides opportunities for students to ask questions, and explore answers, about photosynthesis, cellular respiration, and the movement of molecules across membranes — phenomena that will be studied further when students investigate transpiration in plants (big idea 4).

SYNOPSES OF THE INVESTIGATIONS

Materials must move through membranes of a cell for the cell to maintain its dynamic homeostasis, and this movement is regulated by selectively permeable membranes. The simplest form of movement is diffusion, in which solutes move from an area of high concentration to an area of low concentration. Like solutes, water also moves down its concentration gradient by osmosis.

In **Investigation 4: Diffusion and Osmosis,** students calculate surface area-to-volume ratios, and make predictions about which measurement — surface or volume — has the greater influence on the rate of diffusion. Next, students create artificial cells to model diffusion, followed by observation of osmosis in living cells and measurement of water potential in different types of plants. All sections of the investigation provide opportunities for students to design and conduct experiments to more deeply investigate questions that emerge from their observations and results. Students revisit the concepts of osmosis and water potential when they investigate transpiration in plants (big idea 4).

In **Investigation 5: Photosynthesis,** students learn how to measure the rate of photosynthesis indirectly by using the floating leaf disk procedure to gauge oxygen production. Photosynthesis is a strategy employed by autotrophs to capture light energy to build energy-rich carbohydrates. The process is summarized by the following reaction:

$$2H_2O + CO_2 + \text{light} \rightarrow \text{carbohydrate } (CH_2O) + O_2 + H_2O$$

To determine the rate of photosynthesis, one could measure the production of O_2 or the consumption of CO_2. The difficulty related to measuring the production of oxygen gas is compounded by the complementary process of aerobic respiration consuming oxygen as it is produced. Therefore, the rate of photosynthesis generally is calculated by measuring the consumption of carbon dioxide, but this requires expensive equipment and complex procedures. Students are asked to consider variables that might affect the rate of photosynthesis and the floating disk procedure itself. A number of questions emerge about the process that leads to independent student investigations. The investigation also provides an opportunity for students to apply concepts that they have studied previously, including enzymatic activity, cell structure and function (big idea 4), and the evolution of conserved core processes in plants (big idea 1).

Investigation 6: Cellular Respiration is a revision of Laboratory 5 (Cell Respiration) in the 2001 *AP Biology Laboratory Manual* and reflects the shift toward more student-directed and inquiry-based laboratory experiences as students explore factors that might affect the rate of cellular respiration in multicellular organisms. Heterotrophic organisms harvest free energy stored in carbon compounds produced by other organisms. In cellular respiration, free energy becomes available to drive metabolic pathways primarily by the conversion of ADP to ATP. If sufficient oxygen is available, glucose may be oxidized completely, as summarized by the following reaction:

$$C_6H_{12}O_6 + 6O_{2(g)} \rightarrow 6CO_{2(g)} + 6H_2O + \text{energy}$$

To determine the rate of cellular respiration, one could measure the consumption of O_2 during the oxidation of glucose, or the production of CO_2. In this investigation, students assemble microrespirometers or use gas pressure sensors (probe system) to measure the relative volume (changes in pressure) as oxygen is consumed by germinating seeds. Once students learn how to measure the rate of cellular respiration, questions emerge about the process that leads to independent student investigations about factors that might affect the rate. This investigation can be conducted during the study of cellular processes, interactions (big idea 4), and even evolution (big idea 1) if students raise questions about cellular respiration as a conserved core process, or compare different processes such as C_3, C_4, and CAM plants and the environments in which they evolved.