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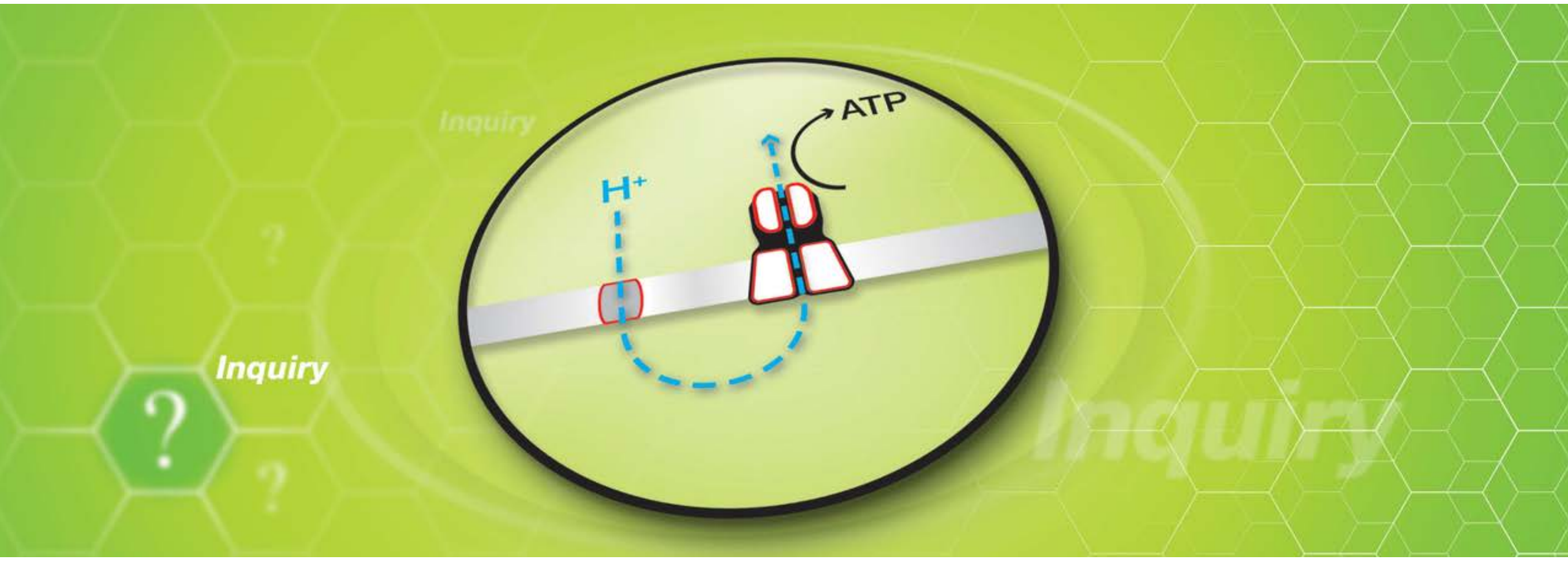


Photosynthesis and Cellular Respiration Kit

A ThINQ!™ Investigation

AP Biology | **Teacher Model Process**

BIO-RAD

Contents

One Teacher's Story of Implementing Inquiry

The following teacher model process provides some grounding for thinking about how inquiry may look in your science classroom as you guide students through the photosynthesis and cellular respiration investigations of this kit. The following discussions and supporting explanations illustrate themes typically observed during inquiry experiences in science and highlight common issues students may encounter as they begin the process of protocol design.

"Inquiry" often conjures a nightmare of turning 40 students with minimal skills loose in a lab with unlimited resources and asking them to design experiments. Although trends in science education have shifted from teacher-led coverage of content to inquiry- based, student-directed activities, most lab investigations at the high school level, including Advanced Placement, require teacher guidance. However, investigations should allow students to ask questions and model the behavior of scientists as they explore answers to those questions and raise new ones. By designing and conducting experiments to test hypotheses, analyzing data, and communicating results, students focus on understanding concepts by merging content with the reasoning skills essential to science. An inquiry-based approach engages students and promotes collaborative learning.

Bio-Rad's Photosynthesis and Cellular Respiration Kit accommodates students with varying levels of mastery and proficiency. As students work through each pre-lab activity and lab investigation, the teacher asks probing questions to assess their understanding of concepts and address misconceptions and technical challenges. This approach fosters student autonomy when students are encouraged to access the Internet to tap available resources (other than the teacher) for information. Obtaining meaningful data is the goal of scientific investigation, but great teachable moments occur when students explore causes of unexpected data and troubleshoot their experimental designs.

Preparation for Inquiry: Content Knowledge

Preparation for inquiry includes priming students with specific content knowledge needed to support their thinking about protocol design in later investigations. The purpose of this step is to provide students with the required background information needed to make informed decisions when determining their research questions and designing experimental steps. Teachers can leverage students' content knowledge as a formative assessment to determine if students understand the science behind the justifications they provide. For example, Ms. Verte prepares students by directing them to generate models of organelles. The following excerpt features discussion of chloroplasts:

Pre-Lab Activity #1: Review of Chloroplast and Mitochondrial Structure

As students filter into the classroom, Ms. Verte assigns them to two teams: Team Chloroplast and Team Mitochondrion. She then splits each team into three groups: Organelle Structure, ATP Synthesis, and Input/Output. She provides each group with several large pieces of paper, construction paper, and colored markers and pencils.

When students are settled in their seats, Ms. Verte turns to the class and says,

"Over the past couple of weeks, we've been exploring photosynthesis and cellular respiration. Scientists believe that, though the two processes evolved independently billions of years ago, today life on Earth depends on both of them. In today's activity, we're going to examine this concept more closely. We're going to do this by looking at the two organelles required for these processes: the chloroplast and the mitochondrion. This is why I've split you into two teams."

She turns to Team Chloroplast.

"Group Organelle Structure — Ben, Marcus, Mary Fran, and Tanya — I'd like you to work together to illustrate the distinctive features of a chloroplast. Start by drawing it on a piece of paper and include all the details you know, and label them, too."

Ms. Verte then turns to Team Mitochondrion.

"Jack, Amelia, Charlotte, and Mike — you do the same for the mitochondrion. We'll compare your drawings when you're done."

Ms. Verte. then says,

"OK, all members of Group ATP Synthesis, your task is to draw and describe how ATP is synthesized in your respective organelles. And Group Input/Output, you will make lists of the chemicals or forms of energy that go into the process your organelles handle — the input — and those that are the result, or output. When you're done, we'll compare the results from Team Chloroplast with those from Team Mitochondrion. Let's get to work!"

As students construct their diagrams, Ms. Verte circulates around the room and visits each group. Ben, Tanya, Marcus, and Mary Fran have drawn a chloroplast and have labeled the outer membrane, the inner membrane, grana, and stroma.

Ms. Verte says.

"What's the name for this membrane?"

"Thy...roid,"

Marcus blurts out.

"It's thylakoid, not thyroid. The thyroid is a gland, here,"

Mary Fran says, pointing at her neck.

"You're right, Mary Fran,"

says Ms. Verte.

"Next semester we'll learn about the endocrine system."

She smiles at Marcus.

"It's easy to confuse these science-y terms."

Ms. Verte taps the thylakoid membranes they have drawn.

"Why do you think the thylakoid membranes are folded?"

There is silence in the group, so Ms. Verte encourages the discussion by saying,

"As you drew the outer membrane, you drew an oval shape, correct?"

The group looks at her and they nod in agreement.

"What happened when you drew the thylakoid membrane?"

"We drew inside the outer and inner membranes,"

says Ben,

"and then we drew these stacked, spirally structures."

Ms. Verte nods and says,

"Overall, which would you say took you longer to draw? In other words, which line is longer — the one you drew for the outer membrane, or the one you drew for the thylakoid membrane?"

"The thylakoid one is a lot longer,"

says Marcus.

"How would the two membranes compare with respect to their surface area, then?"

asks Ms. Verte.

"Oh, that's right! The thylakoid membrane has a bigger surface area,"

answers Marcus.

"That's great, Marcus,"

says Ms. Verte.

"Can you think of why it may have evolved that way?"

"For the electron transport chain and ATP synthesis, so there could be more of it,"

Marcus answers.

In this exchange, Ms. Verte provides students with the opportunity to puzzle through the structure and function of chloroplasts as they consider the role of the thylakoid membrane. Allowing students to assess their prior understandings of science content and revise one another's thinking helps students construct meaning and knowledge that is shared. When facilitated by the teacher, this experience may lead to deeper understanding of complex processes and support more robust communication within teams of students — a necessary component of inquiry based science.

Preparation for Inquiry: Assessing Understanding

These initial discussions are important for students to make their thinking visible in order to determine which ideas should be included in a final model. This process affords teachers with unique opportunities for formative assessment that can also be utilized for content review, revision of thinking, and making connections between ideas that students may not consider to be related. In the following example, Ms. Verte guides students in the review and revision of their work, and supports their capacity to connect photosynthesis, cellular respiration, and ATP synthesis using their models:

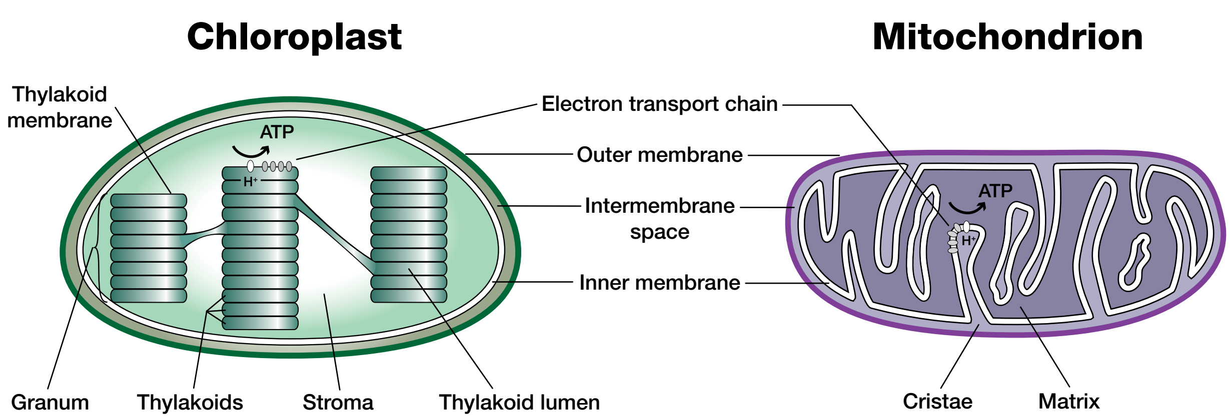
The students finish up their diagrams, and Ms. Verte asks each team to write their findings on the whiteboard, starting with the organelle structure groups. They draw a large chloroplast on the right side of the board and a large mitochondrion on the left. Each group adds details to its respective side of the board.

Ms. Verte then asks,

"I'd like a representative from each group to describe their diagram to the class."

Marcus from Team Chloroplast volunteers to start the discussion.

"Chloroplasts have two envelope membranes: the outer membrane and an inner membrane. They also have a third one called the thylakoid membrane. The thylakoid membrane is folded into these structures, which are called grana. The thylakoid membrane has a large surface area, that's why it's folded up like this. That gives more area for the light reactions to occur. The inside space of the chloroplast is called the stroma, and it's where the carbon dioxide is fixed to glucose."



Matt from Team Mitochondrion then stands up.

"I never realized it before, but that chloroplast description sounds a lot like the mitochondrion. The mitochondrion also has multiple membranes, an inner one and an outer one. The inner one is also longer, but instead of being stacked, it just blebs in like this to form cristae. Just like in the chloroplast, the surface area can be bigger this way, and it's where electron transport and ATP synthesis take place."

"That's cool,"

says Mary Fran.

"Both organelles maximize the amount of membrane space they have for electron transport, but they do it in different ways!"

Ms. Verte nods and smiles. The students are making connections that will help them retain this type of information.

In this example, Ms. Verte's students were able to make connections between photosynthesis and cellular respiration. Ms. Verte knows this connection will be important as students begin thinking about protocol design in later investigations. Seeing their models side by side, and with Ms. Verte's prompting, the students were able to develop a more organized view of the linkages between these processes that will be useful for planning investigations later in the lab.

Conducting Inquiry Investigations: Making Predictions

In many cases the most difficult aspect of inquiry is generating a defined protocol that effectively addresses the research question and works within the constraints of the classroom. Students are likely to struggle with this process at first. One method for supporting students is to ensure they understand the research question being asked, can generate predictions and justify their predictions by drawing on science content knowledge. For example, in the following excerpt Ms. Verte guides her students through this process in order to prepare them for protocol design:

Ms. Verte segues into the Photosynthesis and Cellular Respiration lab investigation by asking,

"Looking at your diagrams, what are two ways you could monitor the rate of photosynthesis? Of cellular respiration?"

Kelly's hand is the first of several to pop up.

"To determine if photosynthesis is happening, you can measure the amount of oxygen produced or the amount of carbon dioxide used up."

"Or you can measure the amount of oxygen used up in cellular respiration or the amount of carbon dioxide produced,"

Ricardo adds.

"Can the rate of photosynthesis affect the rate of cellular respiration?"

Ms. Verte asks, taking the students to a deeper conceptual level.

Some students look puzzled.

"Think about an ecosystem,"

Ms. Verte says.

"What would happen to all critters if plants suddenly disappeared?"

"Wow,"

Eric says.

"Since the animals depend on oxygen produced by the plants, if the rate of photosynthesis decreases significantly, they would all die because cellular respiration would decrease, too."

"I guess we really should clean up oil spills and air pollution,"

Caleb says.

Ms. Verte then introduces the Photosynthesis and Cellular Respiration lab by explaining how they will use algae beads in a CO_2 indicator to examine rates of photosynthesis and cellular respiration.

"Let's talk about carbon dioxide for a minute,"

Ms. Verte says.

"Think back to earlier in the year when we reviewed basic chemistry. What happens when CO_2 is dissolved in water?"

"I know!"

Mary Fran grabs a marker and scribbles an equation on their diagram.

$CO_2 + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$

"When carbon dioxide is produced, does that make the environment more acidic or more basic?"

Ms. Verte asks, prompting the students to make connections between concepts they've studied.

"What happens to the pH?"

"It drops,"

Alex says.

"The environment becomes more acidic."

"Let's make a prediction,"

Ms. Verte says.

"If you incubate the algae beads in the dark for an hour, would you expect the color of the CO_2 indicator to change?"

"No,"

Corey answers.

"I need a bit more than that,"

Ms. Verte says.

"Why? A prediction has to include the reasoning behind it."

"If you keep the beads in the dark,"

Corey explains,

"photosynthesis slows down, so the cell won't use as much CO_2."

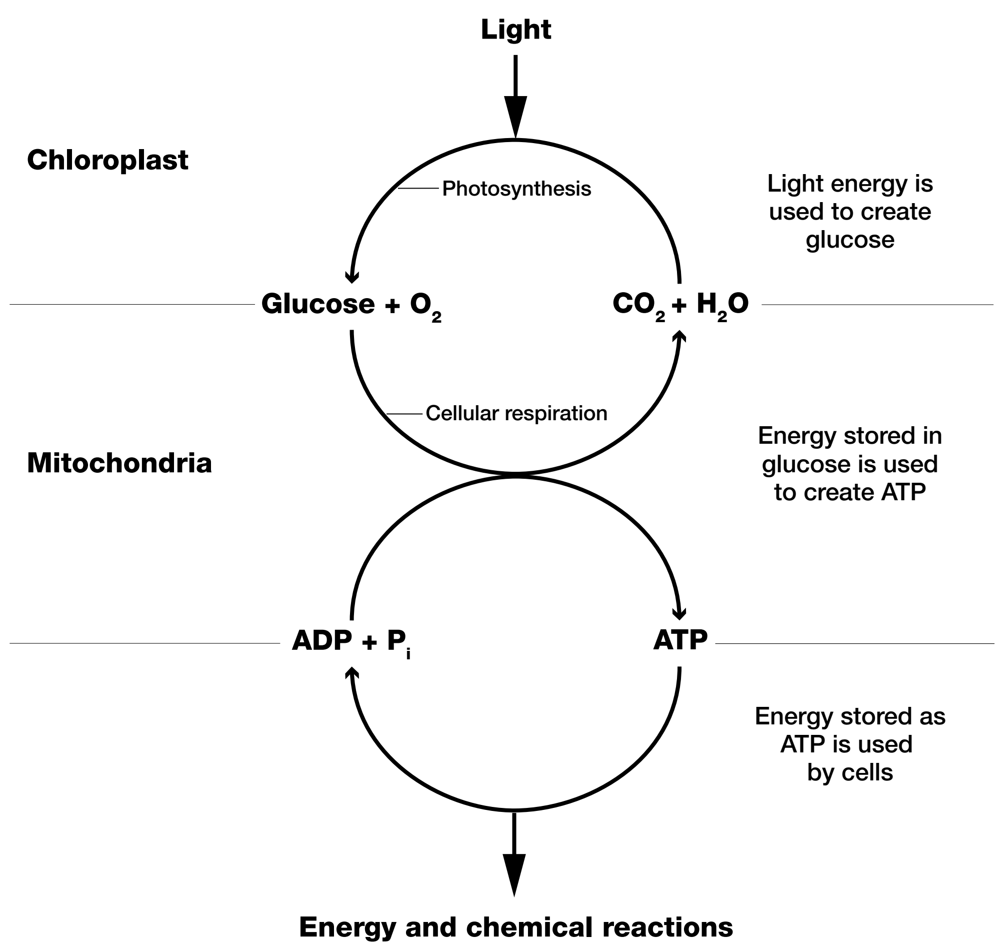
"Show us the equation,"

Ms. Verte says.

Corey strides up to the whiteboard and scribbles an equation on it.

$CO_2 + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$

"See? Photosynthesis isn't happening in the dark so CO_2 levels don't change and neither does the amount of H^+."



"Even if the algae beads are in the dark, aren't they still respiring?"

Ricardo asks.

"Then they still produce CO_2, so more hydrogen ions will be produced in the solution. This will cause the pH to go down and the solution becomes more acidic."

Ms. Verte smiles.

"Great predictions. Can you test them?"

"I guess we'll see tomorrow,"

Lupita says as the bell rings.

In this example, Ms. Verte's students were able to make connections between photosynthesis and cellular respiration. Ms. Verte knows this connection will be important as students begin thinking about protocol design in later investigations. Seeing their models side by side, and with Ms. Verte's prompting, the students were able to develop a more organized view of the linkages between these processes that will be useful for planning investigations later in the lab.

Conducting Inquiry Investigations: Common Issues with Protocol Design

It is likely that your students will encounter challenges as they consider how to construct a sound protocol that tests their predictions. As described in the Initiating Inquiry Investigations document in the teacher manual, one common issue that students may encounter is naming too many variables to test in the course of one investigation. For example, in the following excerpt Ms. Verte guides a group of students as they reflect on their protocol designs:

Investigations #3–6: The Effect of Environmental Variables on the Rates of Photosynthesis and Cellular Respiration (Student-Directed, Inquiry-Based, Teacher-Facilitated)

Ms. Verte greets her class and asks them to put a list of variables that might affect the rates of photosynthesis and cellular respiration on the whiteboard.

"Today I'd like each group to agree on a variable to test. Please list your group's top three choices, so we can be sure the whole class doesn't investigate the same one."

After several minutes, Ms. Verte notices the level of discussion is winding down, so she redirects the class's attention by saying,

"OK, Group 3, which variable do you want to investigate?"

"Algae bead number,"

Esteban says, speaking for the group.

"We'll add five algae beads to one cuvette and 20 to another, and then incubate both cuvettes in the light."

"Any predictions?"

Ms. Verte asks.

"Each bead contains the same number of algae that are photosynthesizing,"

Tanya says.

"Increasing the number of beads might increase the rate of photosynthesis"

"I guess you'll see,"

Ms. Verte says.

"Group 4, which variable do you want to investigate?"

"We'd like to check out temperature and light color,"

Kristin says for the group.

"At the same time?"

Esteban from Group 3 asks.

"Yes,"

Diego says.

"Lowering the temperature should decrease the rates of photosynthesis and respiration, and incubating the algae beads under green light should also slow down photosynthesis."

"Can you explain this a little further?"

Ms. Verte asks.

"What's the reasoning behind your predictions?"

"Plants are green because they reflect green light and absorb energy from other wavelengths, like blue and red, in photosynthesis. If the algae beads are exposed to green light only, photosynthesis shuts down. No photosynthesis, no fixing CO_2 into sugar,"

Diego says.

"And what about temperature?"

Ms. Verte asks.

"Chemical reactions slow down at lower temps because the molecules can't interact as fast,"

Diego says.

"Not to be rude, but you may have
a problem with your experimental design,"
Esteban says.

Diego bristles.
"How so? The chemistry's right."

"Esteban's right,"
Kristin says.
"If our hypothesis is correct and the rates slow, how are we going to know if it's because of the light or the temperature? We've introduced two variables at the same time. We need to investigate each one separately."

"Nice correction. That's a much better experiment,"
Ms. Verte says.
"Let's get started."

Students may consider the inclusion of two variables as interesting and efficient, however it is important that students also understand that testing one variable at a time will provide clearer results than testing two variables that may converge. Ms. Verte's prompting allowed her students to reflect on their protocol and identify where improvements can be made. Instead of telling students how to fix their protocol, Ms. Verte asked open ended questions that provoked reflection. You may find asking open ended questions in these instances useful for helping your students identify issues within their own protocol. Appropriate differentiation and support may be needed depending on students' level of understanding and preparation.

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