TEACHER GUIDE
EXPLAIN 1 LESSON 20

Food and Agriculture Center for Science Education

Module Questions: ***Why are there so many changes to my body during exercise? How does milk help with recovery from these changes?***

What We Figure Out:

We figure out that increased heart rate, breathing rate, and muscle fatigue during exercise all have to do with how the body produces cellular energy to be used by muscle cells during exercise. Starting high-intensity exercise triggers anaerobic cellular respiration that uses the glucose molecules to produce 2 ATP molecules to be used by muscle cells for movement. Heart rate and breathing rate increase when the brain detects the stress of exercise and sends a signal to the adrenal glands to release epinephrine. This hormone increases the heart and breathing rates in order to begin to increase the exchange of oxygen and carbon dioxide in the lungs and bloodstream. It also stimulates the breakdown of stored glycogen in the muscles and liver to produce glucose, which can be used in anaerobic respiration (and later aerobic respiration).

As exercise continues, more oxygen is needed by the muscle cells so that they can undergo aerobic respiration, which produces 38 ATP molecules to be used by muscle cells for movement. Carbon dioxide is produced as a result of both aerobic and anaerobic respiration, which can be removed from the bloodstream by an increased heart rate to pump more blood through the body and an increased breathing rate to facilitate more exhalation of carbon dioxide.

The burning sensation and fatigue come from the buildup of lactate and H^+ accumulating in the muscles as a result of anaerobic respiration. There are pain receptors in muscle cells that sense the drop in pH, tell the brain, and the brain sends back a pain signal to those muscles to encourage them to slow down so that the lactate and H+ can be removed from the muscles.

3D Learning Objective:	**Time estimate:**	**Materials:**
Students revise an explanation using multiple pieces of evidence to show how increased rates of aerobic and anaerobic respiration provide energy for muscles during exercise, resulting in changes in the body during exercise.	50 minutes	Lesson 20 Student Guide

Targeted Elements

SEP:	DCI:	CCC:
CEDS-H2: **Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.**	**LS1.A-H1:** **Systems of specialized cells within organisms help them perform the essential functions of life.** **LS2.B-H1:** Photosynthesis and **cellular respiration (including anaerobic processes) provide most of the energy for life processes.**	**SC-H1:** **Much of science deals with constructing explanations of how things change and how they remain stable.**

Directions

Part 1: Our Motivation

USE OF PHENOMENA
Between Lessons 16-20, students will focus on the topic of exercise from the Module Phenomenon. In Lessons 21-22, they will focus on the topic of recovery from the Module Phenomenon. In Lesson 23, they will investigate a related phenomenon. They will return to the Anchor Phenomenon in Lesson 24 and revise their presentations to help their peers understand how milk can help them recover from exercise.

Have students revisit the Class Consensus Explanation developed in Lesson 15 Part 5: Constructing Explanations. This explanation describes how students answered the Module Questions, *Why are there so many changes to my body during exercise? How does milk help with*

recovery from these changes? This individual review is to see what gaps exist in the explanation from what they have learned so far in the module.
Ask students if these explanations accurately reflect the new evidence they have about the changes in heart rate, breathing rate, muscle burn, and fatigue experienced when exercising in Lesson 15.

- We didn't explain how heart and breathing rates are linked by the muscles needing to get oxygen from the bloodstream.
- We didn't explain how heart rate and breathing rate increase in intense exercise because the muscles need more oxygen and glucose.
- We didn't explain how milk helps us recover after exercise.

Next, point to the questions on the Driving Question Board related to milk and recovery from exercise. Share a few selected questions that align with what students will investigate in the upcoming lesson. Example student questions or ideas could include:

- What happens in the body to make the breathing rate increase?
- Why does our heart rate increase during exercise?
- How do we get energy during exercise?
- Does muscle burn and fatigue have something to do with running out of energy?

Students can record these questions and ideas on their Lesson 20 Student Guide Part 1: Our Motivation. This will help students understand how this lesson connects to what they were trying to figure out about the Module Phenomenon. Use students' questions to transition to the lesson by sharing that, in this lesson, we will update our initial explanations of the Module Questions, *Why are there so many changes to my body during exercise? How does milk help with recovery from these changes?*

Part 2: Developing an Explanation of Heart Rate and Breathing Rate Changes During Exercise

As a brainstorming activity prior to constructing explanations, present and display the summary of trends in changes in various factors from Lesson 18 Part 3: Sharing Our Findings for the class. Ask students to describe what mechanisms occur to result in the increases or decreases that occur in each of the different measurements from the data sets.

Use a Think-Pair-Share Strategy to have students share their ideas. Student responses may vary.

1. Students are given time to think independently about their responses.
2. Students find an elbow partner.
3. Students take turns sharing their thoughts with their partner. Each student should be given time to respond.

Remind students that they can use their resources from Lesson 18 and 19 to help them as they share their ideas. There is no need to come to a specific consensus at the moment. Students can use what the class brainstorms here to help write their explanations below.

Share with students that they will now revise their initial explanation to update their answer to the Module Questions, *Why are there so many changes to my body during exercise? How does milk help with recovery from these changes?* As students work on their Lesson 20 Student Guide Part 2: Developing an Explanation of Heart Rate and Breathing Rate Changes During Exercise, circulate the room to informally assess their explanations and provide feedback by asking questions about their work.

FORMATIVE ASSESSMENT OPPORTUNITY

Students revise an explanation using multiple pieces of evidence to show how increased rates of aerobic and anaerobic respiration provide energy for muscles during exercise, resulting in changes in the body during exercise.

Assessment Artifacts:

- Students' explanations of Heart Rate and Breathing Rate Changes During Exercise (Lesson 20 Student Guide Part 2: Developing an Explanation of Heart Rate and Breathing Rate Changes During Exercise).

Look Fors:

- Students revise their explanations based on the new evidence they have gathered about mechanisms that increase breathing rate, heart rate, and muscle burn/fatigue and the mechanisms that produce cellular energy via anaerobic and aerobic respiration during intense exercise (CEDS-H2, LS1.B-H1, SC-H1).
- Students use evidence from a variety of sources, including data sets and the Science Theater model (CEDS-H2).
- Explanations include how specialized cells play a role in increases in heart rate, breathing rate, fatigue, and generating cellular energy (LS1.A-H1).

Assessment Rubric:

	Emerging	**Developing**	**Proficient**
Sample Student Response	During exercise, breathing rate and heart rate increase because the body is working harder and needs to get more oxygen to the	As a workout starts, your muscles use glucose present in anaerobic respiration to generate 2 molecules of lactate and 2 molecules of ATP, as well as some byproducts. Muscles use ATP as a source of energy to contract, which is	As a workout starts, your myocytes in muscles use glucose present in anaerobic respiration to generate 2 molecules of lactate and 2 molecules of ATP, as well as some byproducts. Muscle cells use ATP as a source of energy to contract, which is how they move rapidly during exercise. We saw evidence of this by observing that

	muscle cells. The muscle cells use oxygen to make energy and they can make less energy without oxygen too. Your muscles start burning because they accumulate pH changes. This makes the nerves feel pain, which makes the muscles burn.	how they move rapidly during exercise. By the second half of my sprint, I felt out of breath and was breathing faster. My breathing rate increased as a result of epinephrine from the adrenal glands. Epinephrine was released as a response of the brain interpreting a fight-or-flight type situation when intense exercise was started. Epinephrine opens up air passages and increases the breathing rate so the body can exchange more carbon dioxide and oxygen. The body needs to exhale the carbon dioxide produced as a result of anaerobic respiration. At the same time, epinephrine also caused my heart rate to increase and my liver and muscles to break down glycogen into glucose. Now that oxygen is available, anaerobic respiration is used less. Instead, glucose and oxygen are transported through the bloodstream to muscles, where they can undergo aerobic respiration, which uses oxygen and glucose to produce 38 ATP. This process also produces carbon dioxide as waste, which is transported through the bloodstream and exhaled due to the increased breathing and heart rates. Aerobic cellular respiration continues as long as there is enough glucose and oxygen to be used. The reason my muscles started burning during intense exercise was due to decreasing pH in the muscles. When the skeletal muscle is using anaerobic cellular respiration as a primary energy source in the earlier stages of an intense workout, H+ ions are an	the levels of lactate in the blood go from 0-1 mmol/L before exercise to over 10 mmol/L during exercise (Parker L et al. 2017). By the second half of my sprint, I felt out of breath and was breathing faster. My breathing rate increased as a result of epinephrine from the Chromaffin cells of the adrenal glands. Epinephrine was released as a response of the brain interpreting a fight-or-flight type situation when intense exercise was started. Epinephrine increases breathing rate so the body can exchange more carbon dioxide and oxygen across the alveoli epithelial cells. The body needs to exhale the carbon dioxide produced as a result of anaerobic respiration. At the same time, epinephrine also caused my heart rate to increase and my liver and muscle cells to break down glycogen into glucose. We saw in the Gollnick PD, Piehl K, Saltin B 1974 study that muscle glycogen levels go from over 80 mmol/kg to under 20 mmol/kg in high-intensity exercise. And we saw that glucose was released from the liver at over 4 mmol/min in high-intensity exercise, compared to less than 1 mmol/min at rest (Wahren J, Felig P, Ahlborg G, Jorfeldt L., 1971). Now that oxygen is available, anaerobic respiration is used less. Instead, glucose and oxygen are transported through the bloodstream to muscle cells, where they can undergo aerobic respiration, which uses oxygen and glucose to produce 38 ATP. This process also produces carbon dioxide as waste, which is transported through the bloodstream via red blood cells, through the alveoli epithelial cells, and exhaled due to the increased breathing and heart rates. Aerobic cellular respiration continues as long as there is enough glucose and oxygen to be used. The reason my muscles started burning during intense exercise was due to decreasing pH in the myocytes. We saw that during intense exercise, we saw muscle pH decrease by between 0.3-0.4 compared to at rest (Street D, Bangsbo J, Juel C. 2001). When the skeletal muscle is using anaerobic cellular respiration as a primary energy source in the earlier stages of an intense workout, H+ ions

		output/byproduct of that process. H+ ions lower the pH of the skeletal muscles. This is detected by nerves that send an electrical signal to alert the brain that pH is dropping from its normal range. The Brain and Somatic Nervous System respond by sending a signal to the skeletal muscle, triggering a pain/burning sensation. This is an effort by the brain to get you to slow down so pH can return to its normal levels.	are an output/byproduct of that process. H+ ions lower the pH of the skeletal muscles. This is detected by receptors in the muscles and they send an electrical signal to alert the brain that pH is dropping from its normal range. The Brain and Somatic Nervous System respond by sending a signal via the motor neurons to the skeletal muscle myocytes, triggering a pain/burning sensation. This is an effort by the brain to get you to slow down so pH can return to its normal levels.
How to Achieve This Level	Student completes 0 out of 3 Look Fors	Student completes 1-2 out of 3 Look Fors	Student completes 3 of 3 Look Fors

To Provide Additional Support for Students

As students work in groups, approach each group to look at their work. If students need additional support in developing their explanations, consider:

- Asking the following questions:
  - What evidence from the previous lessons did you find to add to your explanation?
  - What new ideas did you add to your explanation? What are you trying to describe?
  - What changes occur in the body during exercise to make the heart rate and breathing rate increase? To create fatigue and muscle burning? Why do these changes occur?
  - What is the function of specialized cells at (this step) in why heart rate and breathing rate are increasing? In muscle fatigue and burning?
  - How are the muscles getting energy for exercise? Where is it coming from? Providing students with time to organize the evidence they found, come up with a list of evidence as a class, and discuss which pieces of evidence are most relevant to the explanation.
- Engage students in a peer feedback session. Provide students with the Look Fors, and use a protocol such as Tell-Ask-Give or norms such as SPARK. Students can use the Look Fors to provide feedback to each other on how they can improve selected Look Fors in their work.

Part 3: Updating the Effects of Exercise Model

Ask students to reorient to the Driving Question for the unit, ***How can milk help athletes recover from physical exercise?*** Share with students that because they focused on the effects of exercise on the body in Lessons 18 and 19, they will now update the Class Consensus Effects of Exercise Model from Lesson 12. Share with students that they can take the explanations they wrote on their Lesson 20 Student Guide Part 2: Developing an Explanation of Heart Rate and Breathing Rate Changes During Exercise to help inform how to build these models.

TEACHER SUPPORT
Here, students should be adding onto the Class Consensus Models from Lesson 12 Part 3: Updating the Effects of Exercise and Recovery Models, which should be displayed as large murals on a class wall or saved digitally for projection for the entire class.

Hold a whole-class discussion in which the class adds to the existing Class Consensus Effects of Exercise and Recovery Models. Students can write their initial ideas for additions on their Lesson 20 Student Guide Part 3: Updating the Effects of Exercise and Recovery Models. Walk students through the class consensus discussion steps below so they can update the Class Consensus Effects of Exercise Models.

1. Each group should select one or more reporters to share one part of their explanations to add to the models. Have the first group share one idea to add to the consensus models. This can be one component, arrow, relationship, or any other feature the group wants to select.
2. The next reporters can agree with, disagree with, or revise parts of the model that have already been added or can add new parts. Continue this process until the full Class Consensus Effects of Exercise Model is updated.
3. As students share, some strategies you can use to help the class build the consensus model are:
    a. Helpful sentence starters such as:
        i. We agree with _____'s group, and we also want to add _____.
        ii. We disagree with _____'s group because _____
        iii. We would like to change _____ because (evidence).
    b. Use discussion prompts such as asking the class:
        i. Is there anything else that needs to be added to this component before we move on?
        ii. How does this idea fit with what is on the model currently?
        iii. What new body systems are we introducing? Which organs are included in these systems? What specialized cells are a part of this organ, and what are their functions?

iv. How are we showing the movement of matter in this model? The movement of energy? How are milk nutrients shown in this model?

As you are building the class model, if you find disagreements, follow these steps to help resolve the disagreement:

1. Summarize the two sides of the disagreement.
2. Ask the students to pause and reflect on their reasoning to be on that side.
3. Prompt students to again re-discuss the area of disagreement.
4. If students still disagree, suggest that we can represent areas of disagreement on the class model with question marks or other annotations of uncertainty.

CCSS SUPPORT

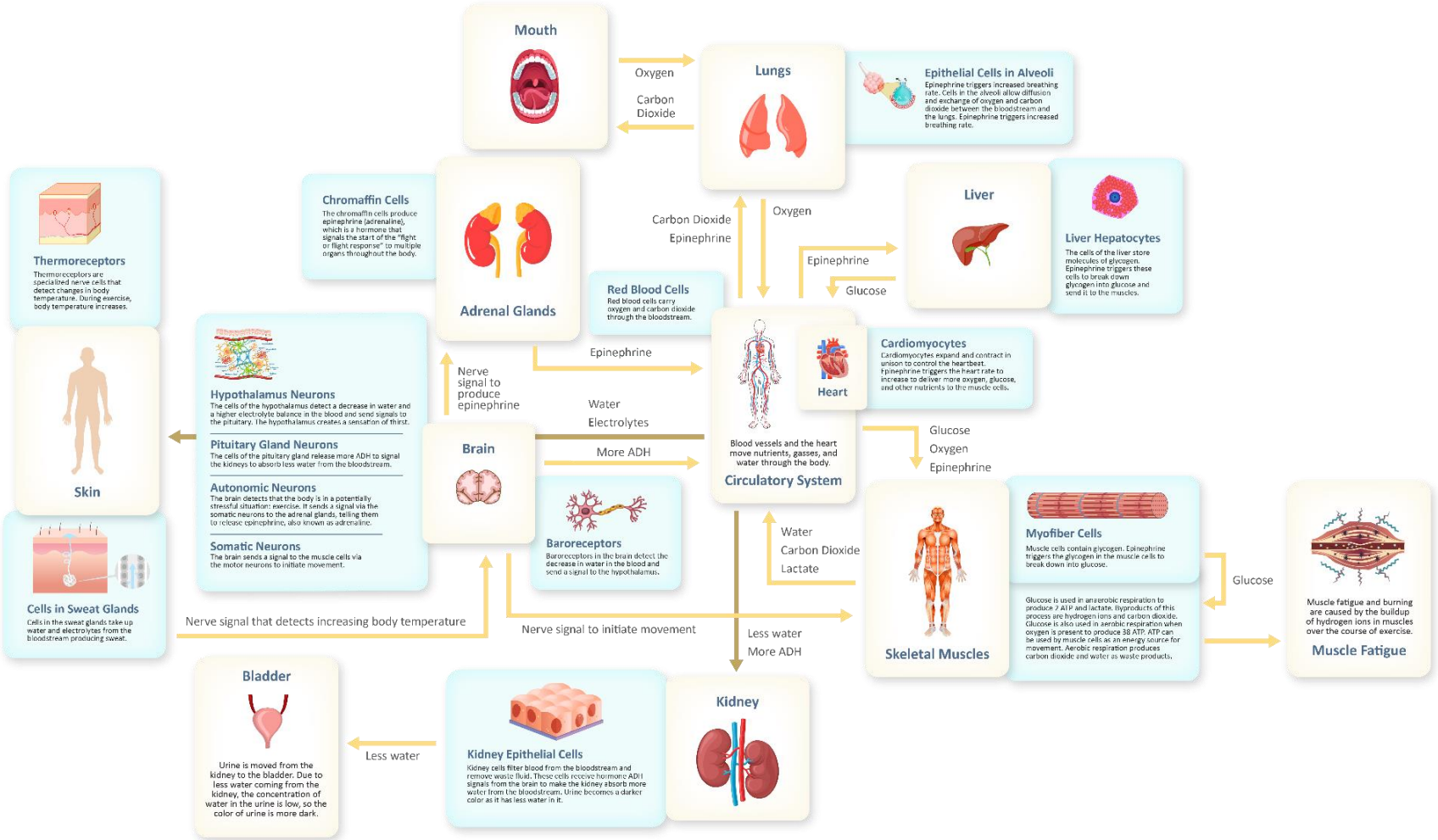
SL 9-10.1(d): Respond thoughtfully to diverse perspectives, summarize points of agreement and disagreement, and, when warranted, qualify or justify their own views and understanding and make new connections in light of the evidence and reasoning presented.

Because student explanations may differ, it is important to emphasize that the revisions to the model are being made based on evidence. You may want to ask students to discuss the difference between evidence vs. opinion when discussing what components to include in the Class Consensus Models.

The following page shows an example of what a Class Consensus Effects of Exercise Model may look like, though you will want to follow the ideas of your class rather than drive them to this exact model.

Example Class Consensus Model

Effects of Exercise Model


Mouth
Oxygen
Carbon Dioxide
Lungs
Epithelial Cells in Alveoli
Epinephrine triggers increased breathing rate. Cells in the alveoli allow diffusion and exchange of oxygen and carbon dioxide between the bloodstream and the lungs. Epinephrine triggers increased breathing rate.
Thermoreceptors
Thermoreceptors are specialized nerve cells that detect changes in body temperature. During exercise, body temperature increases.
Chromaffin Cells
The chromaffin cells produce epinephrine (adrenaline), which is a hormone that signals the start of the "fight or flight response" to multiple organs throughout the body.
Adrenal Glands
Carbon Dioxide
Epinephrine
Oxygen
Liver
Liver Hepatocytes
The cells of the liver store molecules of glycogen. Epinephrine triggers these cells to break down glycogen into glucose and send it to the muscles.
Epinephrine
Glucose
Red Blood Cells
Red blood cells carry oxygen and carbon dioxide through the bloodstream.
Epinephrine
Nerve signal to produce epinephrine
Heart
Cardiomyocytes
Cardiomyocytes expand and contract in unison to control the heartbeat. Epinephrine triggers the heart rate to increase to deliver more oxygen, glucose, and other nutrients to the muscle cells.
Skin
Hypothalamus Neurons
The cells of the hypothalamus detect a decrease in water and a higher electrolyte balance in the blood and send signals to the pituitary. The hypothalamus creates a sensation of thirst.
Pituitary Gland Neurons
The cells of the pituitary gland release more ADH to signal the kidneys to absorb less water from the bloodstream.
Autonomic Neurons
The brain detects that the body is in a potentially stressful situation: exercise. It sends a signal via the somatic neurons to the adrenal glands, telling them to release epinephrine, also known as adrenaline.
Somatic Neurons
The brain sends a signal to the muscle cells via the motor neurons to initiate movement.
Brain
Water
Electrolytes
More ADH
Blood vessels and the heart move nutrients, gasses, and water through the body.
Circulatory System
Glucose
Oxygen
Epinephrine
Baroreceptors
Baroreceptors in the brain detect the decrease in water in the blood and send a signal to the hypothalamus.
Water
Carbon Dioxide
Lactate
Cells in Sweat Glands
Cells in the sweat glands take up water and electrolytes from the bloodstream producing sweat.
Nerve signal that detects increasing body temperature
Nerve signal to initiate movement
Less water
More ADH
Skeletal Muscles
Myofiber Cells
Muscle cells contain glycogen. Epinephrine triggers the glycogen in the muscle cells to break down into glucose.
Glucose is used in anaerobic respiration to produce 2 ATP and lactate. Byproducts of this process are hydrogen ions and carbon dioxide. Glucose is also used in aerobic respiration when oxygen is present to produce 38 ATP. ATP can be used by muscle cells as an energy source for movement. Aerobic respiration produces carbon dioxide and water as waste products.
Glucose
Muscle Fatigue
Muscle fatigue and burning are caused by the buildup of hydrogen ions in muscles over the course of exercise.
Bladder
Urine is moved from the kidney to the bladder. Due to less water coming from the kidney, the concentration of water in the urine is low, so the color of urine is more dark.
Less water
Kidney Epithelial Cells
Kidney cells filter blood from the bloodstream and remove waste fluid. These cells receive hormone ADH signals from the brain to make the kidney absorb more water from the bloodstream. Urine becomes a darker color as it has less water in it.
Kidney

Remind students that this model, and the Recovery model, will be a continuous record of changes that happen in the body in response to exercise and how milk helps the body recover from these changes. Share with students that we will continue making progress on our Module Questions first and later the Driving Question for the unit, which will help us continue adding to these models. If students need a personal record of the model in addition to the class model, you can provide students with a digital image of the model or have them take an image with their personal device, if available.

After updating the class Effects of Exercise Model, ask students to use the model to make a prediction about how they think milk helps the body recover from the effects of exercise they figured out in this module. Use a Think-Pair-Share to have students brainstorm and share their ideas. Student responses may vary.

1. Students are given time to think independently about their responses.
2. Students find an elbow partner.
3. Students take turns sharing their thoughts with their partner. Each student should be given time to respond.

Hold a whole-class discussion for students to share their predictions and record student predictions on the front board. Facilitate the conversation to agree on the following themes in student predictions:

- Our body uses milk to replenish the glucose it used to generate energy during intense exercise.
- Our body uses the protein in it to help recovery in some way.
- Glucose molecules from glycogen are used in aerobic and anaerobic respiration during intense exercise, and digested milk has glucose molecules that could replace them.

TEACHER SUPPORT

Throughout this discussion, it is possible that students may focus on the impact of proteins on recovery instead of glucose or the combination of glucose and proteins. If this is the case, ask students to return to their explanations from Lesson 20 and look for mentions of molecules in milk they are familiar with. This should prompt them to focus on glucose and glycogen. Share with students that they can place their ideas and/or questions about how protein helps in recovery on the Driving Question Board, and those questions will be investigated in Module 4.

Build off student responses to share that in the next lesson, students will investigate how consuming milk as a recovery drink after intense exercise contributes to improved performance in a second workout.

Part 4: Asking New Questions

As a final step in this lesson, students will create a new list of questions that can help them determine what additional information they need to know to help them figure out more about the Module Questions, *Why are there so many changes to my body during exercise? How does milk help with recovery from these changes?* They can write these questions on their Lesson 20 Student Guide Part 4: Asking New Questions. Add these questions to the "Exercise, Milk, and Energy" category of the Driving Question Board so they can continue to be referenced in the coming lessons.

To facilitate students asking questions, use the Question Formulation Technique.

1. With their group, students take 5 minutes to brainstorm questions about what they need to know about the changes to the body during exercise and how milk helps with recovery from these changes.
2. Students then look at all their questions and choose the 3-5 questions they think are most important to be answered to help them figure out the Module Questions.
3. A representative from each group will then share their prioritized questions with the whole class. As students share their prioritized questions, they will add them to the Driving Question Board.

LOOK FOR

In student responses, listen for the following ideas:

- Is it possible to run out of glucose for cellular respiration?
- Does drinking milk after a workout increase performance for a second workout because of the glucose or proteins it has in it?
- Does milk work well as a recovery drink because it refills the glucose, electrolytes, and water that we use during exercise?
- Is the reason milk helps us recover to perform another workout because it has sugars that are broken down to glucose, and it has water in it to replace the water we lose to sweat?
- Can the body run out of glucose eventually?