Marathon Runner - Teacher Materials

Unit 1	Biology

The Curriculum and Instruction Department at New Visions for Public Schools develops free, full-course materials for all areas of high school science, math, ELA, and social studies, for use across our network of 80 New York City schools and beyond.

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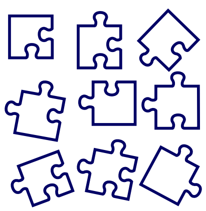
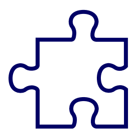
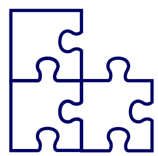
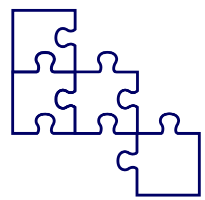
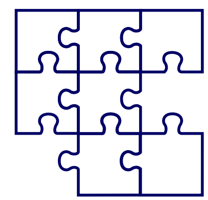
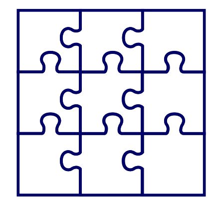
Homeostasis

Performance Expectations
HS-LS1-2, HS-LS1-3, HS-LS1-7

Time
23-38 days

How does the human body maintain dynamic equilibrium and respond to internal and external changes in its environment?

Humans are complex organisms that maintain a narrow set of stable internal conditions through a system of feedback and communication mechanisms among multiple organ systems. In this unit, students are presented with the story of a woman who collapsed after successfully completing a marathon. In order to figure out what happened to her, they plan and conduct investigations related to how body systems interact to effectively monitor and respond to both internal and external environmental changes. Students develop and use models to illustrate processes that occur in the human body in order to maintain homeostasis, including gas exchange, glucose regulation, thermoregulation, and maintaining water balance. They use their final model to write an explanation for what happened to the marathon runner.

Unit Opening	Gas Exchange and Cellular Respiration 5E	Muscles & Energy 5E	Human Thermoregulation 5E	Water Balance 5E	Unit Closing
Anchor Phenomenon →		**5E Lessons connect learning to the performance task** →			**Performance Task**
					
Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	*Did the marathon runner run out of breath or not get enough oxygen? Why do we breathe faster when we exercise?*	*Did the marathon runner's muscles get tired? How do our bodies use energy during exercise?*	*Was the marathon runner overheated? How do our bodies deal with changes in temperature?*	*Was the marathon runner dehydrated? How do our bodies maintain water balance?*	*Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?*

Unit Introduction

> My students loved the Marathon Runner unit. And I loved watching my students as they dove into the discomfort of becoming scientists and figuring out what happened for themselves. This unit will give you everything you need to make the shift towards NGSS teaching - whether it's your first year teaching or you've been in the classroom for 20 years.
>
> - Michelle Ott, HS teacher in Brooklyn

How do we make science education meaningful and relevant to our students? High school biology courses are traditionally filled with lectures and cookbook labs, memorizing vocabulary, and an occasional research report. New science education standards (NGSS/NYSSLS) require a more engaging, accessible vision of science teaching and learning to help *all* students learn about the natural world and become scientifically literate citizens.

Rather than beginning our biology curriculum with the scientific method or characteristics of life, we begin with a real-world story, in which students have the opportunity to figure out a puzzling phenomenon through a series of investigations and scientific modeling. The story of a marathon runner collapsing after the race is immediately engaging to students; further, all students have had experience viewing, talking about or participating in sports that require extreme exercise. From day one, students are scientists, and over time they determine how the systems of the human body interact in order to sustain life.

The three-dimensional, phenomenon-driven materials in this unit support students in engaging in the authentic practices of science. Students construct meaning about the natural world through modeling, investigations, labs and experiments. As students have opportunities to manipulate the physical tools of science, they also engage in productive struggle that can be resolved through creating models from evidence and engaging in consensus building discussions. The materials support teachers in becoming skillful facilitators of student sense-making and deepen teachers' understanding of how to teach science in an interactive way that is driven by students' questions and ideas.

This unit was intentionally designed to begin this year-long course. Establishing a classroom culture of learning science by doing science, rather than learning *about* science is essential, and teachers should establish this culture at the start of the school year. The embedded group learning routines and formative assessments support teachers in learning about their students, both academically and personally. Whether students had strong science programs entering high school, or if three-dimensional teaching and learning is brand new to them (or to the teacher!) this unit was purposefully designed as a way to introduce students to this way of learning and doing science in school.

Unit Coherence

In Unit 1, the overall question about what happened to the marathon runner is intended to motivate student engagement across the unit. It is our intention that from the students' perspective, there is a clear and explicit unit storyline that guides the sequence of activities. Rather than one long continuous unit, we have chosen to use an instructional model to develop four coherent sequences of lessons within Unit 1. Each sequence builds towards figuring out something that contributes to explaining the overall unit-level question about our marathon runner. The phenomena, the instructional model, and the routines embedded throughout the sequences of lessons are all used in service of coherence across Unit 1.

> Introducing a challenging-yet-motivating phenomenon makes my kids want to reach the higher bar I have set. They're more engaged to dive deeper into what is going on and to push themselves to learn more. Consistently using instructional routines and tools like Rumors, Driving Question Boards, and Domino Discover have helped my students write tons of questions and have heated scientific discussions. Furthermore, knowing that the phenomenon is tough or possibly unsolvable makes students more comfortable being wrong.
>
> - Brittany Beck, HS teacher in Brooklyn

Phenomenon-Driven Instruction

Phenomena are a key part of instruction in A Framework for K-12 Science Education and the NGSS. As in the work of scientists, students should be encouraged to move from observable phenomena to generalizable explanations of the natural world. Too often, traditional science instruction has started with generalizable principles, sidelining the lived experience and intuitions that all young people bring to school. In this unit (and all New Visions units) there are two kinds of phenomena: anchor phenomena and investigative phenomena.

Anchor Phenomenon	**Investigative Phenomena**
• One per unit; drives the learning of the unit • Attention-grabbing and relevant • Does not have to be phenomenal	• One per 5E sequence (three in this unit) • Presented in the Engage phase of each 5E

Anchor Phenomenon

To support coherence, students are prompted to figure out one overarching, real-world question over the course of the unit. The anchor phenomenon question is revisited across the unit, and this question motivates the investigations conducted in each of the 5E instructional sequences. A good anchor phenomenon should be attention-grabbing and relevant to students but also thought-provoking, comprehensible, and connected to the science learning goals. It needs to be observable to students through firsthand experiences or through someone else’s experiences, such as through a video or secondary data. If a teacher feels the anchor phenomenon for Unit 1 related to the marathon runner will not be familiar or accessible to all students, we suggest relating it to more familiar forms of extreme exercise. It is important to notice that the phenomenon question anchoring the unit, Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race? is different from the more generalized and abstracted science question for the unit, How does the human body maintain dynamic equilibrium and respond to internal and external changes in its environment? This difference is part of what helps make the unit more student-centered, rather than teacher-centered.

Investigative Phenomena

Based on the Unit 1 Anchor Phenomenon and three-dimensional learning goals for students for the unit, each 5E instructional sequence has a related investigative phenomenon, typically presented in the Engage phase. This phenomenon brings students together around a shared puzzle or experience that frames the learning for that 5E sequence. Similar to the anchor phenomenon question, the questions about the investigative phenomena are intended to be specific and contextualized, rather than the traditional content questions teachers use as their lesson aims. They present what is being figured out; therefore, the scientific concepts that are in the learning goal cannot be part of the wording of the question!

Storyline and Pacing Guide

Unit Opening	Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	**Performance Expectations**	**Anchor Phenomenon** Marathon Runner Collapse: Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	**Time** 2-3 days

Student Questions	What Students Do	Student Ideas
These questions motivate the unit storyline. • Is it possible that the marathon runner ran out of breath or didn't get enough oxygen? • Did the marathon runner's muscles get tired? • Could being overheated have caused the marathon • runner to collapse? • Was the marathon runner dehydrated?	Students read text and data tables in order to tell the story of a marathon runner who successfully completed a race and then collapsed. Through looking at the data and developing an initial model for how the human body works, they try to come up with ideas for what might have happened to her, and discuss what we might do as scientists to figure this out.	*These ideas are revisited throughout the unit storyline.* • We breathe faster and our heart beats faster when we run a marathon. • Our muscles get tired and sore when we exercise. • We get hot and sweat a lot in order to cool off when we run. • We get our energy from food (people eat energy bars before/during a race). • People drink a lot of water or gatorade during marathons. • Sometimes people get injured or get sick when they exercise too much.

After students develop their initial models, and create a driving question board, one question category should relate to questions about gas exchange (for example, questions about Did the marathon runner run out of oxygen?). Tell students that in the next sequence of lessons, they will investigate how breathing works.

Gas Exchange and Cellular Respiration 5E

Did the marathon runner run out of breath or not get enough oxygen? Why do we breathe faster when we exercise?

Performance Expectations
HS-LS1-2, HS-LS1-3, HS-LS1-7

Investigative Phenomenon
Humans breathe faster when exercising.

Time
6-8 days

Student Questions

These questions motivate this 5E sequence and the unit storyline.

- Did the marathon runner not obtain enough oxygen? Was her body not able to properly regulate oxygen or carbon dioxide levels?
- Why does our heart beat faster when we exercise?
- How does the oxygen we breathe get to our muscles?
- How does the body know how to regulate oxygen going in and carbon dioxide going out?
- How are breathing and getting energy related?
- Why do we breathe in or need oxygen?
- How does your body know when to breathe faster or slower?
- How do the respiratory and circulatory systems work together?
- How do other organisms regulate gas exchange?

What Students Do

Students begin this instructional sequence by planning and conducting an investigation on how sugar impacts cellular respiration in yeast in order to generate initial ideas on the inputs and outputs of the process. They engage with data collected and a complex text about cellular respiration in yeast in order to modify and refine an input / output model of cellular respiration. Ideas about the importance of oxygen in generating ATP are surfaced. Next, by analyzing secondary data sets on CO_2 and O_2 levels in the blood, students surface the concept of dynamic equilibrium, and the interaction of body systems in regulating oxygen levels in the blood. They read a visual text in order to construct a sequence chart that explains how feedback mechanisms work to maintain homeostasis and regulate gas exchange through the coordinated effort of multiple body systems at the cellular, organ, and body system levels. Finally students use their input/output models and evaluate the relevance of new evidence, such as the O_2 saturation of the runner, to address the marathon runner question.

Student Ideas

Students figure out these ideas in this 5E sequence.

- We breathe faster and our heart beats faster when we run a marathon or exercise
- Cellular respiration is a process conducted by all organisms that generates ATP (energy) for use in all life processes.
- In cellular respiration, glucose is broken down in the presence of oxygen, generating ATP and releasing carbon dioxide and water as waste products
- During exercise, the need for oxygen increases, in order to generate sufficient ATP.
- Gas exchange occurs between the respiratory and circulatory systems at the lungs -- at the cellular, organ, and organ system levels
- The brain detects rising CO_2 levels, and stimulates faster ventilation, thus maintaining a dynamic equilibrium of blood gasses
- All organisms, including plants, regulate gas exchange in order to respire.

After working individually to develop their models to represent how gas exchange is regulated, in groups students consider where they currently stand on the question from the Driving Question Board: Did the marathon runner run out of oxygen? As a group, they come to a consensus -- Yes, No, or Maybe -- and all groups share their positions which are tallied (most groups share the answer No).

Have students identify which categories/questions they have not addressed yet. One question category should relate to questions about muscles and energy (for example, questions about Did the marathon runner's muscles just get tired or did she run out of energy?). Tell students that in the next sequence of lessons, they will investigate what it means when our muscles get tired.

Muscles & Energy 5E	Did the marathon runner's muscles get tired? How do our bodies use energy during exercise?	**Performance Expectations** HS-LS1-2, HS-LS1-3, HS-LS1-7	**Investigative Phenomenon** Humans experience pain and tiredness with both short and long periods of exercise.	**Time** 6-10 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline: • Why do muscles get 'tired' when exercising? • Where do we get our energy from? • How do muscle cells generate ATP? • How do the needed materials get to the muscle cells, and how are waste products removed? What body systems are involved? • How does the body regulate blood glucose levels? • How does the body use stored energy, such as fat, when exercising? • Why can we go for a long time without eating • but not breathing?	Students begin by describing how tired their muscles feel after exercising. This leads to an investigation in which students gather data on the impact of exercise on CO_2 production, pulse rate, and breathing rate in order to surface how feedback mechanisms across multiple body systems maintain homeostasis during exercise. Students use their data to develop an input-output model of cellular respiration in muscle cells, emphasizing how energy is released from breaking bonds in matter. Students use the model to predict the impact of exercise on muscle cells and steps leading to muscle fatigue. Students then conduct another investigation that surfaces patterns on how feedback mechanisms regulate blood glucose and figure out the role of insulin in regulating blood glucose levels. After investigating the stable blood glucose levels of a long-distance cyclist, they apply their understanding to the Marathon Runner phenomenon.	*Students figure out these ideas in this 5E sequence:* • Working muscles require ATP • ATP is generated through aerobic and anaerobic respiration; aerobic respiration produces more ATP • To generate ATP, muscle cells need oxygen and glucose, carbon dioxide and water are released as waste produces • Glucose is provided through the digestive system and is delivered to muscle cells through interaction with the circulatory system • Blood glucose is regulated through feedback mechanisms; insulin is an important hormone in this process as it allows glucose to enter cells • Food is broken down to provide glucose; several molecules are used to store energy in the form of chemical bonds • Lipids (fat) and glycogen are storage molecules that may be easily broken down into glucose when needed to generate ATP due to excess activity

After working individually to develop their models to represent how homeostasis is maintained in the body (including cellular respiration and glucose regulation) in groups students consider where they currently stand on the question from the Driving Question Board: *Did the marathon runner run out of energy?* As a group, they come to a consensus -- *Yes, No, or Maybe* -- and all groups share their positions which are tallied (most groups share the answer No).

Have students identify which categories/questions they have not addressed yet. One question category should relate to questions about the runner's temperature and the temperature outside (for example, questions about *Did the marathon runner get overheated?*). Tell students that in the next sequence of lessons, they will investigate whether humans have mechanisms to regulate body temperature, they have been learning about gas exchange and sugar regulation.

Human Thermoregulation 5E	Was the marathon runner overheated? How do our bodies deal with changes in temperature?	**Performance Expectations** HS-LS1-2, HS-LS1-3	**Investigative Phenomenon** Humans can tolerate a wide range of temperatures.	**Time** 4-6 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline: • How do humans regulate their internal body temperature? • How do our bodies not overheat when exercising? • How does the external (environmental) temperature impact internal (body) temperature?	Connecting to their earlier questions about extreme exercise and temperature, students share their initial ideas about how we maintain a stable body temperature which leads students to investigate thermoregulation in the human body. They collect data on the impact of changing external temperatures on their own internal body temperatures, which helps them figure out that humans have a complex system for maintaining body temperature. Next students interpret a sequence chart demonstrating how feedback mechanisms enable the human body to thermoregulate. They use their understanding to go back and construct a scientific explanation about the data from their thermoregulation investigation. Students use what they figured out about human thermoregulation to explain why the human body is cooled for heart surgery. Finally, students consider what they have learned about internal and external sources of heat, and demonstrate their understanding of how an exercising person regulates body temperature by evaluating the importance of body temperature data on the Marathon Runner.	*Students figure out these ideas in this 5E sequence:* • Humans (and other endothermic organisms) are able to maintain a relatively stable internal temperature, even under changing external temperatures. • Maintaining a relatively stable body temperature is an example of dynamic equilibrium. • Human body systems use feedback mechanisms in order to maintain dynamic equilibrium. • Examples of feedback mechanisms are vasodilation (dilation of blood vessels) in response to high body temperatures and the vasoconstriction of blood vessels in the response to lowering body temperature.

After working individually to develop their models to represent the maintenance of homeostasis (specifically thermoregulation) in the body, students work in groups to consider where they currently stand on the question from the Driving Question Board: *Was the marathon runner overheated?* As a group, they come to a consensus about the answer, *Yes, No, or Maybe*. All groups share their positions, which are tallied; most groups share the answer *No*. Have students identify which categories or questions they have not addressed yet. One question category should relate to questions about the runner's temperature and the temperature outside, questions like *Was the marathon runner dehydrated?*. Tell students that in the next sequence of lessons, they will investigate whether humans have mechanisms to regulate water balance, since so far they have investigated the regulation of gas exchange, blood glucose, and temperature.

Water Balance 5E	Was the marathon runner dehydrated? How do our bodies maintain water balance?	**Performance Expectations** HS-LS1-2, HS-LS1-3	**Investigative Phenomenon** Humans sweat during exercise, losing water and salts.	**Time** 4-6 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. • Why is our sweat salty? • Why do we sweat so much when we exercise? • What happens in our bodies when we sweat and lose all that water and salt? • What type of fluid should we drink during exercise? • Why is water so important to our lives? • How do humans regulate fluid / water levels in the body? • How does water move into and out of cells?	Students share their initial ideas about the marathon runner being dehydrated and sweaty, and discuss which type of fluid is better to drink during exercise: water or a sports drink. They conduct two investigations to learn about osmoregulation. First they observe osmosis using an onion cell and then they use data about osmoregulation in the kidney. After the investigations, students use their understanding of feedback mechanisms and osmoregulation in order to develop a sequence chart that explains how the body osmoregulates during exercise. Students are then asked to consider what would happen to a freshwater fish being put into salt water. They propose criteria to develop a model that could be used to represent whether or not the fish can maintain stability given the environmental change. Finally, students use their understanding of how an exercising person osmoregulates to evaluate the importance of plasma sodium level data on the Marathon Runner phenomenon.	*Students figure out these ideas in this 5E sequence.* • Water is essential for many bodily functions including temperature regulation and waste removal. • The movement of water in and out of cells is a passive process called osmosis. • In osmosis, water moves towards a higher solute concentration - this has important implications for cells as they may become either plasmolyzed (water drawn out) or burst (too much water moves in). • Water and solute concentrations in the blood are regulated in the kidney. • Consuming too much water too quickly can cause an imbalance in solute and water concentrations leading to a condition called hyponatremia.

After working individually to develop their final models to represent how homeostasis is maintained in the body (focusing on water balance) in groups students consider where they currently stand on the question from the Driving Question Board related to water balance. The class may be responding to the question, “Did the marathon runner dehydrate?” (no, she did not) instead of the question “Did the marathon runner drink too much water?” (yes, she did). This is ok, as long as students are thinking through if there was a disruption (in any way) of how she maintained water balance. If the students respond that no, she did not dehydrate and respond to that prompt in their Water Balance Evaluate model, they should be encouraged to think further about what could have gone wrong, based on the medical tent data. As the plasma sodium levels are lower than normal, students think about what might have gone wrong, as they transition to their final response to the Performance Task.

Unit Closing	Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	**Performance Expectations** HS-LS1-2, HS-LS1-3	**Anchor Phenomenon** Marathon Runner Collapse: Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	**Time** 1-5 days

Student Questions	What Students Do	Student Ideas
These questions are addressed in the performance task. • What is the most likely reason for the runner's disorientation and coma? • Which body systems are interacting? • What feedback mechanisms are occurring to maintain the runners' homeostasis? • How can all of the data be explained using an input/output model of the human body? How can a smaller scale model at the cell level support this explanation?	Based on the marathon runner's data and the investigations conducted throughout the unit, students create a human body model that depicts what caused the runner to collapse. Their models include multiple body systems, and show a zoomed in view of what is happening in an organ or cell. Students also write an explanation to describe the visual representation of their model in which they explain how feedback mechanisms are being used in the runner to maintain homeostasis. **Extension** What can be done to prevent this from happening in the future? Design a safety proposal for marathons to use based on what happened to the marathon runner. How can marathons prevent this type of thing from happening in the future? Based on students' models and final explanations, students develop a set of criteria as a class for the design of a safety proposal, and then in small groups create written proposals to present.	*These ideas were developed throughout the unit storyline.* • The body has a feedback mechanism system for maintaining gas exchange and cellular respiration as well as for glucose regulation, and thermoregulation. The marathon runner's data all shows that her feedback mechanisms for this was working to keep her oxygen and glucose levels constant (therefore she did not run out of breath, or run out of energy). • The body has a feedback mechanism system for maintaining a constant internal body temperature, not matter what is happening to the temperature in the environment (externally). The marathon runner's data shows she did not overheat. • The body requires that the ratio of water and solute (salt) in our cells is in balance. When we drink too much water, too quickly this offsets the balance and can cause hyponatremia. This is supported by marathon runner data. • To prevent this, after exercising people should drink water with a high concentration of salt, such as sports drinks, rather than just plain water.

Based on the investigations and learning throughout the unit, many of the questions asked by students have been answered, and they develop a final model to explain what happened to the marathon runner.

Unit Standards

This unit is designed to meet Next Generation Science Standards Performance Expectations. Since this unit is part of a full-year Biology course, the design includes intentional foregrounding of a limited number of Crosscutting Concepts (CCCs) and Science and Engineering Practices (SEPs). Further, since an aspect of NGSS design is connections to Common Core Math and ELA standards, these connections are highlighted in this section.

Performance Expectations

HS-LS1-2 **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.**
Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.
Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.

In NYS the clarification statement has been edited as follows: Emphasis is on functions at the organism's system level such as nutrient uptake, water delivery, immune response, and organism response to stimuli.

HS-LS1-3 **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.**
Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.
Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.

HS-LS1-7 **Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.**
Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration
Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.

In NYS, all occurrences in this PE of the phrase "cellular respiration" have been replaced with the phrase "aerobic cellular respiration."

Three-Dimensional Learning Goals in This Unit

Given the breadth of three-dimensional standards for high school biology, Unit 1 focuses primarily on ideas related to homeostasis, including gas exchange, thermoregulation, and water balance. These ideas fall within Core Idea LS1 of the NGSS/NYSSLS, *From Molecules to Organisms: Structures and Processes.* This unit also introduces students to the SEP of Developing and Using Models. That is not to say that students will not engage in other SEPs throughout the lessons; however, it is important to foreground and be explicit about a limited number of practices with enough duration to see how students develop their understanding and ability to use this practice. This is important for both student and teacher learning! Similarly, the foregrounded CCC for this unit is *Systems and System Models*, which fits well with our selected SEP and the understanding the human body systems are not acting separately but interacting to maintain balance in the body. As students deepen their understanding of the content to figure out what happened to the marathon runner, they deepen their understanding of how scientists use input-output models to make sense of phenomena at different scales. Scaffolding across the unit supports students' three-dimensional learning and will help shift classrooms to become more NGSS-aligned spaces.

Three Dimensions Foregrounded in Unit 1

This chart is a high-level summary of the foregrounded standards. For more detail about specific elements, see the section on Assessment later in this document.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models	LS1.A Structure and Function	Systems and Systems Models
Planning and Carrying out Investigations	LS1.C Organization for Matter and Energy Flow in Organisms	Energy and Matter
Constructing Explanations and Designing Solutions		Stability and Change

Building on Middle School

High school science teaching necessarily builds on student learning from middle school. It is helpful to consider the middle school standards in order to enact a unit that builds on students' prior experiences. As we are in the middle of a multi-year transition, however, it is also critical to keep in mind that not all students will have experienced an NGSS-designed unit when they come to high school, so the process of building on middle school learning may be particularly complex for years to come. The following sections detail the ways in which this unit builds on middle school standards across the three dimensions.

Disciplinary Core Ideas from Middle School

LS1.A Structure and Function

- In middle school, students learn that all living things are made of cells and that structures inside cells (including mitochondria and the nucleus) carry out the functions of life. They learn about the relationship between cell functions and the structure and function of the different organization levels within the body: tissues, organs and systems. A major shift in middle school in the new science standards is an emphasis that students conceptualize the body as a system with interacting subsystems (rather than learning each body system separately). This supports the deeper understanding of homeostasis and feedback mechanisms at the high school level within Unit 1.

LS1.C Organization for Matter and Energy Flow in Organisms

- Photosynthesis and cellular respiration are introduced in middle school, but at a foundational level, with

the emphasis on input and output and without formulas. Students learn how plants capture energy from light and carbon from air to make sugar/food, and that we get our energy by breaking down food through chemical reactions. This background understanding can be built upon when students develop the input/output models at the cellular and body levels across Unit 1.

Crosscutting Concepts from Middle School

Systems and System Models

This unit builds on the following aspects of Systems and System Models in middle school.

- Functions of a system can be understood by examining its structures.
- Systems are made of subsystems and interact with other systems.
- To represent processes in a system related to energy and flow of matter, input-output models can be used.

Science and Engineering Practices from Middle School

Developing and Using Models

- Students in middle school have experience developing models based on evidence, using models to make predictions and evaluating models to evaluate their limitations. The use of modeling in this unit at the high school level builds on these experiences as students have to develop models at different scales and revise their models to show relationships between systems and components of a system.

Planning and Carrying Out Investigations

- In middle school, students make sense of and carry out investigations; in high school, they build on the practice through developing investigations more extensively. This unit builds on the practice of investigation design through scaffolded lab experiences.

Assessment

Performance expectations (PEs) in the NGSS describe what students should know and be able to do. Unit 1 targets a bundle of three PEs taken from the first core idea in high school life science (HS-LS1), *From Molecules to Organisms: Structures and Processes*; those standards are HS-LS1-2, HS-LS1-3, and HS-LS1-7. This PE bundle informs the types of three-dimensional tasks in which students engage across the unit. Each sequence of lessons within the unit targets elements from one or more of the performance expectations for the unit, and the teacher has opportunities to collect evidence of student learning around these elements within that learning sequence. The unit-level Performance Task only targets a subset of three-dimensional learning goals informed by the bundled PEs for the unit. All other evidence of learning related the other dimensions/elements in the PEs can be found within the instructional sequences. The **Teacher Materials** for each sequence of lessons includes a matrix that lists which student artifacts can provide evidence of student learning for each of three-dimensional learning goals from that sequence.

This unit was designed to support teachers in tracking student progress across the three dimensions, not for mastery within individual lessons. The targeted disciplinary core ideas (DCIs) listed below will be developed throughout the unit. While all of the science and engineering practices (SEPs) may be utilized across the unit, the three target SEPs for the unit are listed below. Similarly, many crosscutting concepts (CCCs) may be useful in making sense of the phenomena in this unit, however the foregrounded, targeted CCCs are listed below.

The following Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts are assessed throughout the unit:

	Gas Exchange and Cellular Respiration 5E	Muscles & Energy 5E	Human Thermoregulation 5E	Water Balance 5E
Developing and Using Models	✔	✔	✔	✔
Planning and Carrying out Investigations		✔	✔	
Constructing Explanations and Designing Solutions			✔	
LS1.A Structure and Function	✔	✔	✔	✔
LS1.C Organization for Matter and Energy Flow in Organisms	✔	✔	✔	
Systems and Systems Models	✔	✔	✔	✔
Energy and Matter		✔		
Stability and Change	✔	✔	✔	✔

At the end of Unit 1, teachers will have evidence in student work (tasks) related to the elements listed in this table and can therefore make claims at the end of this unit related to student proficiency for all three performance expectations.

To support assessment throughout the unit, rubrics have been included in the **Student Materials** to support the Evaluate phase in every 5E instructional sequence. Teachers should customize these rubrics to support their schools' grading systems. Rubrics address both individual reflection, peer review, and the teacher's feedback. The Unit 1 Performance Task also includes a rubric, and the task can be considered a final summative assessment for the unit - we have not included a traditional “unit test” in our materials. Teachers may opt to create their final exam using their states’ previous exam questions, however we believe that the formative assessment tasks embedded in the materials (such as the Looks and Listen For notes, the Explore phase summaries, and the modeling done in the Evaluate phases), along with the Performance Task can serve as sufficient evidence of what students know and can do.

Common Core State Standards (Mathematics)

Standards for Mathematical Practice

MP2 Reason abstractly and quantitatively.	Mathematically proficient students make sense of the quantities and their relationships in problem situations. Students bring two complementary abilities to bear on problems involving quantitative relationships: the ability to decontextualize—to abstract a given situation and represent it symbolically and manipulate the representing symbols as if they have a life of their own, without necessarily attending to their referents—and the ability to contextualize, to pause as needed during the manipulation process in order to probe into the referents for the symbols involved. Quantitative reasoning entails habits of creating a coherent representation of the problem at hand; considering the units involved; attending to the meaning of quantities, not just how to compute them; and knowing and flexibly using different properties of operations and objects.
MP3 Construct viable arguments and critique the reasoning of others.	Mathematically proficient students understand and use stated assumptions, definitions, and previously established results in constructing arguments. They make conjectures and build a logical progression of statements to explore the truth of their conjectures. They are able to analyze situations by breaking them into cases, and can recognize and use counterexamples. They justify their conclusions, communicate them to others, and respond to the arguments of others. They reason inductively about data, making plausible arguments that take into account the context from which the data arose. Mathematically proficient students are also able to compare the effectiveness of two plausible arguments, distinguish correct logic or reasoning from that which is flawed, and—if there is a flaw in an argument—explain what it is. Elementary students can construct arguments using concrete referents such as objects, drawings, diagrams, and actions. Such arguments can make sense and be correct, even though they are not generalized or made formal until later grades. Later, students learn to determine domains to which an argument applies. Students at all grades can listen or read the arguments of others, decide whether they make sense, and ask useful questions to clarify or improve the arguments.
MP6 Attend to precision.	Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context. In the elementary grades, students give carefully formulated explanations to each other. By the time they reach high school they have learned to examine claims and make explicit use of definitions.

Standards for Mathematical Content

HSF-IF.B.5 Functions	Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. For example, if the function h(n) gives the number of person-hours it takes to assemble n engines in a factory, then the positive integers would be an appropriate domain for the function.

Common Core State Standards (ELA/Literacy)

Speaking and Listening Standards

SL.9-10.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others’ ideas and expressing their own clearly and persuasively.

SL.9-10.4	Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.
SL.9-10.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Reading Standards for Literacy in Science and Technical Subjects

RST.9-10.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects

WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.

Implementing Unit 1

This unit should be completed during the first month or two of school. We do not recommend spending more than two months on this unit, as our field testing showed that six to eight weeks is the maximum amount of time students can stay engaged with the unit-level anchor phenomenon.

Within the unit, we also suggest spending no more than two weeks on each 5E instructional sequence. It is important to trust that ideas will build over time. Part of learning to teach NGSS-designed curriculum is getting comfortable with moving on, even if not every student "gets it," with the knowledge that there are additional opportunities to revisit particular standards. See the Assessment section below for guidance on providing multiple opportunities for assessment throughout the unit.

The first time enacting Unit 1 with students may take longer than anticipated, particularly if the pedagogical approach is significantly different from what a teacher is used to. A teacher may want to skip entire lessons or activities, or revert to more traditional approaches when it seems like time is running out. We often ask teachers to think about the best way to modify recipes. Just like when using a recipe for the first time, it's a good idea to stay as true to the materials as possible before making modifications or substitutions! As teachers become more familiar and comfortable with the instructional model, the embedded routines, and three-dimensional teaching overall, the desire to skip things will dissipate. Teachers using our curriculum over time have noticed that they are able to move a bit quicker through this and other NGSS-designed units every year!

Routines

The table below summarizes the routines embedded in this unit. The number indicates the number of times a given routine appears in a lesson.

	Unit Opening	Gas Exchange and Cellular Respiration 5E	Muscles & Energy 5E	Human Thermoregulation 5E	Water Balance 5E	Unit Closing
Class Consensus Discussion		1	1	1	1	
Consensus-Building Share			1	1	1	
Domino Discover		3	3	3	2	
Idea Carousel					1	
Questions Only		1				
Read-Generate-Sort-Solve		1	1			
Rumors		1			1	
Think-Talk-Open Exchange		1	1			

Literacy Strategies

The table below summarizes the literacy strategies embedded in this unit. The number indicates the number of times a given strategy appears in a lesson.

	Unit Opening	Gas Exchange and Cellular Respiration 5E	Muscles & Energy 5E	Human Thermoregulation 5E	Water Balance 5E	Unit Closing
Claim-Evidence-Reasoning (CER)				1		
Sequence Chart		1			1	
Text Annotation	2	1	1		2	
Three-Level Guide		1		1		

Videos in this Unit

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Unit Opening	Marathon Video	https://www.youtube.com/watch?v=3Ouf2rVTT_U	NA	NA
Gas Exchange and Cellular Respiration 5E	Video of ventilation and gas exchange in the lungs	https://www.youtube.com/watch?v=XTMYSGXhJ4E	NA	NA
Muscles & Energy 5E	Insulin and glucagon	https://www.khanacademy.org/test-prep/mcat/biomolecules/hormonal-regulation/v/insulin-and-glucagon	NA	NA
Human Thermoregulation 5E	A 50-mile race of a lifetime: Girl vs. horse	https://www.nbcconnecticut.com/news/sports/ultramarathoner-50-mile-race-against-horses-nicole-teeny/3394469/	NA	NA
Human Thermoregulation 5E	The Intense 8 Hour Hunt	https://www.youtube.com/watch?v=826HMLoiE_o	NA	NA
Unit Closing	Runners World article: Pass The Salt?	https://www.runnersworld.com/nutrition-weight-loss/a20784078/pass-the-salt/	NA	https://www.hearst.com/-/us-magazines-terms-of-use#_TERMS_OF_USE

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Unit Closing	Hammer Nutrition text: Hydration - What do You Need to Know	https://www.hammernutrition.com/knowledge/advanced-knowledge/hydration-what-you-need-to-know	NA	NA
Unit Closing	Scientific American article: Strange But True: Drinking Too Much Water Can Kill	https://www.scientificamerican.com/article/strange-but-true-drinking-too-much-water-can-kill/	NA	NA

Lab Materials in this Unit

Lesson	Lab	Materials needed (per group)
Gas Exchange and Cellular Respiration 5E	Cellular Respiration in Yeast Lab minutes: 45-60 minutes	❏ 3 plastic water bottles (disposable) or erlenmeyer flasks ❏ 3 packets yeast ❏ 3 balloons ❏ 300 mL warm water ❏ 3 sugar packets ❏ measuring tape
Gas Exchange and Cellular Respiration 5E	Analyzing Blood Oxygen Levels Investigation Lab minutes: 45 minutes	
Muscles & Energy 5E	Exercise and Cellular Respiration Investigation Lab minutes: 45-60 minutes	❏ beaker ❏ test tube or cup ❏ bromothymol blue solution (BTB) ❏ straw ❏ stop watch
Muscles & Energy 5E	Glucose Regulation Investigation Lab minutes: 45-60 minutes	❏ Arizona Iced Tea can (large) ❏ sugar ❏ clear cups ❏ bromothymol blue (dilute) ❏ vinegar (dilute) ❏ sodium hydroxide (dilute) ❏ beakers ❏ small clear containers or squirt bottles

Lesson	Lab	Materials needed (per group)
Human Thermoregulation 5E	Human Thermoregulation Investigation Lab minutes: 45-60 minutes	❑ digital oral thermometer ❑ immersion thermometer ❑ bowl or large beaker of hot water ❑ stopwatch or clock ❑ thermometer probes (2) ❑ bowl or large beaker of cold water
Water Balance 5E	Osmosis in Onion Cells Investigation, Osmoregulation in the Kidney Investigation Lab minutes: 45-60 minutes	❑ Red onion slices ❑ Cover slips ❑ Microscope slides ❑ Water ❑ Scalpel or knife ❑ Dropper or pipette ❑ Distilled water ❑ Colored pencils ❑ Salt solution ❑ Paper towels

Other Materials in this Unit

Lesson	Materials needed
Unit Opening	❑ Small post-its or adhesive tags ❑ *Initial Human Body Model* ❑ *Driving Question Board Scaffolded Question Set* ❑ Post-it notes ❑ chart paper or digital access ❑ *See-Think-Wonder* ❑ *Driving Question Board Scaffolded Question Set*

Lesson	Materials needed
Gas Exchange and Cellular Respiration 5E	❑ sticky notes ❑ chart paper or whiteboard ❑ image of an athlete breathing heavily (video or GIF) ❑ *Characteristics of a Model Consensus List (Example)* ❑ *Characteristics of a Model Consensus List (Example)* ❑ *Class Consensus Discussion Steps* ❑ *Biological Levels of Organization* ❑ Driving Question Board (questions related to this 5E) ❑ Chart from Engage of students' ideas related to breathing and exercise ❑ Colored pencils ❑ *Gas Exchange Card Sequence* ❑ MedlinePlus text: Gas exchange ❑ BBC diagram: Respiration ❑ *Sequence Chart* ❑ Class wide scientific model characteristics ❑ Driving Question Board from the start of the unit should be available
Muscles & Energy 5E	❑ Input-output model from previous 5E ❑ *Muscles at Different Scales* (optional) ❑ Lumen Learning text: Muscle Metabolism (additional information) ❑ Harvard article: How Sweet Is It? ❑ Class Wide Scientific Model Characteristics ❑ Driving Question Board from the start of the unit should be available ❑ *Muscles & Energy Model* (sample student work)
Human Thermoregulation 5E	❑ chart paper ❑ Resources on supporting scientific explanation in the Biology Course Guide ❑ Class wide scientific model characteristics ❑ Driving Question Board from the start of the unit should be available
Water Balance 5E	❑ Sticky notes ❑ Chart paper ❑ Computer access (with Internet) ❑ Chart paper ❑ Markers ❑ Mashable article: Goldfish, released into the wild, are somehow surviving in saltwater ❑ Class wide scientific model characteristics ❑ Driving Question Board from the start of the unit should be available

Lesson	Materials needed
Unit Closing	❏ Class wide Driving Question Board ❏ *Final Explanatory Model* ❏ *Final Explanation* ❏ *Performance Task Rubric*

Teacher Materials for Unit 1

Unit Opening

Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?

Performance Expectations

Anchor Phenomenon
Marathon Runner Collapse: Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?

Time
2-3 days

Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race? A marathon is a 26.2 mile race. People often train for months leading up to the race in order to successfully complete this type of long distance running challenge. Sometimes, runners aren't able to finish the race or runners collapse and die shortly after the race. Use your findings from research articles, data sets, and class activities to explain why one runner became very ill during the race, and how the race could be better organized to prevent illness in the future.

ANCHOR PHENOMENON	Why would a marathon runner become disoriented during the race, then collapse afterward?	This is a topic that should incite student curiosity and wonder! By working with students to surface what they believe could have gone wrong with a marathon runner, students will express both their prior knowledge and their curiosity, allowing them to engage with the unit and increasing student buy-in.
DRIVING QUESTION BOARD	Students explore their ideas.	Based on ideas that have surfaced through student discussion, students create an initial model and driving question board.
PERFORMANCE TASK	Students review the performance task.	Review the Performance Task with students.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

Why would a marathon runner become disoriented during the race, then collapse afterward?

This is a topic that should incite student curiosity and wonder! By working with students to surface what they believe could have gone wrong with a marathon runner, students will express both their prior knowledge and their curiosity, allowing them to engage with the unit and increasing student buy-in.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups	None	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ Initial Human Body Model ❏ Tell the Story	None	❏ Small post-its or adhesive tags ❏ *Initial Human Body Model* ❏ *Driving Question Board Scaffolded Question Set* ❏ Marathon Video

Surfacing Student Ideas

1. Show the Marathon Video (23:10-24:53), or a similar video to the class to introduce them to the idea of a marathon or similar endurance sport.
2. Prompt students to talk in pairs about things that are happening in the human body during exercise, this may be from the video or their own knowledge of exercise.

Conferring Prompts

Confer with students as they create their model.

- How do you feel during extended exercise?
- What is happening in your body?
- What are some processes that might be connected to the processes you have labeled?
- What are some related components?
- How can you represent your ideas clearly?
- How can you use labels, arrows, and other types of annotations to represent your ideas?

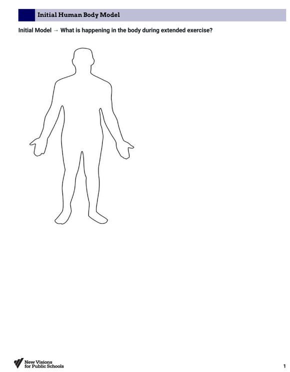
3. Distribute the handout *Initial Human Body Model*.

Access for All Learners

Not all students may be familiar with or connect to the concept of a marathon. Prompt students to think about other types of endurance sports or activities that require similar exertion. Students may discuss sports or activities they engage with such as basketball, soccer, or dance.

4. Individually, students complete the model of the things that are happening in the human body during extended exercise. For sample student work, see *Initial Human Body Model*.

5. Students share with a partner, and if appropriate, add one idea to their model from discussing with their classmate.


Initial Human Body Model

Initial Model → What is happening in the body during extended exercise?

Implementation Tip

It is not necessary to call these diagrams models at this point. The practice of modeling can emerge through this activity and throughout the unit. Encourage students to make their model as detailed as possible.

Telling the Story

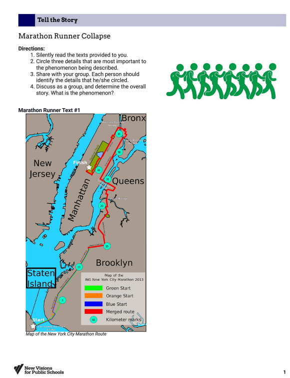
1. Distribute each student's *Tell the Story* handout.

2. Remind students that they just surfaced a lot of ideas about what happens to our bodies during extensive exercise, and we are going to learn about what happened to one woman that attempted to run a marathon in NYC.

3. Students read and use **text annotation** for the three texts individually, circling three details that are the most important to the phenomenon being described.

4. Students share their ideas in their group, with every individual identifying the details that they thought were important.

5. As a group, students decide which ideas they think are important, and use those ideas to write out what happened, or the story of the phenomenon.


Tell the Story

Marathon Runner Collapse

Directions:
1. Silently read the texts provided to you.
2. Circle three details that are most important to the phenomenon being described.
3. Share with your group. Each person should identify the details that he/she circled.
4. Discuss as a group, and determine the overall story. What is the phenomenon?

Marathon Runner Text #1

Access for All Learners

This is the first time students are using the strategy **text annotation**. Be sure to look at the Unit 1 teacher guide for the action pattern for this routine.

Conferring Prompts

Confer with students as they work in groups to tell the story.
- Why do you think this detail is important?
- Did your group members and you circle the same details?
- How did you agree, as a group, to the overall story?

Implementation Tip

This may be the first time students are exposed to the idea of a phenomenon, and that the phenomenon (and associated Performance Task) will guide their learning throughout the unit. After engaging with the telling the story, prompt students to describe what that term “phenomenon” means to them.

Driving Question Board

Students explore their ideas.

Based on ideas that have surfaced through student discussion, students create an initial model and driving question board.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups	None	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ Tell the Story	None	❏ Post-it notes ❏ chart paper or digital access ❏ *See-Think-Wonder* ❏ *Driving Question Board Scaffolded Question Set*

Surfacing Student Ideas

1. Students have already previewed the Medical Tent Data in the *Tell the Story* and are wondering what the data means and what it can tell them about the different runners.

2. Let students know that they will now have an opportunity to engage with the data table, and see what new information it gives us about the runner that collapsed.

3. Students use the See-Think-Wonder organizer, found below the medical tent data to make sense of the information. For sample student responses, see *See-Think-Wonder*.

4. Based on the data table, text, and their previous experiences with exercise, prompt students to consider what are all of the processes that may “go wrong” with marathon runners (or anyone engaged in exercise).

5. Students use small post-its or adhesive tags to indicate on their original model.

Implementation Tip

If this is the first time students have used a See-Think-Wonder organizer to make sense of a data table, take a moment to review the steps:

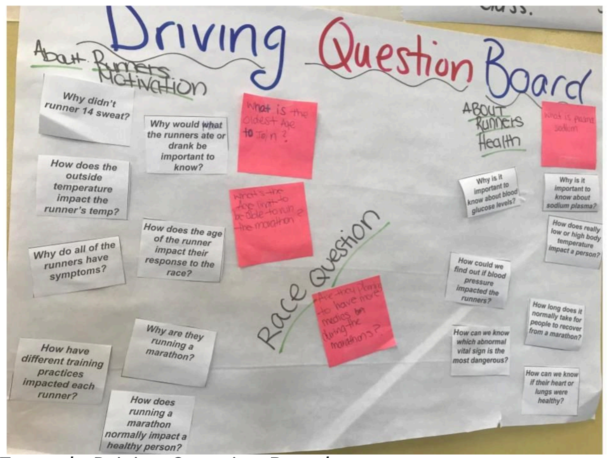
- In the See column, students note what they can see factually from the data table, without making inferences
- In the Think column, students note what the data makes them think about, including inferences and patterns that they notice
- In the Wonder column, students surface remaining questions they have about the data or the patterns they noticed
- Students may wonder what the normal ranges for each of these data points are, do not provide these ranges yet, they will be given to students at the end of each 5E learning sequence
- Students may wonder what some of the values mean, that is ok at this point, they will have an opportunity to revisit the medical tent data throughout the unit

Developing Questions

1. At this point, students should have a lot of questions! Let them know that they will be investigating what happened to the marathon runner that collapsed throughout this unit. This is important to find out because the event organizers want a safe run for everyone and we all want to stay safe when we are engaging in intense exercise or sports.

2. Individually, students come up with questions they would need to answer in order to figure out the marathon runner problem. Each question goes on a separate sticky note.

3. As a whole class or in small groups, students share and categorize their questions, as they organize the questions on chart paper.



Example Driving Question Board

Conferring Prompts

Confer with students as they create and categorize questions.

- Why do these questions belong together?
- What is the category that connects these?
- Are there other questions within this category?
- Now that you see all of your questions grouped together, do other questions come up?
- For each category, is it possible to develop an umbrella question that encompasses all of the other sub-questions in that category?

Differentiation Point

If this is the first time students have generated a Driving Question Board (DQB) they may struggle with coming up with appropriate scientific questions. If so, provide students with the *Driving Question Board Scaffolded Question Set* for a DQB that can serve as an example or starting point. If using the scaffolded question set, encourage each individual or group to generate some questions on their own.

For more guidance on using the DQB throughout the unit, see the Unit 1 Guide.

Performance Task

Students review the performance task.

Review the Performance Task with students.

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

Standards in Unit Opening

Performance Expectations

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
	LS1.A Structure and Function • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. LS1.A(3)	

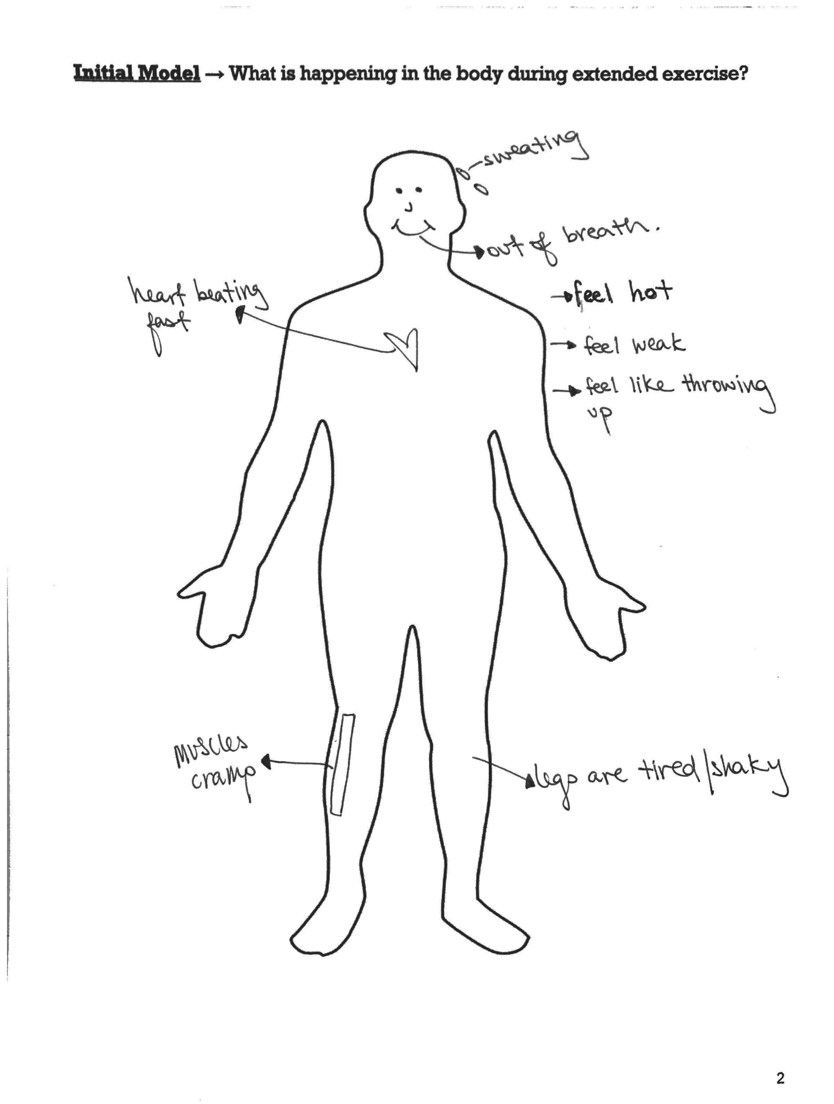
Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task
LS1.A Structure and Function		Performance Task Organizer	

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task
Mathematics			
ELA/Literacy	RST.9-10.1 RST.9-10.7 WHST.9-10.2 SL.9-10.1 SL 9-10.4		

Student Work for Unit Opening



Example student work for the initial human body model

See-Think-Wonder Graphic Organizer

See	Think	Wonder
- Runner 0014 dropped out of the race. - Runners finished the race in a wide range of times. - Every runner has a high oxygen saturation. - Runner 1059 has the lowest blood glucose level (90 mg/dL). -Runner 0358 has the lowest plasma sodium level (130 mEq/L).	- Runner 1059 is an experienced runner. - No one had trouble getting enough oxygen. - Runner 0358 is too old and overweight to run.	- what is 73 kg in pounds? - what is the normal blood glucose level? - why is body temperature important? - How can you change your plasma sodium level?

Classroom Resources for Unit Opening

Driving Question Board Scaffolded Question Set

Driving Question Board Scaffolded Question Set

Cut out these cards.

How does the outside temperature impact the runner's temperature?	How does the age of the runner impact her response to the race?	How can we know which abnormal vital sign is the most dangerous?
Why does the runner have these symptoms?	Why is it important to know about blood glucose levels?	Why is it important to know about sodium plasma?
How can we know if her heart or lungs were healthy?	Why would what the runner ate or drank be important to know?	How have different training practices impacted the runner?

Why didn't the marathon runner sweat?	How long does it normally take for people to recover from a marathon?	How does running a marathon normally impact a healthy person?
Why are they running a marathon?	How could we find out if blood pressure impacted the runner?	How does really low or high body temperature impact a person?

Gas Exchange and Cellular Respiration 5E

Did the marathon runner run out of breath or not get enough oxygen? Why do we breathe faster when we exercise?

Performance Expectations
HS-LS1-2, HS-LS1-3, HS-LS1-7

Investigative Phenomenon
Humans breathe faster when exercising.

Time
6-8 days

In this 5E instructional sequence, students are investigating the questions about breathing that surfaced during the Driving Question Board launch: Did the marathon runner run out of breath? Did the marathon runner not get enough oxygen? This leads to questions about why humans breathe faster when exercising. Students investigate the interaction between the respiratory and circulatory systems that are both required to work properly, as well as the feedback mechanisms that regulate all of this, to ensure that we can carry out cellular respiration and keep exercising. Students figure out that the marathon runner probably did not collapse due to being out of breath.

ENGAGE	Why do we breathe (ventilate) faster when exercising?	Connecting to their earlier questions about the marathon runner's breathing and oxygen, students share their initial ideas about why we breathe faster when we exercise and use our muscles. This leads students to express a need to investigate **gas exchange** in the human body further.
EXPLORE 1	How do organisms generate ATP to use as an energy source for life processes?	Students **conduct an investigation** on how sugar impacts **cellular respiration** in a model organism, yeast, in order to generate initial ideas on the **inputs and outputs of the process**, and to start to understand the phenomenon introduced in the Engage phase. In this phase, students are starting to figure out how organisms, including humans, generate ATP to use as an energy source, and the materials that cells need to do so.
EXPLAIN 1	Developing an understanding of how cells generate ATP in the process of cellular respiration.	Students engage with **data collected and a complex text** about **cellular respiration** in yeast in order to **modify and refine a model that shows inputs and outputs in the system.**
EXPLORE 2	How does the body regulate O_2 levels in the blood?	In the previous Explore/Explain, students surface the importance of oxygen in generating ATP. By **analyzing secondary data sets** on CO_2 and O_2 levels in the blood, students surface the concept of **dynamic equilibrium**, and the **interaction of body systems** in regulating oxygen levels in the blood.
EXPLAIN 2	Using visual texts to construct an explanation of how interacting systems regulate gas exchange.	Students partner-read a **visual text** in order to **construct a sequence chart that explains** how **feedback mechanisms work to maintain homeostasis and regulate gas exchange through the coordinated effort of multiple body systems at the cellular, organ, and body system levels.**
ELABORATE	How do different plants regulate gas exchange?	Students extend their ideas about **gas exchange** by **constructing a model** to demonstrate how plants **regulate** gas exchange.
EVALUATE	How does the regulation of gas exchange connect to changes we see during intense exercise?	Students **use their input/output model**, and their new understanding of **cellular respiration and the regulation of gas exchange** through the **interaction of multiple body systems** in order to address the Marathon Runner problem. Students evaluate the relevance of new evidence, such as the O_2 saturation of the runner.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

Why do we breathe (ventilate) faster when exercising?

Connecting to their earlier questions about the marathon runner's breathing and oxygen, students share their initial ideas about why we breathe faster when we exercise and use our muscles. This leads students to express a need to investigate **gas exchange** in the human body further.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	❑ sticky notes ❑ chart paper or whiteboard ❑ image of an athlete breathing heavily (video or GIF)

Launch

1. Remind students that during the Driving Question Board launch, one category of questions that emerged was related to breathing and/or if sufficient oxygen was available (for example: Did the marathon runner run out of breath or not get enough oxygen?). Ask students to share more about why they asked questions about breathing. Listen for the observation that when running or exercising, your breathing increases.

2. Use students' questions and observations about breathing to transition to the guiding question: Why do we breathe faster when we are exercising?

3. Prompt students to consider the body models they generated during the anchor phenomenon launch, and their own experiences running or exercising heavily. If students need support generating ideas, provide a brief video, image, or GIF of an athlete breathing heavily.

4. Individually, students respond to the prompt, brainstorming as many ideas as possible.

Access for All Learners

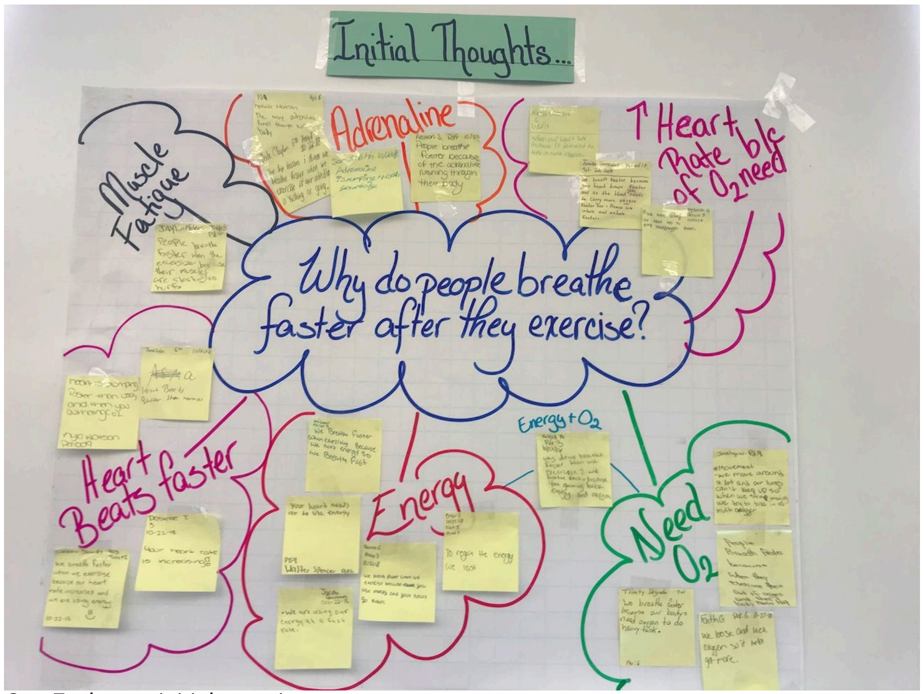
All students have some background knowledge on the topic of exercise and respiration. Be sure to provide opportunities for students to articulate those ideas at this point, by selecting examples that make sense to them.

Surfacing Student Ideas

1. Each student reads through their ideas, and decides on their most important idea, writing that one idea on a sticky note. Remember, this should be a response to the question: Why do we breathe faster when we are exercising?

2. Use the group learning routine **Rumors** to surface student ideas.

3. After students have shared their ideas through Rumors, categorize student ideas to address during the instructional sequence.



Gas Exchange initial questions

4. Prompt students to think about why they might need air or oxygen.

5. End the discussion by asking students how they might investigate the need for air or oxygen.

Routine

The goal of the **Rumors** routine is to have students exchange ideas while listening for similarities and differences in thinking. It's meant to be low stakes, so it is frequently used to surface initial student ideas about phenomena during the Engage phases. This is the first time the routine **Rumors** appears in this unit. Please read the Biology Course Guide for detailed steps about this routine.

Classroom Supports

Create a poster or space on a whiteboard for categories of student ideas that have come up. Use the title: Why do we breathe faster when we are exercising? You can refer back to the poster throughout this 5E plan.

Look & Listen For

Students have background knowledge (and have thought about this using their body models during the Anchor Phenomenon Launch). In the discussion they may surface ideas around:

- the need for oxygen
- excreting carbon dioxide
- the need for energy
- alternative conceptions such as “We breathe to cool down.”

Explore 1

How do organisms generate ATP to use as an energy source for life processes?

Students **conduct an investigation** on how sugar impacts **cellular respiration** in a model organism, yeast, in order to generate initial ideas on the **inputs and outputs of the process**, and to start to understand the phenomenon introduced in the Engage phase. In this phase, students are starting to figure out how organisms, including humans, generate ATP to use as an energy source, and the materials that cells need to do so.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Surfacing Ideas for Experimental Design ❏ Cellular Respiration in Yeast Investigation - Basic Protocol ❏ Cellular Respiration in Yeast Investigation ❏ Graphing Support - Scaffold ❏ Making Sense of Investigation Design ❏ Yeast Respiration Investigation Rubric	❏ 3 plastic water bottles (disposable) or erlenmeyer flasks ❏ 3 packets yeast ❏ 3 balloons ❏ 300 mL warm water ❏ 3 sugar packets ❏ measuring tape	❏ *Characteristics of a Model Consensus List (Example)*

Launch

1. Ask students to remind us what we are trying to figure out (whether the marathon runner ran out of breath). Tell students that so far, we have a lot of ideas about our own breathing; point to Rumors patterns if still visible in the classroom. At this point the class should have some ideas surfaced around that we might need oxygen and that it connects to needing energy for exercise (or to exercise in some way). Have students recall their earlier discussion about how we might investigate our need for oxygen, with emphasis on the fact that we want to investigate this here in the classroom.

2. Introduce the idea that you will use a model organism to begin to collect data on what is happening in human muscle cells. Prompt students to provide some ideas on why we would study yeast, when we are really interested in investigating humans and why they breathe quickly during exercise.

3. Remind students that they have already interacted with and generated a scientific model, the human body outline. Point out that model organisms are also scientific models.

Classroom Supports

Post the class consensus list on characteristics of a scientific model as a tool to support students with this important idea, which they will develop over the course of the unit.

4. Using what they know about generating their first model (the human body outline), prompt students to generate characteristics of a scientific model. Give students an opportunity to brainstorm their initial ideas of what a scientific model is and then confer with a partner about their thoughts.

5. Generate a class consensus list, and post it in the room. See the *Characteristics of a Model Consensus List (Example)*.

Note: At this point, it is fine if students do not have a completely clear or accurate definition of a scientific model! They will return to this class list throughout the unit.

Look & Listen For

Students may generate ideas such as:

- A model organism is cheaper and easier to manipulate
- Using a model organism is more humane
- We can't see inside a human easily
- Humans and yeast both need to complete life processes

Investigation: Cellular Respiration in Yeast

1. Provide each student with the *Cellular Respiration in Yeast Investigation*. In each group, students set up 3 beakers:
    - Beaker 1: 0 sugar packets
    - Beaker 2: 1 sugar packet
    - Beaker 3: 2 sugar packets

Lab Safety Note: Do not allow students to handle broken glass at any time. An adult should use forceps, tongs, scoops, or other mechanical devices for removing broken glass from the work area. Goggles should be worn by everyone during labs that involve glassware and / or any substances.

2. After setting everything up correctly, students start on the data collection.

3. Once students have collected their groups' data, have them enter it into a shared spreadsheet, so that they can aggregate the data and make sense of trends.

4. Have students work in groups to record their ideas about the data in the Analysis of Classwide Data in *Making Sense of Investigation Design*.

Conferring Prompts

Confer with students as they work in collaborative groups to collect data and complete the See-Think-Wonder chart.

Suggested conferring questions (these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):

- Why are we studying yeast, if we are really interested in humans?
- What is your group's experimental question?
- What is your group's hypothesis? What made you develop this?
- What are you measuring? How are you measuring it?
- What is (are) the thing(s) that stay the same (controls) in the experiment? Why do we need most things to stay the same?
- What would be the best way to organize the data you are collecting?
- What is happening in the bottle? Why is it happening?
- What are you able to see, and what aren't you able to see, in this process?

Look & Listen For

While students work on the See-Think-Wonder look for the following ideas:

- The trend that as sugar increased, circumference of the balloon and height of the foam increased (that the rate of cellular respiration increased)
- Sugar and water (used to activate the yeast) were added as inputs
- Gas (in the balloon and in the foam) was an output
- Energy is an output (not seen, but discussed in the prelab)
- Gas may be an input (as it is in the system) but no evidence yet that a gas entered the yeast cell)

Differentiation Point

Experimental Design
Some students may already be familiar with the practices related to experimental design. To challenge students further, provide only the basic protocol (most of the details are removed), and ask students to generate their own procedure or use the procedure to investigate a similar question, such as: What is the impact of different sugar types (honey, brown sugar, etc) on cellular respiration in yeast?

Data Interpretation
Set up the lab and data collection in the same manner as outlined above. After students have collected their data, pause to surface and review experimental design as necessary, using the Same-Different Chart as a scaffold to support students in thinking about the difference between variables. Allow students to revise the portion of the lab that asks them to identify these variables. When graphing, use the graphing decision chart before students graph data and the peer-to-peer graphing rubric after graphing. Both materials are a part of *Cellular Respiration in Yeast Investigation* and will help surface which student may need additional graphing support.

Whole-Class Investigation Summary

1. Ask students to work independently to complete the Investigation Summary section in *Making Sense of Investigation Design*, then use these completed pages to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the phenomenon.

Look & Listen For

Possible student ideas from the Summary page:

- Yeast are useful model organisms, but yeast (and the system they are found in) is different and less complex than muscle cells and a human body.
- Sugar is a source of energy for the yeast, but students may still wonder how it is used to fuel activities in the cell.
- Gas is an important component, but students may wonder which gas(es) and if it is an input or just an output (or both).
- Students may still wonder how breathing is connected to cellular respiration and/or working muscle cells.

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

5. Provide students with *Yeast Respiration Investigation Rubric*. Ask students to use the investigation rubric to self and peer assess their progress on engaging with the investigation individually and as a group.

Integrating Three Dimensions

Each question in the Summary targets a different element in the standards for this unit, so make a determination about the ideas that are most important to surface in the classroom to set the stage for the Explain phase.

Routine

This is the first time **Domino Discover** is being used in this unit. This routine is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Biology Course Guide for support with this routine.

Access for Multilingual Learners

Domino Discover provides receptive language opportunities for students who are **entering and emerging** language learners. For those who are **transitioning and expanding**, this routine provides time to rehearse language with peers, so that students are not responsible for on-the-spot responses before they are ready.

Self and Peer Assessment

1. Ask students to work independently to complete the Investigation Discussion prompts in *Graphing Support - Scaffold*, then discuss the findings with their group.

2. Provide time for students to use the *Yeast Respiration Investigation Rubric* to reflect on their own participation in the investigation, and that of their peers.

Explain 1

Developing an understanding of how cells generate ATP in the process of cellular respiration.

Students engage with **data collected and a complex text** about **cellular respiration** in yeast in order to **modify and refine a model that shows inputs and outputs in the system.**

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Triads	❑ Class Consensus Discussion	❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ Input-Output Model for Cellular Respiration ❑ Cellular Respiration in Yeast Text ❑ Summary Task	None	❑ *Characteristics of a Model Consensus List (Example)* ❑ *Class Consensus Discussion Steps* ❑ *Biological Levels of Organization* ❑ Driving Question Board (questions related to this 5E) ❑ Chart from Engage of students' ideas related to breathing and exercise

Refine Class Consensus on Scientific Models

1. Using the example of yeast, prompt students to come up with additions to the class wide list of the characteristics of a scientific model.
2. Through class discussion, surface new ideas, as well as ideas students are finding particularly helpful or important, and record those on the class consensus list. At this point, it is fine if students do not have a completely clear or accurate definition of a scientific model. They will return to this class list throughout the unit.

Classroom Supports

Continue to develop the class consensus list, as this will support student thinking about scientific models throughout the unit.

Integrating Three Dimensions

Throughout this Explain phase, students are addressing and making sense of data using **CCC #4 - Systems and System Models**; keep in mind that the Explain phase is not only about figuring out core ideas, but about using crosscutting concepts to do that figuring out.

Generate Input-Output Models

1. Prompt students to work in pairs on handout *Input-Output Model for Cellular Respiration*, based on the data collected in the investigation and the lists of inputs and outputs they created in the Explore 1 phase. These do not need to be polished pieces of work, but they should represent the current thinking of each group.

Access for Multilingual Learners

Think-Talk-Open Exchange is a routine that provides access to **transitioning** language learners. While students might not realize they need the think time, this silent planning time provides the additional processing time transitioning students need. As an added bonus, this time is helpful for many other students as well!

Look & Listen For

While students are engaged in Think-Talk-Open Exchange, circulate and listen for these ideas, to provide a bridge to the text:

- Trying to figure out why carbon dioxide is created through respiration
- Trying to make a connection between respiration and the work or activities that cells do
- Grappling with questions about where the sugar actually goes during respiration

Identifying Components to Add to Models

1. Provide students the handout *Cellular Respiration in Yeast Text*. Frame the rationale for reading this text by naming some specific point(s) that came up in the **Think-Talk-Open Exchange**. For example:

   - “When your groups were talking just now, I noticed that some groups were trying to figure out how yeast relate to humans. This is really interesting! As we read this, we can try and fill in gaps or problems with our group models.”

   - “During the TTOE just now, I heard Kameelah asking her group about what was in the bubbles in the yeast experiment. I’ve heard a lot of ideas about this. Let’s try to figure this out in today’s lesson.”

2. Prompt students to read and annotate individually for the following, using the annotation guide in their handouts:
    - points that confirm your group's model
    - points that contradict your group's model
    - points that help to modify or add to your group's model

3. Pause the class to ensure that students have a strong understanding of the hierarchical organization of the levels of the human body by showing *Biological Levels of Organization*.

4. Ask students to return to their group models, to add or modify components that were not in the earlier version.

Differentiation Point

□↔○
○↔□
□↔○

Here are some options for ensuring that all students have access to the information in the Cellular Respiration text, since there is one version of the text.

1. Shared reading group: support students by having them read the text along with a teacher, in a small group setting.
2. Anticipation guide: provide students with statements that the text will either confirm or negate. Then have them read the text with an eye for these points.

Class Consensus Discussion

1. Orient the class to the purpose and the format of the group learning routine **Class Consensus Discussion**. You may say something like this:

"We have a lot of different ideas circulating in the room right now, and they are in the form of different models. It is really important for us to get to some agreement on how we represent what we know about respiration, so that we have a shared understanding to build upon as we move ahead. In order to do this we are going to do something called a **Class Consensus Discussion**. First I will select a few different groups to share their ideas. Then, we will let each group share their model, and discuss what we can agree to as a class."

2. You may decide to walk students through the entire poster, or take them through the steps as you facilitate it.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

3. Select two or three groups' models to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of cellular respiration. The decision about which models to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

4. Ask the first group to share their model. You can do this by:
   - Projecting using a document camera; OR
   - Copying the models to be shared and passing them out to the class; OR
   - Taking a picture of each model and projecting them as slides.

5. Proceed through the steps in the Consensus Discussion Steps. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk; use the guidelines below to ensure the class focuses on ideas that will drive the lesson and unit forward.

6. Return to student questions from the start of the 5E (Engage), in order to bring up lingering issues not yet resolved, such as:

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas.

This is the first time doing such a discussion in this unit, so focus more on the steps and the process. In future parts of this unit, you will use this format to do more in-depth discussions and consensus building. Refer to the Biology Course Guide for support with this routine.

Classroom Supports

Post the steps to the class consensus discussion in the room, as a reference to which you can return to future lessons.

- How does our body sense that we need to breathe faster?
- How much oxygen do we need?
- How does oxygen get to our muscles?
- Did the marathon runner not obtain enough oxygen? Or was her body unable to properly regulate oxygen levels?

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- The role of oxygen in generating energy through cellular respiration; without oxygen, cellular respiration cannot happen.
- The idea that humans breathe faster during exercise, in order to deliver more oxygen for cellular respiration.
- All organisms, including humans, need oxygen to generate ATP to use as an energy source, and during exercise we use more energy.

Note: We haven't addressed the mechanisms behind gas exchange, so there is no need to clarify this if students still have questions!

Implementation Tip

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #4 - Systems and System Models** explicit for students by elevating and probing for ideas related to the idea that models can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. This is an important element **CCC #4 - Systems and System Models** at the high school level.

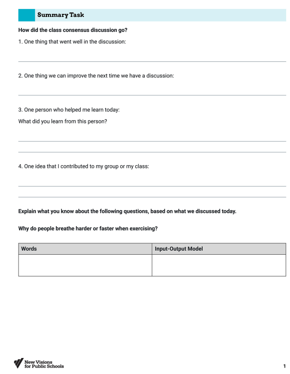
Access for Multilingual Learners

Rather than assigning a list of vocabulary words—a technique that rarely works for learning new vocabulary—this activity allows language learners to learn vocabulary from context, which may be particularly helpful for **transitioning** language learners, who already have some mastery of language.

Summary Task

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to circle back to the ideas in this text, in the coming parts of the 5E lesson.



Summary Task

How did the class consensus discussion go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today.

Why do people breathe harder or faster when exercising?

Words	Input-Output Model

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Implementation Tip

This summary is really important! It’s an opportunity to check in on each student’s thinking at this point in the unit, in a few different areas: 1) understanding how they are using the three dimensions to make sense of a phenomenon, breathing faster; 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It’s important to get all of this from individual students, so you know these things on a student-by-student basis.

Explore 2

How does the body regulate O_2 levels in the blood?

In the previous Explore/Explain, students surface the importance of oxygen in generating ATP. By **analyzing secondary data sets** on CO_2 and O_2 levels in the blood, students surface the concept of **dynamic equilibrium**, and the **interaction of body systems** in regulating oxygen levels in the blood.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Questions Only	❑ Three-Level Guide

Materials

Handouts	Lab Supplies	Other Resources
❑ Blood Oxygen Graphs ❑ Blood Oxygen Graphs Three-Level Guide ❑ Analyzing Blood Oxygen Levels Investigation Rubric	None	❑ Colored pencils

Launch

1. Begin by asking students to remind us what we are trying to figure out, (such as: Did the marathon runner run out of breath or oxygen?). In this investigation, students will begin to figure out answers to their unanswered questions from the previous Explore and Explain phases:
    - How does our body know to breathe faster or slower?
    - How much oxygen do we need?
    - How does oxygen get to our muscles?
    - How does CO_2 get out?
    - Did the marathon runner not obtain enough oxygen? Or was her body not able to properly regulate oxygen or carbon dioxide levels?

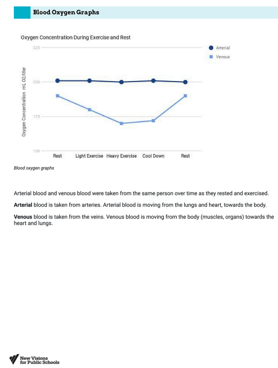
2. Ask if students know the difference between arteries and veins, and explain that arteries take blood away from the heart, while veins return blood to the heart. This background information serves as framing for the rest of the Explore phase, and it does not detract from the ideas students are intended to construct together.

Implementation Tip

When returning to the Driving Question Board, be sure to change these suggested teacher notes so that they match your class's actual questions!

Investigate Data Using a Three-Level Guide

1. Launch students into interacting with the complex graph: *Blood Oxygen Graphs*.
2. Students use the **Three-Level Guide** strategy and the steps in the *Blood Oxygen Graphs Three-Level Guide*; to interpret the graph and determine patterns.
3. Confer with students as they work in pairs to complete the three-level guide.



Access for All Learners

Visual texts can be a great tool to provide access in science classrooms for students who are not strong readers. Three-level guides build in time to think about and interpret a visual text, in order to get as much meaning as possible from the materials.

Conferring Prompts

Confer with students as they work in pairs to complete the three-level guide.
Surface student thinking about the differences between arterial and venous blood.

Suggested conferring questions
(these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):

- How do gas levels differ during light exercise as compared to intense exercise?
- Why would there be differences in each gas at different places in the body?
- Why are there different levels of each gas?

Implementation Tip

Since this is students' first time doing a **Three-level Guide**, consider facilitating this as a pair activity, with whole-class check-ins to make sure everyone is following the process. It is okay to take additional time on the first instance of using a Three-Level guide.

Whole-Class Investigation Summary

1. In pairs, students use the group learning routine **Questions Only** to generate a set of questions about the relationship between oxygen, carbon dioxide, and the body.

2. Pairs share out their questions, in order to generate a comprehensive class list of ideas.

3. At the end of the routine, each group should select and add to an agreed-upon input-output model. These do not need to be polished pieces of work, but they should represent the current thinking of each group.

Look & Listen For

In the class share out, highlight questions similar to the following:

- Where do these gases come from?
- How do they get into and out of the body?
- How does the body "know" when to bring in more oxygen from the environment?
- Why does the amount of oxygen in arterial blood stay almost constant, even when exercising?

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

5. Provide students with *Analyzing Blood Oxygen Levels Investigation Rubric*. Ask students to use the investigation rubric to self and peer assess their progress on engaging with the investigation individually and as a group.

Routine

The **Questions Only** routine offers students an opportunity to generate questions that can guide their investigations about a phenomenon. This is the first time this routine appears in this unit! Please read the Biology Course Guide for detailed steps about this routine.

Explain 2

Using visual texts to construct an explanation of how interacting systems regulate gas exchange.

Students partner-read a **visual text** in order to **construct a sequence chart that explains** how **feedback mechanisms work to maintain homeostasis and regulate gas exchange through the coordinated effort of multiple body systems at the cellular, organ, and body system levels.**

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Lab groups	❏ Domino Discover	❏ Sequence Chart

Materials

Handouts	Lab Supplies	Other Resources
❏ Summary Task	None	❏ *Gas Exchange Card Sequence* ❏ MedlinePlus text: Gas exchange ❏ BBC diagram: Respiration ❏ *Sequence Chart* ❏ Video of ventilation and gas exchange in the lungs

Launch

1. Introduce the guiding question for this Explain phase activity, connecting to one or more questions from the end of the Explore phase: How does the body regulate gas exchange?

Integrating Three Dimensions

Throughout this Explain phase, students are addressing and making sense of data using **CCC #7 - Stability and Change;** at the high school level this CCC addresses feedback mechanisms, which are an underlying way of thinking about biological systems that cuts across topics and is explicitly taught as a lens in this 5E.

Use Cards and Text to Build a Sequence Chart

1. Provide student groups with the cards for the **Sequence Chart** activity. Explain the directions for the activity, making it clear that this task is not a simple matching activity. For example:

"I have just given every group a set of cards. There are some ideas on these cards that we've already thought about in this unit. Other ideas might be new. Your job is to work with your group to come up with a sequence for these cards that makes sense. There are different ways to piece together the information, so don't worry about getting the one right answer."

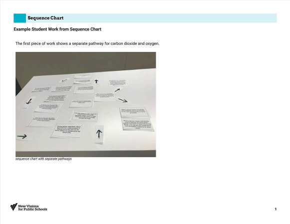
2. Provide student groups with the text and video as resources, once they get stuck or are clear about what they need to figure out next. These resources provide information for modifying the card sequence.

Look & Listen For

While students are engaged in completing the **Sequence Chart** activity, circulate and listen for or ask about these key ideas:

- Trying to make a connection between respiration and the work or activities that cells do.
- Grappling with questions about where the sugar actually goes during respiration.

Use the *Sequence Chart* to guide how you support students.


Sequence Chart

Example Student Work from Sequence Chart

The first piece of work shows a separate pathway for carbon dioxide and oxygen.

sequence chart with separate pathways

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Differentiation Point

Here are some options for ensuring that all students have access to the **Sequence Chart** activity.

- Have students who are struggling to get started go through the cards and annotate all of the ones that relate to Carbon Dioxide and all the ones that relate to Oxygen, as a way to start categorizing the cards.
- Start a group with a smaller set of cards, then adding others in later in the class.

Access for All Learners

We found that students need support and facilitation to do this sequence chart well. Keep in mind that this is not a simple matching game. Instead, be available to help students make sense of the material and work together to create a sensible sequence. There are many valid answers or pathways.
Prompting students to sequence or reorganize information provides access to learners who need additional time to process and make sense of the learning.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:

"We are going to use a **Class Consensus Discussion**, just like we did a few days ago, to learn about all the thinking in the room and come to some decisions about how the human body "knows" how to have the right amount of different gases at all times."

2. You may decide to walk students through the entire poster again, or take them through the steps as you facilitate it.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

3. Select two or three groups' sequence charts to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of gas exchange. The decision about which models to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

4. Ask the first group to share their model. You can do this by:
    - Projecting using a document camera; OR
    - Copying the models to be shared and passing them out to the class; OR
    - Taking a picture of each model and projecting them as slides.

5. With each group that presents, pause and reflect on which components are happening at the cell, organ, or body system level. You can keep a chart paper with this information, or just ask students to note which levels are implicated in the different sequence charts. Begin to set up the idea that there are systems at different levels interacting here.

6. Proceed through the steps in the Consensus Discussion Steps. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk, so be sure to facilitate the conversation so that key ideas emerge.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Refer to the Biology Course Guide for support with this routine.

Integrating Three Dimensions

Make sure this idea of a feedback mechanism is treated as a concept, not just as a vocabulary word. This is students' first time in the unit considering this complex idea, but they will come back to it multiple times. If many students note that the sequence charts all look the same, then go ahead and name that pattern as a *feedback mechanism*. But there is no need to rush into definitions.

7. Return to student questions that bring up lingering issues not yet resolved, such as:
    - Is it possible just to run out of oxygen?
    - Is it possible to have too much carbon dioxide in our blood? What would happen?
    - Did the marathon runner not obtain enough oxygen? Or was her body unable to properly regulate oxygen levels?
    - Do all living things regulate gas in the same way?

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- Oxygen moves easily into the bloodstream from the air in the lungs.
- The brain detects increased carbon dioxide in the blood, and that makes you breathe faster.
- Carbon dioxide is a product of respiration, and it ends up in blood in order to be breathed out.
- These sequence charts show a *feedback mechanism*.

Note: Dynamic equilibrium and homeostasis do not need to be introduced as vocabulary at this point. Instead, provide students time to observe this pattern and articulate what they are seeing. This concept will return in the two subsequent 5E plans.

Access for Multilingual Learners

Rather than assigning a list of vocabulary words—a technique that rarely works for learning new vocabulary—this activity allows language learners to learn vocabulary from context. This approach is particularly helpful for **transitioning** English Language Learners.

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about how the body regulates gas exchange.

Summary Task

Today we completed a class consensus discussion after looking at a few different sequence charts. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today.

1. How does the body regulate gas exchange?

2. Why do we say that gas exchange is a feedback mechanism?

3. How is gas exchange regulated at the cell, organ, and body system level? Give one example of each.

Cellular level:

New Visions for Public Schools 1

Integrating Three Dimensions

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) understanding how they are using the three dimensions, including the concept of gas exchange, to make sense of a phenomenon, breathing faster; 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

How do different plants regulate gas exchange?

Students extend their ideas about **gas exchange** by **constructing a model** to demonstrate how plants **regulate** gas exchange.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Read-Generate-Sort-Solve	None

Materials

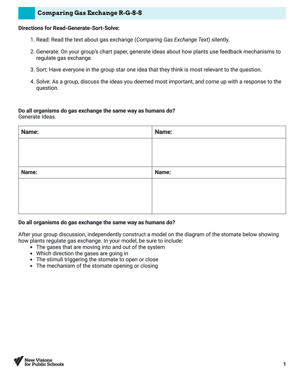
Handouts	Lab Supplies	Other Resources
❑ Comparing Gas Exchange Text ❑ Comparing Gas Exchange R-G-S-S	None	

Text-Based Task

1. Organize students into triads. Highlight for students that in the previous Explore & Explain, they figured out how humans regulate gas exchange in order to generate ATP to use as an energy source for life processes (like exercise) and to expel waste products.
2. If this question has not surfaced yet, prompt students to consider whether they think other organisms regulate gas exchange the same way humans do. Ask them to list reasons why this might be helpful to figure out. Note: It is possible that students may have asked whether this process of gas exchange is the same for all living things. If so, let them know this is the question they will be figuring out in this Elaborate.
3. Provide the guiding prompt for working through *Comparing Gas Exchange Text*: How do plants regulate gas exchange, and how is that similar to or different from how humans do so?
4. Provide the text on plants students.
5. Facilitate the group learning routine **Read-Generate-Sort-Solve** using the handout *Comparing Gas Exchange R-G-S-S* as a way for students to synthesize and extend their thinking.

Access for All Learners

In the Explain phase, the teacher was able to assess student learning around how the human body regulates gas exchange. This phase of the 5E allows for students who are still unsure of that idea to develop it further through learning about other organisms.



Comparing Gas Exchange R-G-S-S

Directions for Read-Generate-Sort-Solve:

1. Read: Read the text about gas exchange (*Comparing Gas Exchange Text*) silently.
2. Generate: On your group's chart paper, generate ideas about how plants use feedback mechanisms to regulate gas exchange.
3. Sort: Have everyone in the group star one idea that they think is most relevant to the question.
4. Solve: As a group, discuss the ideas you deemed most important, and come up with a response to the question.

Do all organisms do gas exchange the same way as humans do?
Generate Ideas.

Name:	Name:
Name:	**Name:**

Do all organisms do gas exchange the same way as humans do?

After your group discussion, independently construct a model on the diagram of the stomate below showing how plants regulate gas exchange. In your model, be sure to include:

- The gases that are moving into and out of the system
- Which direction the gases are going in
- The stimuli triggering the stomate to open or close
- The mechanism of the stomate opening or closing

Routine

The **Read-Generate-Sort-Solve** routine promotes collaborative engagement in problem-solving and supports students in articulating their thinking and making it transparent, before considering solutions. This is the first time the class has engaged in this routine, so be sure to refer to the Biology Course Guide for planning support.

Look & Listen For

Students may generate ideas such as:

- Plants exchange gas with their environment.
- Plants regulate gas exchange through a set of feedback mechanisms.
- Diffusion is an important, key process for the movement of gas.
- Plants have cells that enable gas exchange and transport between components of the leaf system at different scales

Evaluate

How does the regulation of gas exchange connect to changes we see during intense exercise?

Students **use their input/output model**, and their new understanding of **cellular respiration and the regulation of gas exchange** through the **interaction of multiple body systems** in order to address the Marathon Runner problem. Students evaluate the relevance of new evidence, such as the O_2 saturation of the runner.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Domino Discover	None

Materials

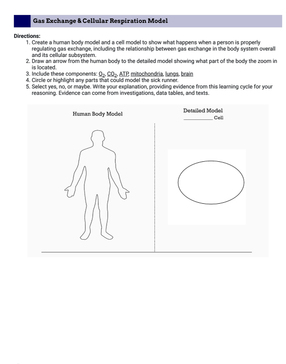
Handouts	Lab Supplies	Other Resources
❑ Gas Exchange & Cellular Respiration Model ❑ Gas Exchange & Cellular Respiration Model Rubric	None	❑ Class wide scientific model characteristics ❑ Driving Question Board from the start of the unit should be available

Revisit the Performance Task

1. Prompt students to consider where they currently stand on the question category from the Driving Question Board that they have been investigating throughout this 5E instructional sequence (for example: Did the marathon runner run out of breath or not get enough oxygen?).

2. Students work individually on *Gas Exchange & Cellular Respiration Model*, in the Performance Task Organizer. They should make choices on how to represent their ideas using the model they are developing. In the models, students are representing how a human normally regulates gas exchange at different scales and how the components of the body and the body as a system overall relate to each other.

3. Confer with students while they are working.



Gas Exchange & Cellular Respiration Model

Directions:
1. Create a human body model and a cell model to show what happens when a person is properly regulating gas exchange, including the relationship between gas exchange in the body system overall and its cellular subsystem.
2. Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3. Include these components: O_2, CO_2, ATP, mitochondria, lungs, brain
4. Circle or highlight any parts that could model the sick runner.
5. Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Human Body Model

Detailed Model
__________ Cell

Conferring Prompts

Confer with students as they work to develop their models. Prompt students to return to the class wide scientific model characteristics, posted in the room.

Suggested conferring questions:

- Can you confirm, contradict, or modify anything on the list based on your interactions with models throughout these investigations on gas exchange and cellular respiration?
- How can you use the characteristics on the list to inform the development of your own model?

4. Provide students with the normal oxygen saturation level 95-100%, or refer them to the graph from Explore 2. This information should be recorded in their organizer.

5. Students individually use their model to evaluate the claim on whether or not the runner was not able to regulate oxygen, and collapsed because of this (*Did the runner run out of oxygen?*). Prompt students to use the medical tent data to support their claim. They should also consider data and evidence gathered during the investigations completed during this instructional sequence, as well as their new understandings.

6. Use the *Gas Exchange & Cellular Respiration Model Rubric* for students to self-reflect on their progress and to provide individual feedback towards the final task.

Implementation Tip

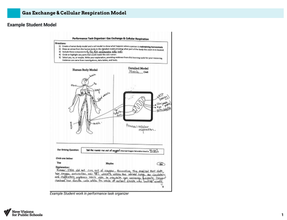
When returning to the **Driving Question Board**, be sure to change these suggested teacher notes so that they match your class' actual questions!

Document Class Thinking

1. Prompt students to discuss, with their groups, their decision on the question: Did the marathon runner run out of oxygen? Students can use the notes in their Performance Task Organizers in these discussions.

2. Each group comes to a consensus answer to the question—*Yes, No, or Maybe*—and should be able to articulate their reasoning.

3. Use the *Gas Exchange & Cellular Respiration Model Rubric* for for students to self-reflect on their progress and to provide individual feedback towards the final task. As a teacher, use the sample student work, *Gas Exchange & Cellular Respiration Model* to guide feedback to students.



4. Conduct a **Domino Discover** to hear from each group, and tally the responses on chart paper. It is not necessary to discuss all the positions or get to class consensus at this point. Based on the investigations in this 5E instructional sequence, most groups will say *No*. Groups that shared *Yes* or

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Biology Course Guide for support with this routine.

Maybe may need some additional support during the next 5E instructional sequence when ideas related to cellular respiration and feedback mechanisms repeat.

Revisit the Driving Question Board

1. Use the **Driving Question Board** routine to discuss which of their questions have been answered.
2. Have students identify which categories/questions they have not figured out yet. Students should share out these questions, and document new questions that arise based on what they have been learning, which can be added to the Driving Question Board.
3. One question category still unanswered should relate to questions about muscles and energy (for example, questions about: Did the marathon runner's muscles just get tired or did she run out of energy?). Tell students that in the next sequence of lessons, they will investigate what it means when our muscles get tired. Some students may already anticipate connections to what they were learning in this Gas Exchange instructional sequence, which should be noted, and revisited during the Muscles and Energy sequence.

Implementation Tip

Use the **Driving Question Board** unit routine to document students' evolving questions.

Standards in Gas Exchange and Cellular Respiration 5E

Performance Expectations

HS-LS1-2	**Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.** Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system. Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.

In NYS the clarification statement has been edited as follows: Emphasis is on functions at the organism's system level such as nutrient uptake, water delivery, immune response, and organism response to stimuli.

HS-LS1-3	**Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.** Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels. Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.
HS-LS1-7	**Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.** Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.

In NYS, all occurrences in this PE of the phrase "cellular respiration" have been replaced with the phrase "aerobic cellular respiration."

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3)	LS1.A Structure and Function • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. LS1.A(3) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. LS1.A(4) LS1.C Organization for Matter and Energy Flow in Organisms • As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. LS1.C(3) • As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. LS1.C(4)	Systems and Systems Models • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. CCC4(3) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Developing and Using Models		*Input-Output Model for Cellular Respiration Summary Task*	*Blood Oxygen Graphs Three-Level Guide Summary Task*	*Comparing Gas Exchange R-G-S-S*	Cell and Body Model in *Gas Exchange & Cellular Respiration Model* *Gas Exchange & Cellular Respiration Model Rubric*
LS1.A Structure and Function	Rumors: students' post-its and the emergent categories		Questions Only *Gas Exchange Card Sequence;* *Summary Task* *Summary Task*	*Comparing Gas Exchange R-G-S-S*	Cell and Body Model in *Gas Exchange & Cellular Respiration Model* *Gas Exchange & Cellular Respiration Model Rubric* Yes-No-Maybe Explanation in *Gas Exchange & Cellular Respiration Model*
LS1.C Organization for Matter and Energy Flow in Organisms	Rumors: students' post-its and the emergent categories	*Input-Output Model for Cellular Respiration Summary Task* Cellular Respiration in Yeast Investigation			Cell and Body Model and Yes-No-Maybe Explanation in *Gas Exchange & Cellular Respiration Model*
Systems and Systems Models		Making Sense of the Cellular Respiration in Yeast Investigation *Input-Output Model for Cellular Respiration Summary Task*		*Comparing Gas Exchange R-G-S-S*	Cell and Body Model in *Gas Exchange & Cellular Respiration Model* *Gas Exchange & Cellular Respiration Model Rubric*
Stability and Change			*Gas Exchange Card Sequence;* *Summary Task*	*Comparing Gas Exchange R-G-S-S*	Yes-No-Maybe Explanation in *Gas Exchange & Cellular Respiration Model* *Gas Exchange & Cellular Respiration Model Rubric*

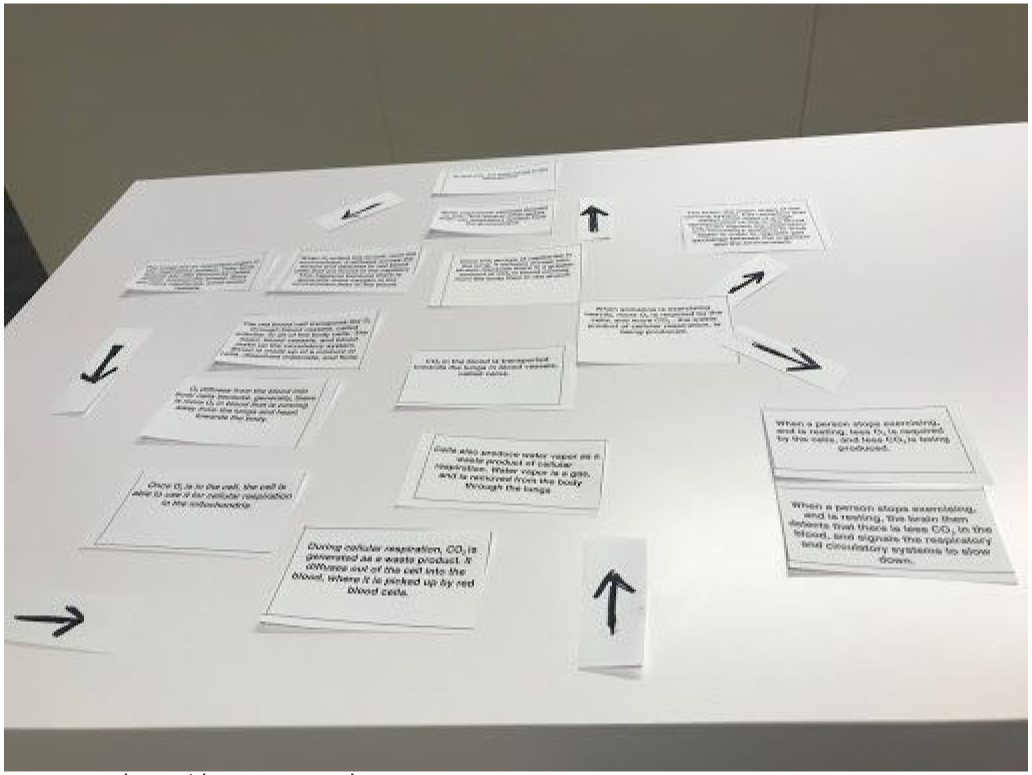
Common Core State Standards Connections

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics		MP2 MP3 HSF-IF.B.5 8.F.B.5	MP2 MP3 HSF-IF.B.5 8.F.B.5	MP2	MP2
ELA/Literacy		RST.9-10.1 RST.9-10.7 SL.9-10.4 SL.9-10.5	RST.9-10.1 RST.9-10.7 SL.9-10.4 SL.9-10.5	WHST.9-10.9	WHST.9-10.2 WHST.9-10.9 SL.9-10.4

Student Work for Gas Exchange and Cellular Respiration 5E

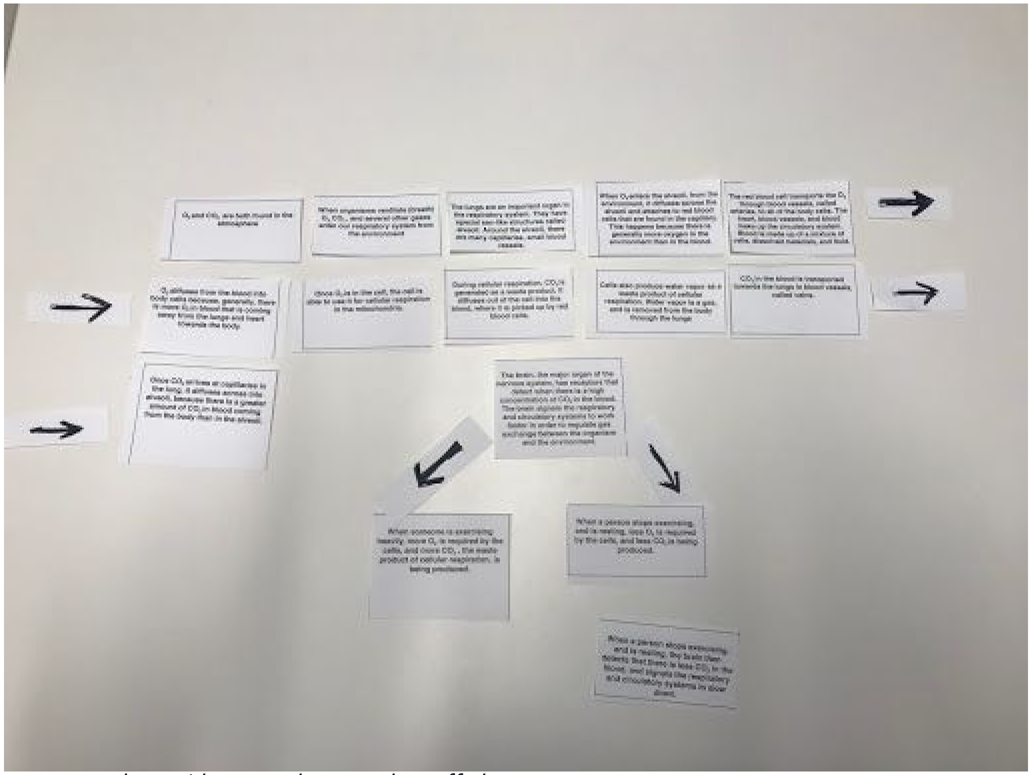
Example Student Work from Sequence Chart

The first piece of work shows a separate pathway for carbon dioxide and oxygen.



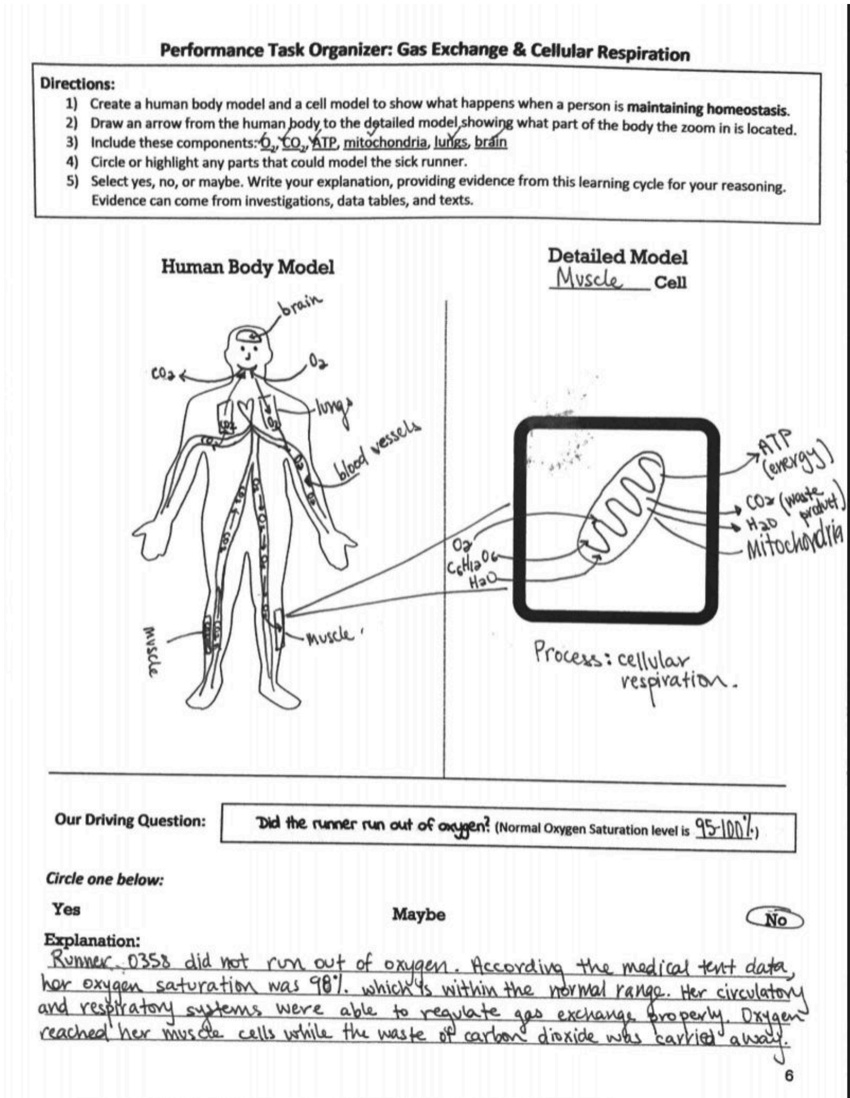
sequence chart with separate pathways

The second piece of work shows a more linear flow, with one off-shoot that represents exercise and rest.



sequence chart with one pathway and an off-shoot

Example Student Model



Performance Task Organizer: Gas Exchange & Cellular Respiration

Directions:
1) Create a human body model and a cell model to show what happens when a person is **maintaining homeostasis.**
2) Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3) Include these components: O_2, CO_2, ATP, mitochondria, lungs, brain
4) Circle or highlight any parts that could model the sick runner.
5) Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Human Body Model | **Detailed Model** Muscle **Cell**

Our Driving Question: Did the runner run out of oxygen? (Normal Oxygen Saturation level is 95-100%)

Circle one below:

Yes | Maybe | No

Explanation: Runner 0358 did not run out of oxygen. According the medical tent data, her oxygen saturation was 98% which is within the normal range. Her circulatory and respiratory systems were able to regulate gas exchange properly. Oxygen reached her muscle cells while the waste of carbon dioxide was carried away.

6

Example Student work in performance task organizer

Implementation Notes from Field Test Teachers

These are some points that we have learned from teachers' use of this unit:

- At this point in the unit students have seen several different types of models (input/output model, body model, and use of model organisms). Throughout this instructional sequence you should have gone back to the characteristics of model list and made revisions and understanding of models should be shifting in students.
- Remember both models should be showing what normally happens during respiration.
- For the Detailed Model, students should be creating an input-output model of cellular respiration. It is okay if they show this occurring in a yeast cell at this point because that is what they interacted with during the learning cycle. Alternatively, students could show it in human muscle cell.
- In the Human Body Model you should expect students to show how the respiratory and circulatory systems normally interact. This should include oxygen and carbon dioxide reaching the lungs and being transferred to or from the circulatory system. A great model might even include an increase in heart rate and breathing rate in response to exercise.
- To break down some barriers it may be useful to provide students will pictures of the body systems for them to see the location of different organs in the body. During the field test, we found that some students didn't know where the lungs were located and this was a barrier to the task and not really related to what we are assessing. You will also need to encourage students to just draw boxes with labels if they are concerned about their artistic ability.
- At this point, many students will still be drawing the components you have learned about, but will struggle to show how they connect and interact within the body. It is okay to move on even if students are still struggling as these ideas about cellular respiration will circle back again in the next 5E instructional sequence

Classroom Resources for Gas Exchange and Cellular Respiration 5E

Characteristics of a Model Consensus List (Example)
Class Consensus Discussion Steps
Biological Levels of Organization
Characteristics of a Model Consensus List (Example)
Gas Exchange Card Sequence

Characteristics of a Model Consensus List (Example)

Class Consensus List:
Characteristics of a Scientific Model

It is a picture/representation/drawing of the thing we are studying.

It helps us see or visualize something.

It lets us think about impacts of actions/cause & effect.

It is a 'testable' version of something.

We can (more) easily manipulate variables.

Difficult to see or experiment on human cells.

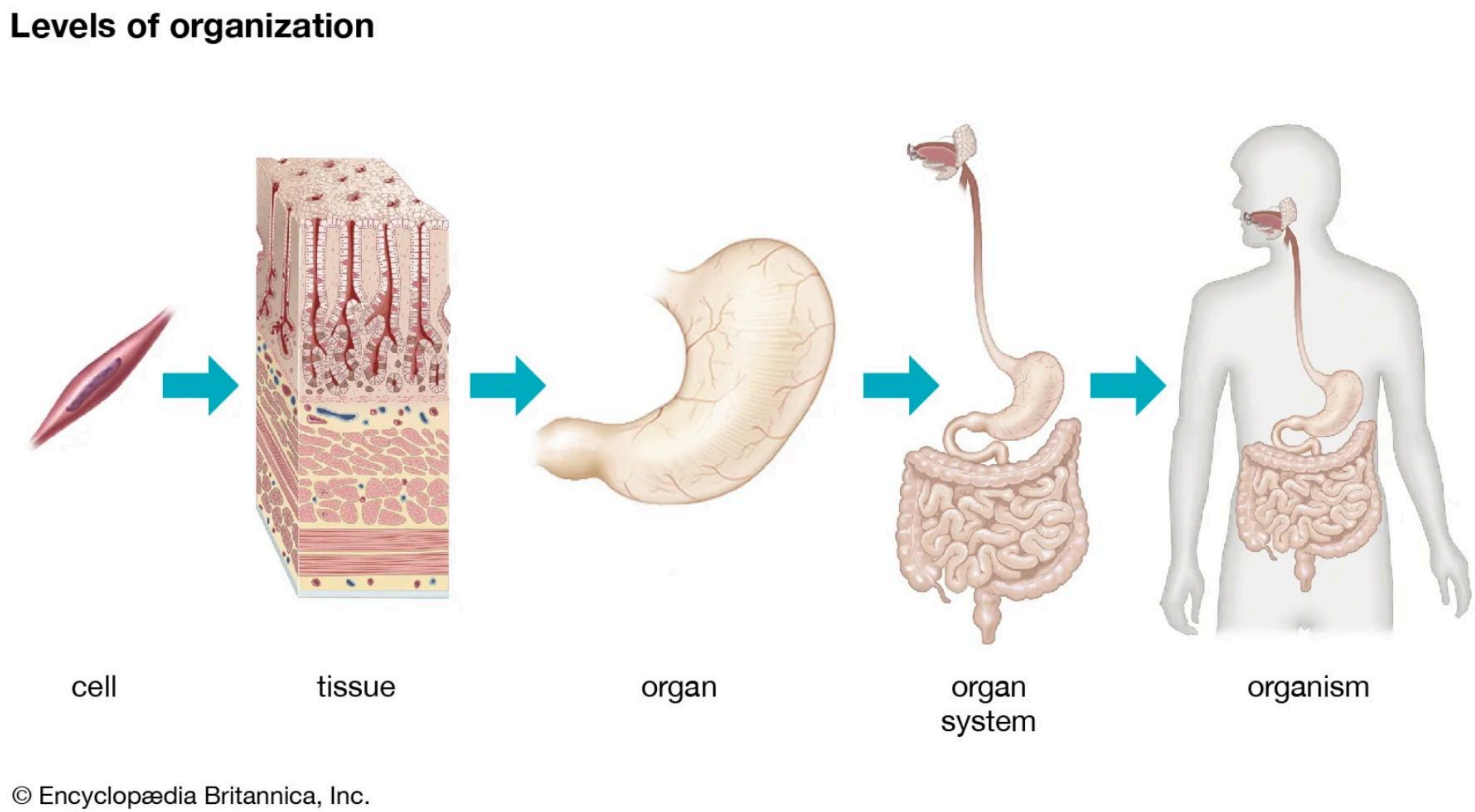
Cheaper, simpler, faster, more efficient.

Class Consensus Discussion Steps

1) we select a few different groups' ideas.
2) The first group shares out their work.
3) one person repeats or reiterates what the first group shared.
4) Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5) Everyone confers in table groups.
6) Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.



Biological Levels of Organization

Class Consensus List:
Characteristics of a Scientific Model

It is a picture/representation/drawing of the thing we are studying.

It helps us see or visualize something.

It lets us think about impacts of actions/cause & effect.

It is a 'testable' version of something.

Gas Exchange Card Sequence

Use this master to create cards for the card sequence activity.

The atmosphere is made up of gases, including O_2 and CO_2.	When organisms ventilate (breathe), O_2, CO_2, and several other gases enter our respiratory system from the environment.	The lungs are an important organ in the respiratory system. They have special sac-like structures called alveoli. Around the alveoli, there are many capillaries and small blood vessels.
When O_2 enters the alveoli from the environment, it diffuses into the bloodstream and attaches to red blood cells that are found in the capillary. This happens because there is generally more oxygen in the environment than in the blood.	The red blood cell transports the O_2 through blood vessels, called arteries, to all of the body cells. The heart, blood vessels, and blood make up the circulatory system. Blood is made up of a mixture of cells, dissolved materials, and fluid.	O_2 diffuses from the blood into body cells because, generally, there is more O_2 in blood that is coming away from the lungs and heart towards the body.
Once O_2 is in the cell, the cell is able to use it for cellular respiration in the mitochondria.	During cellular respiration, CO_2 is generated as a waste product. It diffuses out of the cell into the blood, where it is picked up by red blood cells.	CO_2 in the blood is transported towards the lungs in blood vessels called veins.

Once CO_2 arrives at capillaries in the lung, it diffuses across into alveoli, because there is a greater amount of CO_2 in blood coming from the body than in the alveoli.	When someone is exercising heavily, more O_2 is required by the cells, and more CO_2, the waste product of cellular respiration, is being produced.	The brain, the major organ of the nervous system, has receptors that detect when there is a high concentration of CO_2 in the blood. The brain signals the respiratory and circulatory systems to work faster in order to regulate gas exchange between the organism and the environment.
Cells also produce water vapor as a waste product of cellular respiration. Water vapor is a gas, and is removed from the body through the lungs.	When a person stops exercising and is resting, the brain then detects that there is less CO_2 in the blood, and signals the respiratory and circulatory systems to slow down.	When a person stops exercising and is resting, less O_2 is required by the cells, and less CO_2 is being produced.

Muscles & Energy 5E	Did the marathon runner's muscles get tired? How do our bodies use energy during exercise?	**Performance Expectations** HS-LS1-2, HS-LS1-3, HS-LS1-7	**Investigative Phenomenon** Humans experience pain and tiredness with both short and long periods of exercise.	**Time** 6-10 days

In this 5E instructional sequence, students investigate the following question category surfaced during the Driving Question Board launch: Did the marathon runner run out of fuel or energy? This leads to questions about why humans run out of energy or feel tired when exercising, and how we can use energy from food or from stores in our bodies to exercise. Students investigate how cells convert the energy found in glucose into ATP that can be used to fuel life processes, and how the body regulates glucose through feedback mechanisms, so we are able to keep exercising. Students figure out that it's unlikely that the marathon runner collapsed because she ran out of energy.

ENGAGE	Why do our muscles become tired when exercising?	Connecting to their earlier questions about the marathon runner not having enough energy, students notice and describe how tired their **muscles feel after exercising**. This leads them to express a need to **investigate** where and how we get energy, why we feel tired, and how energy gets to our muscles.
EXPLORE 1	How do muscle cells obtain the materials they need and get rid of waste products, so they can continue to do their work during exercise?	Students **gather data during an investigation** on the impact of exercise on CO_2 production, pulse rate, and breathing rate in order to surface how **feedback mechanisms across multiple body systems maintain homeostasis during exercise.**
EXPLAIN 1	Developing an understanding of how muscle cells require the delivery of certain materials and the removal of waste products in order to function effectively during exercise.	Students use **data collected from multiple investigations** to **develop an input-output model** of **cellular respiration in muscle cells,** emphasizing how **energy is released from breaking bonds in matter.** Students **use the model to predict** the impact of exercise on muscle cells and steps leading to **muscle fatigue.**
EXPLORE 2	How is the amount of glucose in the blood regulated, so that cells always get what they need to do respiration?	Students **conduct an investigation** that surfaces **patterns on how feedback mechanisms regulate blood glucose**.
EXPLAIN 2	Generating annotated graphs in order to explain how feedback mechanisms regulate blood glucose levels.	Students work in pairs to **generate annotated graphs** representing **feedback mechanisms**, starting with the role of insulin in **regulating blood glucose levels** before and after meals.
ELABORATE	How does the body use stored energy, in the form of fat, to fuel life activities?	Students test out their ideas and conceptions about **energy and matter** in the body. Students investigate the **role of body fat and glycogen** in maintaining homeostasis, by **analyzing a graph** representing the stable blood glucose levels of a long-distance cyclist. This task connects to prior learning and extends students' understanding as they integrate **understanding of how energy and matter is used, stored, converted, and released as body heat** to the environment.
EVALUATE	How can we compare dynamic equilibrium in different body systems?	Students **compare graphs** representing **dynamic equilibrium** in the **regulation of O_2 and blood glucose levels** in order to surface the variability in the range of tolerance of **different components of the human body system.** This task launches students into applying their understanding to the Marathon Runner phenomenon.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

Why do our muscles become tired when exercising?

Connecting to their earlier questions about the marathon runner not having enough energy, students notice and describe how tired their **muscles feel after exercising**. This leads them to express a need to **investigate** where and how we get energy, why we feel tired, and how energy gets to our muscles.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Experiencing Muscle Fatigue	❏ Rubber bands or clothespins (one per group) ❏ Clock or stopwatch	❏ Input-output model from previous 5E ❏ *Muscles at Different Scales* (optional)

Launch

1. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to becoming tired or running out of energy. Here are some possible questions that may have come up:
    - Did the marathon runner run out of energy?
    - Was the runner just really tired out?

2. Ask students to share more about why they asked questions about energy or becoming tired during extensive exercise.

3. Prompt students to remember a time when their muscles were tired after exercising. For example:

    - "We have figured out a few things, in the last 5E, about whether the runner just ran out of breath, and to do that we learned about respiration going on in all of our cells. Now, we are going to figure out if the runner in some way didn't have enough energy to keep exercising. Before we start on that, think about a time you have observed someone exerting themselves, or a time you were exercising hard. What happened?"

4. Have students share a few experiences in response to the prompt.

Look & Listen For

Students definitely have background knowledge on getting tired from exercise! They may surface ideas around:

- Muscles need energy.
- Muscles start to burn or ache.
- Running out of breath is related to muscle tiredness.
- If you sprint up stairs, you can run out of energy fast.
- You may need more energy when exercising for a while.

You may also hear these ideas, which will be addressed in future 5Es.

- You get tired because you sweat a lot.
- You get tired because you are so hot.

Surfacing Student Ideas

1. Provide students with the *Experiencing Muscle Fatigue* handout. The activity demonstrates how the muscles in the finger can become tired after trying to pull apart a tightly wrapped rubber band. A clothespin can be substituted for a rubber band, if desired.

2. Have students complete the activity in pairs, then discuss their experience and answers with a partner. As students are working in pairs, confer with them about their learning.

Conferring Prompts

Confer with students as they work in pairs. Here are some areas of focus:

- Their prediction on why it was harder to stretch the rubber band on the second attempt (question #3)
- What they will need to do next to figure out why our muscles become tired during exercise (question #4)
- How students are using their initial input-output model (generated in the previous 5E instructional sequence) to generate ideas.

3. As students' partner work is wrapping up, let them know that they are going to do a **Domino Discover** group learning routine to surface the ideas about the question for this 5E: Why do we feel like we run out of energy when we exercise? Give pairs time to prepare, then start the routine.

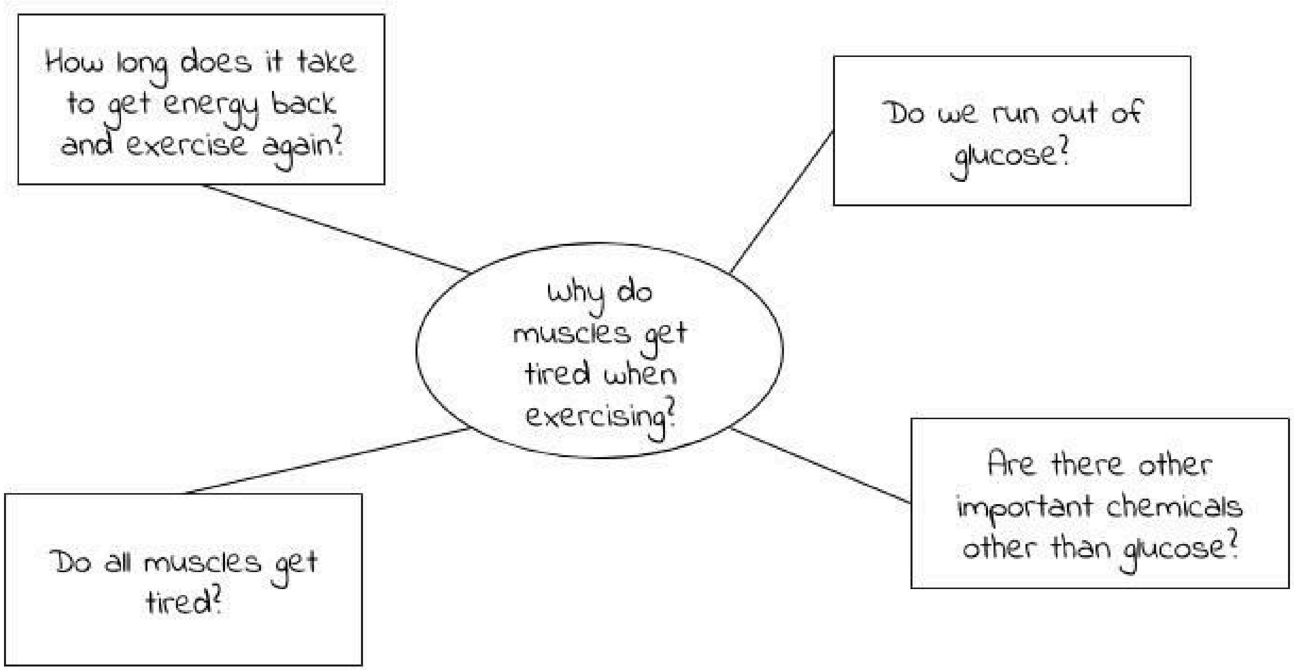
4. Chart the answers on a class chart that will stay up as a reminder of this investigative phenomenon throughout the 5E.

Classroom Supports

Create a poster or space on a whiteboard for categories of student ideas that have come up. Use the title: Why do we feel like we run out of energy from exercise? (Or use a more appropriate question that comes from the students!) You can refer back to the poster throughout this 5E plan.

Routine

There is not going to be a whole lot of variation in what students surface in this **Domino Discover**. In fact, part of what is interesting is that humans all experience a similar kind of fatigue from this activity!



Example Class Chart

Access for All Learners

All students have some background knowledge on the topic of muscle tiredness. They may be sports fans or athletes, or maybe there are stairs in the school building that everyone hates to walk up! Be sure to provide opportunities for students to articulate those ideas at this point, by prompting them to connect to their own experiences.

Look & Listen For

During the Domino Discover, the following ideas are likely to surface and are worth returning to.

From question 3 in the handout:

- Muscles runs out of sugar or glucose
- Not enough oxygen
- Too much carbon dioxide
- Muscles break down

From question 4 in the handout:

- This lab only looked at fingers; perhaps other muscles do not become tired in the same manner.
- We have not looked into what is happening at the cellular, organ, or body system levels during exercise.
- How do humans use sugar/food/fuel during exercise?
- What is happening in muscles during exercise?
- How do materials needed for cellular respiration get to muscle cells?

Differentiation Point

Support for using input-output models: Some students may need a reminder or scaffolded support on how to use their initial input-output model to make predictions about why our muscles become tired.

Support for visualizing muscle cells: Some students may need support visualizing the skeletal and muscular systems, particularly how muscle cells make up an organ called a muscle. This is an idea that many students will remember from middle school, but for those who do not, some small group instruction will support them.

1. Provide the *Muscles at Different Scales* handout to the group.
2. Introduce the guiding prompt: Why do muscles become tired during exercise?
3. Prompt students to use their input-output model to make a prediction and initial response to the guiding question.

Confer with students around these questions:

- When exercising, which inputs and outputs will change?
- What will the cell need more of?
- What will the cell need to get rid of?
- Where do these materials come from?
- What other variables, not indicated on your model, are important for the function of working muscles?

Explore 1

How do muscle cells obtain the materials they need and get rid of waste products, so they can continue to do their work during exercise?

Students **gather data during an investigation** on the impact of exercise on CO_2 production, pulse rate, and breathing rate in order to surface how **feedback mechanisms** **across multiple body systems maintain homeostasis during exercise.**

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Consensus-Building Share	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Exercise and Cellular Respiration Investigation ❑ Making Sense of Exercise and Cellular Respiration ❑ Exercise and Cellular Respiration Investigation Rubric ❑ Exercise and Cellular Respiration Investigation -Scaffolded	❑ beaker ❑ test tube or cup ❑ bromothymol blue solution (BTB) ❑ straw ❑ stop watch	

Launch

1. Ask students to re-cap why they are trying to figure out whether the marathon runner ran out of energy. Have a few students connect the current work to the overall storyline of the unit.

2. Remind students about where they are in the unit. This reminder could be: “So far, we have several ideas about how our body generates ATP to use as an energy source during exercise, and we know that glucose is an important part of this process. We generated and modified our input-output models a few times already, based on what we learned in the last 5E. We talked about investigating our need for energy, and how exercise increases the overall rate of cellular respiration and therefore ATP or energy.”

3. Connect the work completed to date to the lab students will do in this Explore phase. While it’s important to include students’ thinking in the design of the investigation, they cannot be expected to come up with the use of bromothymol blue BTB as an indicator. In order to get them thinking about the use of BTB, demonstrate how it could be relevant to answer the next set of questions:

    - “We know that carbon dioxide is a byproduct or waste product of respiration. If we want to figure out something about exercise and muscle tiredness without actually looking inside the human body, one thing we could look at is carbon dioxide output. Does anyone have ideas about how to do that? I'm going to demonstrate one way. We can blow into a solution of BTB; it changes color as the carbon dioxide increases. How could we use that to design an investigation?"

4. Ask students to write their initial ideas for using BTB to test for respiration while exercising.

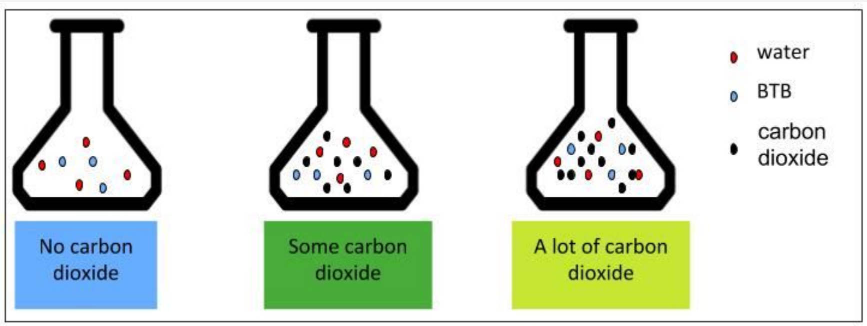
Implementation Tip

At this point the class should have surfaced ideas related to generating and using energy, so we can exercise for an extended period of time. It is important to connect this learning to the ideas students are figuring out in this Explore phase.

Differentiation Point

Although students who had science throughout middle school probably had some opportunities to learn about indicators, it is likely that some students have never considered the usefulness of indicators. If this is the case in your class, the following activity can be used to differentiate for all or part of the class:

1. Have students draw three flasks, labeling them "no carbon dioxide," "some carbon dioxide," and lots of carbon dioxide."
2. Show students how to draw a particle model of these three situations, with one color for water, one for carbon dioxide, and one for BTB.
3. Explain that it's helpful to remember that if you add carbon dioxide to a flask with water and BTB, the number of other particles stays the same.
4. The goal is to create a visual tool that students who have less fluency with using indicators, and designing investigations using indicators, can use in the rest of the Explore phase. An example tool is below.



Sample Diagram

Design an Investigation

1. Ask lab groups to brainstorm how they can investigate the relationship between exercise and cellular respiration. Prompt students to use their input-output models and their own experiences with exercise to generate appropriate variables and a procedure.

2. Hand the *Exercise and Cellular Respiration Investigation* out to the class, determining if there are groups that should work with the more scaffolded version.

3. Ensure that lab groups have sufficient time to complete the design sections of the lab, so that they have a clear plan for their investigation. The lab handout guides them through the relevant steps.

Implementation Tip

Appropriate indicators of cellular respiration include:

- breathing rate (in breaths per minute)
- heart rate (in beats per minute, based on pulse rate)
- carbon dioxide production (time it takes bromothymol blue to change color)

Make sure students consider measuring indicators at rest (with no exercise) and after 1-2 minutes of exercise.

Differentiation Point

Based on student readiness and instructional goals, students can design their own investigation, using the initial version of the lab, or use the scaffolded version that includes a suggested procedure and data tables.

Carry out Investigation and Collect Data

1. Students work in lab groups to carry out the investigations they have planned. It is important to remind students to be careful only to exhale through the straw into the BTB solution, not inhale.

Lab Safety Note: Do not allow students to handle broken glass at any time. An adult should use forceps, tongs, scoops, or other mechanical devices for removing broken glass from the work area. Goggles should be worn by everyone during labs that involve glassware and / or any substances.

2. During data collection, and once the data collection is complete, prompt students to use the See-Think-Wonder graphic organizer to articulate their ideas about the data.

Conferring Prompts

Confer with students as they work in collaborative groups to collect data and complete the See-Think-Wonder chart.

Suggested conferring questions:

- How did exercise impact the rate of CO_2 production? Why?
- How can you use this data to provide evidence for your input-output model?
- How did exercise impact pulse rate? Why?
- How is increasing pulse rate connected to cellular respiration?
- Compare and contrast this investigation to our investigation on yeast.
- In this investigation, we exercised for 1 minute at time. How might our bodies respond differently when exercising for longer periods of time (like in a marathon)?

Whole Class Investigation Summary

1. Have student groups work through the *Making Sense of Exercise and Cellular Respiration* section of the investigation, discuss the most important finding from their data collection, and come to a group agreement on what they would like to share.

2. Facilitate a share-out of ideas, using the group learning routine **Consensus-Building Share**.

Look & Listen For

While students are engaged in the **Consensus-Building Share**, listen for the following comments and chart them, for the class's reference in the Explain phase. Related to question 4 and question 5:

- Students know the inputs and outputs of cellular respiration, which is used to generate energy for all life processes.
- Students have ideas about how the brain / nervous system and/or other mechanisms may be involved in coordinating the multiple body systems at work to maintain homeostasis (the term feedback mechanism will be introduced in the next Explore/Explain).
- Energy (sugar molecules, ATP) is an important component, but many questions remain around how energy is regulated and used in the body during exercise.

Overall trends:

- The trend that as one exercises, pulse rate, breathing rate, and CO_2 production increase.
- The inference that the rate of cellular respiration increases during exercise (evidence: O_2 requirement increases, CO_2 excretion increases, circulatory system works faster to exchange materials).
- Because glucose is required for cellular respiration, we can infer that the need for glucose will increase in muscle cells.

3. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Routine

This is the first time the routine **Consensus-Building Share** appears in this unit. This routine is a way to make sensemaking visible and move towards a class-wide consensus around a new idea. Be sure to look at the Biology Course Guide for the action pattern for this routine.

As the whole-class activity for this Explore, it is important to surface as many of the ideas in the Look and Listen For section as possible. For the first time using this routine, it is appropriate to prompt students with questions such as "Did any group find something similar?" or "Can anyone add to that?"

4. Provide students with *Exercise and Cellular Respiration Investigation Rubric*. Ask students to use the investigation rubric to self and peer assess their progress on engaging with the investigation individually and as a group.

Explain 1

Developing an understanding of how muscle cells require the delivery of certain materials and the removal of waste products in order to function effectively during exercise.

Students use **data collected from multiple investigations** to **develop an input-output model** of **cellular respiration in muscle cells,** emphasizing how **energy is released from breaking bonds in matter.** Students **use the model to predict** the impact of exercise on muscle cells and steps leading to **muscle fatigue.**

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Think-Talk-Open Exchange	❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ Muscle Cell Input-Output Model ❑ Muscle Fatigue Text ❑ Summary Task	❑ battery-powered electronic item (such as a cell phone)	❑ Lumen Learning text: Muscle Metabolism (additional information)

Revisit Class Consensus on Scientific Models

1. Prompt students to revisit the class consensus list on scientific models.
2. Through class discussion, surface new ideas, as well as ideas students are finding particularly helpful or important, and record those on the class consensus list.

Classroom Supports

Continue to develop the class consensus list, as this will support student thinking about scientific models throughout the unit.

Class Consensus List:
Characteristics of a Scientific Model

It is a picture/representation/drawing of the thing we are studying.

It helps us see or visualize something.

It lets us think about impacts of actions/cause & effect.

It is a 'testable' version of something.

We can (more) easily manipulate variables

Difficult to see or experiment on human cells

Cheaper, simpler, faster, more efficient

Generate Input-Output Models for Muscle at Rest vs. Exercising

1. Explain to students that we are going to build on the models everyone created and discussed in the first 5E by making models of muscle cells in different states: at rest and exercising. "When we learned about gas exchange and cellular respiration, we focused on how cells take in oxygen and use it. Now we are going to focus on what happens in muscle cells that could make a runner get tired. Could an athlete ever just be out of energy?"

2. Prompt students to work independently on the *Muscle Cell Input-Output Model* handout. This provides a place to organize ideas from the investigation. The input-output model is a little more complicated than the one in the previous 5E, as you are asking students to think about being at rest vs. exercising. Additionally, it offers a way to visualize the inputs-outputs of muscle *tissue*, a group of muscle cells together. If students are confused with the distinction between cells and tissues, the differentiation activity from the Explore addresses this distinction.

Identify Relevant Information to Add to Models

1. Have students share their independently-created input-output models with their group mates. Prompt students to flag (using a sticky note) at least one area in their own input-output model that requires more investigation. Some things that students may flag, based on the investigations completed so far, include the following:
    - Where does the tiredness or burning you feel in muscles come from?
    - Where does the energy come from?
    - Does sweat come from our muscles moving?
    - We have evidence of more CO_2 going out; is there also more O_2 going in?
    - Are all the same inputs and outputs there when at rest, just in lower amounts?

Implementation Tip

Having students flag their input-output models with one or more colored sticky notes makes it easy for you to scan the room and determine that all students have identified a gap or a question in their texts.

2. Bring the class together to look at a few of the models that have been created, and introduce the idea of energy. It is likely that only a few students in the class have added a great deal of detail about energy, since until now they have focused on the flow of matter like oxygen and carbon dioxide. Bring this up to the class:

"I'm noticing that many of your models have descriptions of matter in common. But scientists also can model systems by following the flow of *energy* in and out. I know you have learned about types of energy in middle school. Take a moment and talk with your partner. Let's try and make a list of some types of energy that people have heard of before."

3. Allow partners to speak for a moment, then create a list on chart paper of the kinds of energy that students know about. It is likely that they will bring up heat energy, sound energy, light energy, and kinetic/mechanical energy. Students may also remember gravitational potential energy from middle school.

4. It is unlikely that students will bring up chemical potential energy. The idea of energy being released in the breaking of bonds is an important idea to utilize in the models of muscles, and this can be done through a connection to students' prior knowledge. Show students an electronic item that is battery-powered and that obviously produces more than one form of energy. You can show a cell phone, lamp, or small toy.
    - "Talk to your partner, and list the types of energy produced by this device. Then figure out where that energy comes from."

5. Give students time to think through this with partners, then have a few groups share their answers. There will likely be consensus that there is stored energy in the battery; use this to introduce the term *chemical potential energy*, which also describes energy stored in glucose molecules.

6. Prompt students to flag any additional places in their models that are open questions, now that they have considered the need to represent the flow of energy in and out of the muscle tissue.

Access for All Learners

Some students may struggle identifying gaps in their models. They may say, "I don't have any more questions." In this situation, individual conferring really can support students. Ask a student, "Can you walk me through each of the things in your model right now?" and invite them to think aloud through every step. Show how there are places where they are unsure: those are great places to flag as questions!

Integrating Three Dimensions

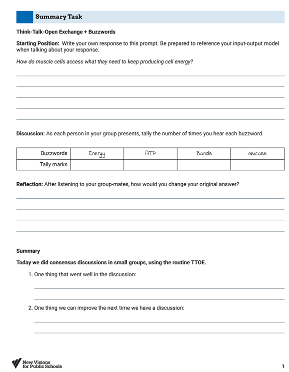
Throughout this Explain phase, students are revising input-output models using a high school element of **CCC #5 - Energy and Matter**. Keep in mind that students need to go beyond explaining how muscle cells work; this Explain is designed to support them in using a crosscutting concept to do this sensemaking. Be sure to make **CCC #5 - Energy and Matter** explicit for students by elevating and probing for ideas related to the concept that energy cannot be created or destroyed—it only moves between one place and another place, between objects, or between systems.

7. Distribute the *Muscle Fatigue Text* to the class. Prompt students to read and annotate individually for the following, using the annotation guide in their handouts:
    - Points that confirm your group's model
    - Points that contradict your group's model
    - Points that help to modify or add to your group's model

8. Ask students to return to their individual models, to add or modify components that were not in the earlier version--especially flagged items that they can fix now.

Discuss Models in Groups

1. Ask students to get into groups of three (triads) to prepare for a **Think-Talk-Open Exchange**. Distribute the *Summary Task*



Summary Task

Think-Talk-Open Exchange + Buzzwords

Starting Position: Write your own response to this prompt. Be prepared to reference your input-output model when talking about your response.

How do muscle cells access what they need to keep producing cell energy?

Discussion: As each person in your group presents, tally the number of times you hear each buzzword.

Buzzwords	Energy	ATP	Bonds	Glucose
Tally marks				

Reflection: After listening to your group-mates, how would you change your original answer?

Summary

Today we did consensus discussions in small groups, using the routine TTOE.

1. One thing that went well in the discussion:
2. One thing we can improve the next time we have a discussion:

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2. As a starting position for the discussion, ask students to use the current version of their models to respond to this prompt individually: *How do muscle cells access what they need to keep producing energy?*

3. Explain that in this variation of **Think-Talk-Open Exchange**, everyone will pay attention to the way their peers are using specific concepts to build their answer. In the handout, there is a space for tallying the "buzzwords." Since this is the first time students are doing this routine, it is best to give them the buzzwords to track, but in future enactments of this routine, they should come up with their own lists.

4. Guide the class through the routine, reminding students to use their models to explain their points.

5. After each student has had a round of think and talk time, provide 3 minutes for open exchange. Then have students complete the reflection, to note any changes to their original answers such as:
    - The circulatory system (as well as the respiratory system discussed in the previous 5E) plays a vital role in transporting materials to all cells in the body.
    - Cellular respiration and all life processes involve multiple components interacting at different scales: organelles, cells, tissues, organs, and body systems.

Take Time for These Key Points

Listen for these key points:
- Inputs and outputs of cellular respiration
- Function of ATP as chemical energy source to drive the work of muscles (and all life processes)
- Muscle cells become fatigued when lacking one or more of the inputs, or have an accumulation of waste products.

As a transition, prompt students to think about glucose as something that has to be regulated, connecting to points that came up in the group discussions. Prompt students with questions such as: Where does glucose for your muscle cells come from? or How do we know if we have enough or too much glucose?

Routine

This is not the first time doing the routine **Think-Talk-Open Exchange** but this time we are using a variation called **Think-Talk-Open Exchange + Buzzwords** which needs a little additional introduction. Refer to the Biology Course Guide for support with this routine.

Access for Multilingual Learners

Think-Talk-Open Exchange + Buzzwords is a great routine for emerging language learners, as it provides them with a space to listen to others' spoken language. It also supports transitioning language learners by providing intentional think and preparation time, instead of forcing extemporaneous sharing.

Explore 2

How is the amount of glucose in the blood regulated, so that cells always get what they need to do respiration?

Students **conduct an investigation** that surfaces **patterns on how feedback mechanisms** **regulate blood glucose**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Normal Blood Glucose Graph ❏ Glucose Regulation Investigation ❏ Making Sense of Glucose Regulation Investigation ❏ Glucose Regulation Investigation Rubric	❏ Arizona Iced Tea can (large) ❏ sugar ❏ clear cups ❏ bromothymol blue (dilute) ❏ vinegar (dilute) ❏ sodium hydroxide (dilute) ❏ beakers ❏ small clear containers or squirt bottles	❏ Harvard article: How Sweet Is It?

Launch

1. Ask students to recall what they are trying to figure out (whether the marathon runner ran out of energy). Tell students that, so far, they have a lot of ideas about how our body generates ATP to use as an energy source during exercise and that glucose is an important part of this process. Point to the input-output model or patterns generated from the Explore 1 & Explain 1 discussions. At this point the class should have some ideas surfaced around the need for glucose as an energy source for cellular respiration, but they still don't know how our body regulates blood glucose levels. Have students recall their earlier discussion around how oxygen is regulated in the body, and ask them to think about how they might investigate a similar process with blood glucose.

2. Remind students that, just like in the yeast lab, it is sometimes difficult to see a process occuring in the human body. Introduce the idea that you will simulate processes that occur in the human body, and other resources, in order to figure out how blood glucose is regulated.

Carry out Investigation and Collect Data

Students work in lab groups to carry out a set of investigations on how the body regulates glucose. There are three related investigations that may be set up in stations or done as group tasks sequentially:

- Arizona Iced Tea Demonstration
- *Normal Blood Glucose Graph* with See-Think-Wonder
- *Glucose Regulation Investigation*

Arizona Iced Tea Demonstration

1. Provide a large Arizona Ice Tea can to demonstrate the drink
2. In a separate clear cup, pour in about 12 tablespoons of sugar (approximately the amount of sugar in one can)
3. Introduce the scenario (or provide a written scenario) at the station: "A student is sitting in class drinking a giant bottle of Arizona tea. She isn't doing a strenuous activity, so her body doesn't need all of the sugar right away. What happens to all the sugar?"
4. Students brainstorm their responses, and discuss in their lab group, noting their response in their science notebook.

Differentiation Point

This demonstration can be easily modified to include a different beverage or even different food products, based on student interest. Visit the site Harvard article: How Sweet Is It? for a list of common beverages and the sugar content.

Conferring Prompts

Confer with students as they work in collaborative groups

Suggested conferring questions:

- Does the student store the energy? How?
- How do we use the energy found in the sugar?
- How do you feel after you drink a sugary beverage?

Set up for *Normal Blood Glucose Graph* + See-Think-Wonder

1. Provide students with the *Normal Blood Glucose Graph* that includes a See-Think-Wonder organizer.
2. Students work collaboratively to interpret the graph, using the See-Think-Wonder organizer

Conferring Prompts

Confer with students as they work in collaborative groups

Suggested conferring questions:
- How would you describe blood glucose levels over time?
- How does the timing of a meal impact blood glucose levels? Why?
- Do you think every person shows the same pattern? Why or why not?

Set up for *Glucose Regulation Investigation*

1. Distribute the student-facing handout, *Glucose Regulation Investigation*.

Lab Safety Note: Sodium hydroxide is a strong base that can be harmful to the skin or eyes, even in dilute forms. Be sure to have students wear goggles and lab gloves during this investigation.

2. Explain that we will simulate glucose regulation, using model 'blood.' The model blood is clear, so that we can see the mechanism by which glucose is regulated (a clear cup).

3. Distribute supplies using stations. Each station has:
    - 1 labeled clear container or cup of bromothymol blue diluted with some water (so that it's a pastel teal color -- see the 'normal' color below)
    - 1 labeled plastic cup of "Glucose" with a pipette = vinegar (diluted)
    - 1 labeled plastic cup of "Insulin" with a pipette = sodium hydroxide (diluted)

'Blood' color	What it means
Royal blue	Blood glucose is too low
Green/teal	Blood glucose is a normal level (homeostasis)
Yellow	Blood glucose is too high

4. Students work in collaborative groups to complete the lab.

The "normal" green color represents normal sugar levels (really bromothymol blue). Students get this cup at the beginning. They then add 5 drops of "Glucose" (really vinegar) and the liquid turns yellow. Oh no--that means too much sugar! We need to get back to homeostasis! They must now add 10 drops of "insulin" (really sodium hydroxide), but now glucose (sugar) is too low, indicated by royal blue. They then struggle to get their cups back to the normal green color by doing this simple acid/base reaction. They experience for themselves this feedback loop!

Conferring Prompts

Confer with students as they work in collaborative groups

Suggested conferring questions:

- Based on this activity, what do you think homeostasis means?
- How were you able to maintain homeostasis in the model blood?
- Is the blood glucose level in the model blood the same all of the time, or does it fluctuate? Why?
- What was the role of insulin? How did it help restore homeostasis?

Implementation Tip

- Do not use paper cups as the sodium hydroxide can break down the cup
- Squirt bottles can be used instead of pipettes to limit spills.
- Students should use proper safety gear such as gloves and eye goggles
- You must do a run through beforehand to ensure that the number of drops is correct for your specific set up. It will vary slightly by how much you dilute the BTB or the sodium hydroxide. You do not have to dilute the vinegar or sodium hydroxide -- this is suggested just to be extra safe.

Whole Class Investigation Summary

1. In collaborative groups, prompt students to review the observations and notes collected during the investigations and the completed *Glucose Regulation Investigation* handout.
2. Prompt students to discuss how these three investigations connect to each other.
3. Students generate a brief written summary that represents the important observations they noted. Each summary should end with at least one question that group still wants to figure out based on their observations.
4. Facilitate a share-out of ideas, using the group learning routine, **Domino Discover.**

Routine

The **Domino Discover** routine is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Biology Course Guide for support with this routine.

Example Student Response

People can take in a large amount of sugar when eating and drinking. Blood glucose levels can change over the course of a day. After a meal, blood glucose levels increase, and then slowly decrease. It seems that there is always some glucose in the blood. Glucose levels are controlled through a feedback mechanism, when glucose is high, insulin lowers the glucose. When sugar is low, we eat more food to get sugar. We still don't know how insulin works to make the blood sugar lower.

Look & Listen For

Students may generate ideas such as:

- When we consume food and drinks, we obtain sugar that can be used for energy.
- Blood glucose fluctuates throughout the day.
- Blood glucose increases right after a meal.
- Blood glucose decreases between meals.
- Blood glucose never goes above a certain amount and never goes below a certain amount (a set point).
- Feedback mechanisms maintain internal conditions (by adding a little or taking away a little) of something, even when external conditions change.
- In this case, adding insulin moved the system (the model blood in this case) away from homeostasis. Adding a certain amount of sugar brings the system back to homeostasis (and vice versa).
- Students may wonder how insulin lowers blood glucose.
- Students may wonder why blood glucose does not dip below (or rise above) a certain amount, even overnight when people are not eating.
- Students may wonder how people may continue to exercise if they are not eating or drinking sugar.

5. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

6. Provide students with *Glucose Regulation Investigation Rubric*. Ask students to use the investigation rubric to self and peer assess their progress on engaging with the investigation individually and as a group.

Explain 2

Generating annotated graphs in order to explain how feedback mechanisms regulate blood glucose levels.

Students work in pairs to **generate annotated graphs** representing **feedback mechanisms**, starting with the role of insulin in **regulating blood glucose levels** before and after meals.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Normal Blood Glucose Graph (enlarged so that there is room to annotate) ❑ Summary Task	None	❑ Insulin and glucagon

Launch

1. Introduce the guiding question for this Explain phase activity, connecting to one or more questions from the end of the Explore phase: How does the body regulate blood glucose?

Integrating Three Dimensions

Throughout this Explain phase, students returning to **CCC #7 - Stability and Change**; at the high school level this CCC addresses feedback mechanisms, which are an underlying way of thinking about biological systems. Students started to think about this framing in the first 5E; this is an opportunity to continue working to use the CCC.

Annotate a Graph

1. Provide student pairs with an enlarged version of *Normal Blood Glucose Graph*, previously seen by students in the Explore phase. Divide up portions of the graph, so that pairs are focusing on one section of the graph (it could be divided up into three sections for example). Students will annotate what they already may know from the Explore phase, using insulin, eating, and blood glucose.

2. Show students the video Insulin and glucagon . As they watch the video, students are gathering information to add to their annotated graph. Provide students with the following terms that should be included in the graph:
    - Insulin
    - Glucagon
    - Pancreas
    - Blood glucose
    - Glycogen
    - Muscle cells
    - ATP
    - Hypothalamus (brain/nervous system)

Access for All Learners

Prompting students to sequence or reorganize information provides access to learners who need additional time to process and make sense of the learning.

Implementation Tip

Providing students with time to take this graph apart and interpret it section by section helps them get as much as possible from this data set.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like "We are going to use a **Class Consensus Discussion**, just like we did a few days ago, to learn about all the thinking in the room and come to some decisions about how the human body regulates blood glucose."

2. You may decide to walk students through the entire poster again, or take them through the steps as you facilitate it.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

3. Select two or three groups' annotated graphs to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of glucose regulation and of the crosscutting concept of feedback mechanisms.

4. Ask the first group to share their model. You can do this by:
   - projecting using a document camera; OR
   - copying the models to be shared and passing them out to the class; OR
   - taking a picture of each model and projecting them as slides

5. With each group that presents, pause and reflect on how maintaining balance occurs through constant feedback.

6. Proceed through the steps in the Consensus Discussion Steps. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk, so be sure to facilitate the conversation so that key ideas emerge.

7. Return to student questions that bring up lingering issues not yet resolved, such as:
   - What is low blood sugar? What is high blood sugar?
   - If you are not drinking enough water, will that affect glucose?

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Refer to the Biology Course Guide for support with this routine.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make CCC #7 - Stability and Change explicit for students by elevating and probing for ideas related to feedback mechanisms and how they can stabilize or destabilize a system. This is an important element CCC # 7 - Stability and Change at the high school level. Make sure this idea of a *feedback mechanism* is treated as a concept, not just as a vocabulary word. Developing a complex understanding of feedback and how it relates to balance and homeostasis is key.

Take Time for These Key Points

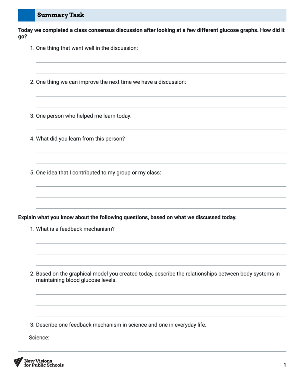
Pause the discussion and ask for clarification, particularly of the following key points:

- The brain triggers the release of hormones that either release or store glucose.
- There is always glucose in the blood. We need it even if all we are doing is resting.
- You don’t need to be taking in food to keep up your blood glucose.
- These graphs are another representation of a *feedback mechanism*.

Note: This 5E sequence does not get into the topic of diabetes, which occurs when glucose regulation is not in homeostasis. However, insulin resistance (diabetes) is discussed in Unit 3.

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.
2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about how the body regulates gas exchange.



Summary Task

Today we completed a class consensus discussion after looking at a few different glucose graphs. How did it go?

1. One thing that went well in the discussion:
2. One thing we can improve the next time we have a discussion:
3. One person who helped me learn today:
4. What did you learn from this person?
5. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today.

1. What is a feedback mechanism?
2. Based on the graphical model you created today, describe the relationships between body systems in maintaining blood glucose levels.
3. Describe one feedback mechanism in science and one in everyday life.

Science:

New Visions for Public Schools 1

Integrating Three Dimensions

This summary is really important! It’s an opportunity to check in on each student’s thinking at this point in the unit, in a few different areas: 1) understanding how they are using the three dimensions, including the concept of feedback mechanisms and glucose regulation; 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It’s important to get all of this from individual students, so you know these things on a student-by-student basis.

Differentiation Point

The end of this Explain phase is an opportunity to assess student understanding around how the human body regulates blood glucose. The next phase, the Elaborate, allows for students who are still unsure of that idea to develop it further through learning about how the human body stores and uses energy.

Elaborate

How does the body use stored energy, in the form of fat, to fuel life activities?

Students test out their ideas and conceptions about **energy and matter** in the body. Students investigate the **role of body fat and glycogen** in maintaining homeostasis, by **analyzing a graph** representing the stable blood glucose levels of a long-distance cyclist. This task connects to prior learning and extends students' understanding as they integrate **understanding of how energy and matter is used, stored, converted, and released as body heat** to the environment.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups	❏ Read-Generate-Sort-Solve	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Blood Glucose and Exercise ❏ Storage Molecules ❏ Where Does the Fat Go? ❏ Experimenting with Fat Loss	None	

Text-Based Task

1. Organize students into triads.

2. Highlight for students that in the previous Explore/Explain, they figured out how humans regulate blood glucose levels, in order to generate energy for life processes (like exercise). It is possible that students may have asked about the role of fat in regulating blood glucose levels or the ability of humans to sustain exercise. If so, let them know this is the question they will be figuring out in this Elaborate. If this question has not surfaced yet, prompt students to consider where energy or glucose comes from when a person has not eaten in a long time. Ask them to list reasons why this might be helpful to figure out.

3. Provide students the guiding prompt that they will use as they work through the resources: How does a cyclist's muscle cells obtain glucose for cellular respiration, if he does not consume any calories during his ride?

4. Provide each student in each group with a different resource:
    - *Blood Glucose and Exercise*
    - *Storage Molecules*
    - *Where Does the Fat Go?*

Routine

The **Read-Generate-Sort-Solve** routine promotes collaborative engagement in problem-solving and supports students in articulating their thinking and making it transparent, before considering solutions. Refer to the Biology Course Guide for planning support.

5. Use the group learning routine **Read-Generate-Sort-Solve** for students to articulate their ideas so far.

Differentiation Point

Distribute resources to students based on readiness or interest.

Look & Listen For

Students may generate ideas such as:

- The cyclist's blood glucose stays within normal range, but it does increase slightly and decrease slightly over time.
- When exercising (or engaging in any life process), muscle cells use glucose, then breakdown glycogen, and when glycogen is depleted,

fat is metabolized to fuel cellular respiration.

- As a person exercises, there may be a slight increase in blood glucose, in order to maintain homeostasis, releasing glycogen from the liver and muscle cells.
- In breaking down fat for cellular respiration, the majority of the mass that was stored in fat is released as CO_2 and exhaled.
- The energy used for cellular respiration is held in the bonds of storage molecules; the mass is found in the atoms.

Note: Students may have a lot of questions about diets, carbohydrate intake, etc. that go beyond the scope of this unit. Some of these types of questions will surface again in a later unit on food systems and sustainability (Unit 5 *Food for All)*

Access for All Learners

The graph title and topic can be modified to better fit student interest and background knowledge base. For example, it can be used to depict any endurance sport. Alternatively, provide students with a brief cycling clip to provide context.

Designing an Investigation

1. While students are still arranged in triads, provide them with the handout *Experimenting with Fat Loss*
2. Have them discuss the scenario at the top and discuss ways to experimentally test the student's questions. In their groups, students should talk through how they would design their investigations.
3. Have students individually complete their experimental designs.

Integrating Three Dimensions

This individual response allows students a chance to individually practice SEP 3 - Planning and carrying out investigations. In this instance, they will not conduct their investigations, but they are asked to think through the entire planning process independently. Use the student work from this phase to formatively assess how students are progressing with this practice.

Evaluate

How can we compare dynamic equilibrium in different body systems?

Students **compare graphs** representing **dynamic equilibrium** in the **regulation of O_2 and blood glucose levels** in order to surface the variability in the range of tolerance of **different components of the human body system.** This task launches students into applying their understanding to the Marathon Runner phenomenon.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups (3-4 students)	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Muscles & Energy Model from Performance Task Organizer ❏ O2 Graph and Blood Glucose Graphs (from above) ❏ Muscles & Energy Model Rubric	None	❏ Class Wide Scientific Model Characteristics ❏ Driving Question Board from the start of the unit should be available ❏ *Muscles & Energy Model* (sample student work)

Surfacing Student Ideas

1. The first two 5E instructional sequences (Gas Exchange and this one) are highly interconnected with cellular respiration, dynamic equilibrium, and the interaction of body systems as themes. Students have surfaced many commonalities and differences between how the body regulates gas exchange and blood glucose levels.

2. In small groups, prompt students to compare/contrast how the body regulates blood levels of oxygen and glucose, using a 3-column chart or similar organizer.

Blood Glucose Regulation	Similarities	Blood Oxygen Regulation

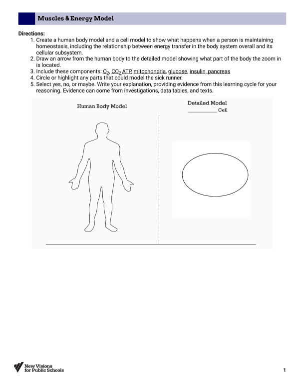
• Humans tolerate a wide range of levels • Regulated through the actions of the hormones -- insulin and glucagon • Glucose obtained through food and the actions of the digestive system	• Both essential for cellular respiration • Both regulated by feedback mechanisms • Both essential to maintain homeostasis • Both show an increase in demand during exercise • Both require interaction btw multiple body systems (circulatory, respiratory, nervous systems)	• Humans tolerate a very low range of levels • The nervous system detects high CO_2 levels (and sometimes low O_2 levels) prompting the respiratory system to increase the ventilation rate • Oxygen obtained through the actions of the respiratory system (from the atmosphere in humans)

Revisiting the Performance Task

1. Prompt students to consider where they currently stand on the question category from the Driving Question Board that they have been investigating throughout this 5E instructional sequence (for example, Did the marathon runner run out of energy?).

2. Students work individually on the Muscles & Energy section of their Performance Task Organizer. They should make choices on how to represent their ideas using the model they are developing. In the models, students are representing how a human normally regulates blood glucose.

3. Confer with students while they are working.


Muscles & Energy Model

Directions:
1. Create a human body model and a cell model to show what happens when a person is maintaining homeostasis, including the relationship between energy transfer in the body system overall and its cellular subsystem.
2. Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3. Include these components: O_2, CO_2 ATP, mitochondria, glucose, insulin, pancreas
4. Circle or highlight any parts that could model the sick runner.
5. Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Human Body Model

Detailed Model
__________ Cell

Conferring Prompts

Confer with students as they work to develop their models. Prompt students to return to the class wide scientific model characteristics, posted in the room.

Suggested conferring questions:
- Can you confirm, contradict, or modify anything on the list based on your interactions with models throughout these investigations on gas exchange and cellular respiration?
- How can you use the characteristics on the list to inform the development of your own model?

4. Provide students with the normal range for blood glucose levels 90-130 mg/dL (you can also refer students to the graph from Explore 2). This information should be recorded in their organizer.

5. Students individually use their model to evaluate the claim on whether or not the runner was not able to regulate glucose, and collapsed because of this (Did the runner run out of energy or fuel?). Prompt students to use the medical tent data to support their claim. They should also consider data and evidence gathered during the investigations completed during this instructional sequence, as well as their new understandings.

6. Use the *Muscles & Energy Model Rubric* for students to self-reflect on their progress and to provide individual feedback towards the final task.

Implementation Tip

When returning to the Driving Question Board, be sure to change the suggested teacher notes in *Muscles & Energy Model* so that they match your class' actual questions!

Document Class Thinking

1. Prompt students to discuss with their groups their decision, on the question: Did the marathon runner run out of energy or fuel? Students can use the notes in their Performance Task Organizer for these discussions.

2. Each group comes to a consensus answer to the question -- *Yes, No, or Maybe* -- and should be able to articulate their reasoning.

3. Conduct a **Domino Discover** to hear from each group, and tally the responses on chart paper. It is not necessary to discuss all the positions or get to class consensus at this point. Based on the investigations in this 5E instructional sequence, most groups will say *No*.

Routine

This **Domino Discover** routine is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Read more about **Domino Discover** in the Biology Course Guide.

Revisit the Driving Question Board

1. Use the **Driving Question Board** routine to discuss which of their questions have been answered.
2. Have students identify which categories/questions they have *not* figured out yet. Students should share out these questions, and document new questions that arise based on what they have been learning, which can be added to the Driving Question Board.
3. One question category still unanswered should relate to questions about muscles and energy (for example, questions about Did the marathon runner overheat?). Tell students that in the next sequence of lessons, they will investigate what it means when we become overheated.

Implementation Tip

Use the **Driving Question Board** unit routine to document students' evolving questions.

Standards in Muscles & Energy 5E

Performance Expectations

HS-LS1-2 **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.**
Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.
Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.

In NYS the clarification statement has been edited as follows: Emphasis is on functions at the organism's system level such as nutrient uptake, water delivery, immune response, and organism response to stimuli.

HS-LS1-3 **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.**
Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.
Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.

HS-LS1-7 **Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.**
Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration
Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.

In NYS, all occurrences in this PE of the phrase "cellular respiration" have been replaced with the phrase "aerobic cellular respiration."

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3) Planning and Carrying out Investigations • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. SEP3(2)	LS1.A Structure and Function • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. LS1.A(4) LS1.C Organization for Matter and Energy Flow in Organisms • As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. LS1.C(3) • As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. LS1.C(4)	Systems and Systems Models • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. CCC4(3) Energy and Matter • Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. CCC5(3) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Developing and Using Models		*Making Sense of Exercise and Cellular Respiration* *Muscle Cell Input-Output Model* *Summary Task*	*Glucose Regulation Investigation* *Making Sense of Glucose Regulation Investigation*		*Muscles & Energy Model* *Muscles & Energy Model Rubric*
Planning and Carrying out Investigations		*Exercise and Cellular Respiration Investigation* *Making Sense of Exercise and Cellular Respiration*			
LS1.A Structure and Function			*Glucose Regulation Investigation* *Making Sense of Glucose Regulation Investigation*		T-chart *Muscles & Energy Model* *Muscles & Energy Model Rubric*
LS1.C Organization for Matter and Energy Flow in Organisms	Domino Discover	*Exercise and Cellular Respiration Investigation* *Making Sense of Exercise and Cellular Respiration* *Muscle Cell Input-Output Model* *Summary Task*	*Normal Blood Glucose Graph*	Read-Generate-Sort-Solve	*Muscles & Energy Model* *Muscles & Energy Model Rubric*
Systems and Systems Models		*Exercise and Cellular Respiration Investigation* *Making Sense of Exercise and Cellular Respiration* *Muscle Cell Input-Output Model*			*Muscles & Energy Model* *Muscles & Energy Model Rubric*
Energy and Matter		*Exercise and Cellular Respiration Investigation* *Making Sense of Exercise and Cellular Respiration* *Muscle Cell Input-Output Model* *Summary Task*		Read-Generate-Sort-Solve	

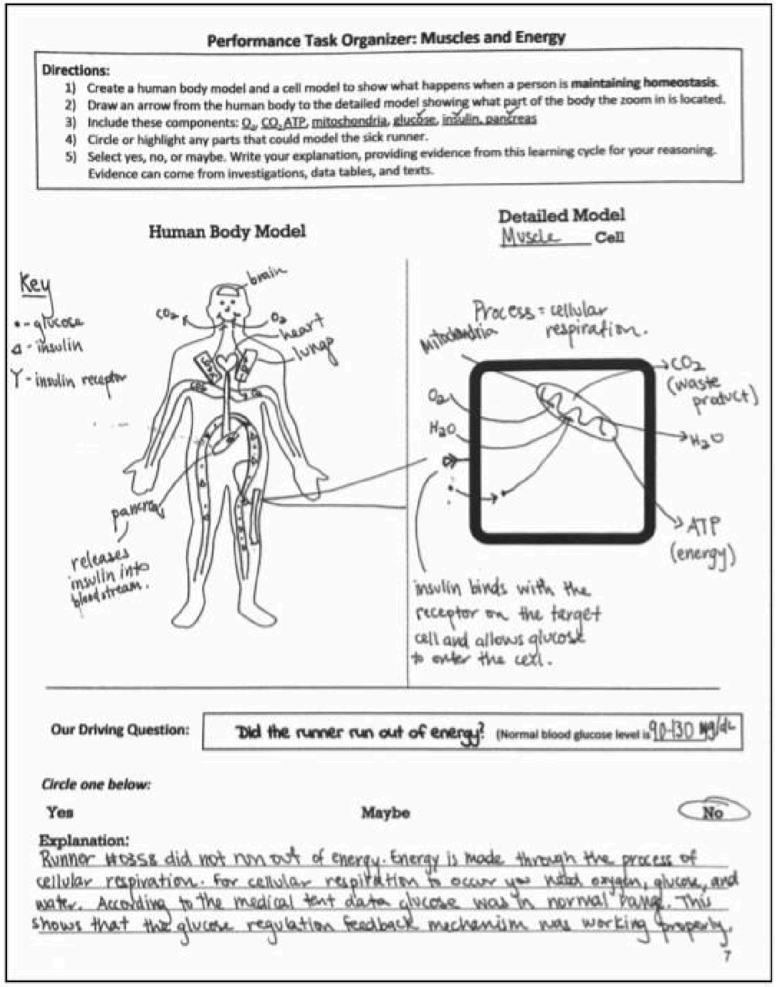
	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Stability and Change			*Glucose Regulation Investigation* *Making Sense of Glucose Regulation Investigation* *Normal Blood Glucose Graph*	Read-Generate-Sort-Solve	T-chart *Muscles & Energy Model* *Muscles & Energy Model Rubric*

Common Core State Standards Connections

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics	MP2	8.F.B.5 MP2 MP3 MP6 HSS.ID.B.6	8.F.B.5 MP2 MP3 MP6 HSS.ID.B.6	8.F.B.5	MP2
ELA/Literacy		RST.9-10.1 WHST.9-10.9 SL.9-10.4	RST.9-10.1 WHST.9-10.9 SL.9-10.4	RST.9-10.1	WHST.9-10.2 SL.9-10.4

Student Work for Muscles & Energy 5E

Example Student Model



Performance Task Organizer: Muscles and Energy

Directions:
1) Create a human body model and a cell model to show what happens when a person is **maintaining homeostasis**.
2) Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3) Include these components: O_2, CO_2, ATP, mitochondria, glucose, insulin, pancreas
4) Circle or highlight any parts that could model the sick runner.
5) Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Our Driving Question: Did the runner run out of energy? (Normal blood glucose level is 90-130 mg/dL

Circle one below:

Yes **Maybe** **No**

Explanation:
Runner #0358 did not run out of energy. Energy is made through the process of cellular respiration. For cellular respiration to occur you need oxygen, glucose, and water. According to the medical tent data glucose was in normal range. This shows that the glucose regulation feedback mechanism was working properly.

7

Muscles and Energy Model student work example

Implementation Notes from Field Test Teachers:

- Throughout this instructional sequence you should have gone back to the characteristics of models list and made revisions and understanding of models should continue to shift in students.
- You may want students to review their feedback from their Gas Exchange models before starting this new model as well. We want students to move towards making connections between different components of their models at this point.
- Remind students they should be showing what NORMALLY happens in the body.
- In the human body outline students can build off of their previous outline. You should expect students to show gas exchange and build upon the interactions of the circulatory and respiratory systems. They should also be able to include pancreas and its release of insulin. A great model may include the liver and interactions with glycogen.
- Students have some options for the detailed cell model. They could show a zoom in of the interactions between insulin and an insulin receptor allowing glucose into the cell. They could also show cellular respiration again or anaerobic cellular respiration leading to muscle fatigue.
- At this point students should really be showing the interactions between components and components on different levels of scale (organs, cells, and molecules).
- It may be useful to introduce the idea of a key/legend at this point.
- To break down some barriers it may be useful to provide students with pictures of the body systems for them to see the location of different organs in the body. We found that some students didn't know where the lungs were located and this was a barrier to the task and not really related to what we are testing.
- You will also need to encourage students to just draw boxes with labels if they are concerned about their artistic ability.

Human Thermoregulation 5E	Was the marathon runner overheated? How do our bodies deal with changes in temperature?	**Performance Expectations** HS-LS1-2, HS-LS1-3	**Investigative Phenomenon** Humans can tolerate a wide range of temperatures.	**Time** 4-6 days

In this 5E instructional sequence, students investigate the questions about body temperature surfaced during the Driving Question Board: Did the marathon runner overheat? Is it ever too hot outside to run? This leads to questions about how humans are able to maintain a fairly stable internal temperature, even when environmental temperatures fluctuate, or even when we generate heat energy during strenuous exercise. Students investigate how our body maintains stable internal temperatures through a series of feedback mechanisms, so that we are able to keep exercising. Students figure out that the marathon runner probably did not collapse because of overheating.

ENGAGE	Why are humans able to withstand great temperature extremes?	Connecting to their earlier questions about extreme exercise and temperature, students share their initial ideas about how humans maintain a stable body temperature and withstand extremes in temperature. This leads students to express a need to investigate **thermoregulation** in the human body further.
EXPLORE	How do changes in external temperature affect internal body temperature?	Students **conduct an investigation** on human **regulatory mechanisms** by collecting data on the **impact of changing external temperatures on internal body temperature**. Students use the data they collect to figure out that humans have a complex system for maintaining body temperature.
EXPLAIN	How do humans maintain a dynamic equilibrium through thermoregulation?	Students use a three-level guide to interpret a complex diagram demonstrating how **feedback mechanisms** enable the human body to **thermoregulate**. Using this new learning, students **construct a scientific explanation** of the **data collected** in the Explore phase.
ELABORATE	How can humans outrace faster animals, like horses and antelopes?	Students bring together their ideas and conceptions about **thermoregulation** by applying their thinking to a new way to model it, and use that model to explain why human thermoregulation allows them to outrun horses and antelopes. Using a template, and their understanding of **feedback systems**, students **construct a model** demonstrating the interactions and transfer of energy between systems of the human body. Students determine where animal thermoregulation differs from human thermoregulation and how that impacts racing ability.
EVALUATE	How does the body thermoregulate during exercise?	Students consider both internal and external sources of heat, and demonstrate their understanding of how an exercising person **regulates body temperature** by **evaluating the importance of body temperature data** on the Marathon Runner problem.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

Why are humans able to withstand great temperature extremes?

Connecting to their earlier questions about extreme exercise and temperature, students share their initial ideas about how humans maintain a stable body temperature and withstand extremes in temperature. This leads students to express a need to investigate **thermoregulation** in the human body further.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Temperature Extremes	None	❑ chart paper

Launch

1. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to overheating. Ask students to share more about why they asked questions about overheating or becoming hot during exercise.

Look & Listen For

- Humans can live and exercise in a wide range of temperatures.
- We have all been out in the cold and in the heat, and we were able to survive.
- Some of us have gotten really hot while exercising.

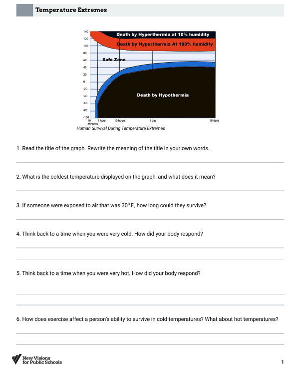
2. Use students' questions and observations about environmental temperatures to transition to the guiding question: How does the human body tolerate such a wide range of temperatures?

3. In pairs, provide students with the *Temperature Extremes* handout to read and respond to the scaffolded prompts.

4. Prompt students to consider the body models they generated during the anchor phenomenon launch as they respond to the prompts. They may also recall their own experiences exercising heavily being in cold or hot environments.

Access for All Learners

All students have experienced variations in temperature. Use this launch activity to help students identify common experiences and make connections to the phenomenon they are figuring out.


Temperature Extremes

Human Survival During Temperature Extremes

1. Read the title of the graph. Rewrite the meaning of the title in your own words.

2. What is the coldest temperature displayed on the graph, and what does it mean?

3. If someone were exposed to air that was 30°F, how long could they survive?

4. Think back to a time when you were very cold. How did your body respond?

5. Think back to a time when you were very hot. How did your body respond?

6. How does exercise affect a person's ability to survive in cold temperatures? What about hot temperatures?

New Visions for Public Schools 1

Surfacing Student Ideas

1. Ask each group to select the most important idea they have come up with through reviewing the graphs.
2. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the phenomenon.

Look & Listen For

The following ideas may come up from students' answers to Question 7:

- Humans can tolerate a wide range, but at temperatures that are too high or too low, we get sick or die.
- Humans can decide to take actions that help in high or low temperatures, such as clothing choices, shelter, heating, or shade.
- The human body automatically does things to cool down when we are hot, such as sweating.
- The human body automatically does things to warm up when we are cold, such as shivering and moving around.

Classroom Supports

Create a poster or space on a whiteboard for categories of student ideas that have come up. Use the following title: How does the human body tolerate such a wide range of temperatures? You can refer back to the poster throughout this 5E instructional sequence.

Routine

If students are gaining proficiency with **Domino Discover**, add complexity by saying that ideas cannot be repeated. In this situation, all groups come with multiple possible things to share.

Explore

How do changes in external temperature affect internal body temperature?

Students **conduct an investigation** on human **regulatory mechanisms** by collecting data on the **impact of changing external temperatures on internal body temperature**. Students use the data they collect to figure out that humans have a complex system for maintaining body temperature.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Human Thermoregulation Investigation ❏ Thermoregulation Investigation - Scaffolded ❏ Making Sense of Thermoregulation ❏ Human Thermoregulation Investigation Rubric	❏ digital oral thermometer ❏ immersion thermometer ❏ bowl or large beaker of hot water ❏ stopwatch or clock ❏ thermometer probes (2) ❏ bowl or large beaker of cold water	

Launch and Plan an Investigation

1. Ask students to recall what they are trying to figure out: whether the marathon runner overheated. Point out the poster from the Engage phase, and remind students about the ideas that have been generated so far about the ways in which humans tolerate a wide range of temperatures and react to external temperature changes.

2. Have students recall their earlier discussion about how we might investigate the ways in which the human body's internal temperature reacts to changes in external temperature.

3. Provide each student with the investigation handout: *Human Thermoregulation Investigation*.

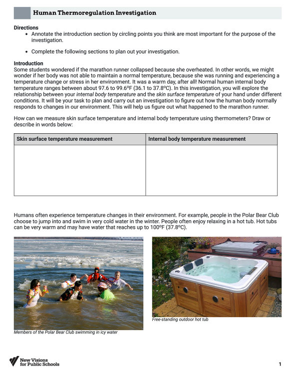
4. Prompt students to work in groups on the Introduction and Planning the Investigation sections.

5. Have students work on developing their investigation design, first individually then as a group.

6. Select a few groups with different investigation designs to share their plans.

7. Facilitate a class discussion about which design is most appropriate for our agreed-upon research question(s).

Note: For this investigation, unlike some others, it is important for all groups to be working from a common procedure, since they will aggregate data at the end of the investigation. Temperature changes in humans are very small and subtle, so being able to aggregate data across a class is important.



Human Thermoregulation Investigation

Directions

- Annotate the introduction section by circling points you think are most important for the purpose of the investigation.
- Complete the following sections to plan out your investigation.

Introduction
Some students wondered if the marathon runner collapsed because she overheated. In other words, we might wonder if her body was not able to maintain a normal temperature, because she was running and experiencing a temperature change or stress in her environment. It was a warm day, after all! Normal human internal body temperature ranges between about 97.6 to 99.6ºF (36.1 to 37.8ºC). In this investigation, you will explore the relationship between your *internal body temperature* and the *skin surface temperature* of your hand under different conditions. It will be your task to plan and carry out an investigation to figure out how the human body normally responds to changes in our environment. This will help us figure out what happened to the marathon runner.

How can we measure skin surface temperature and internal body temperature using thermometers? Draw or describe in words below:

Skin surface temperature measurement	Internal body temperature measurement

Humans often experience temperature changes in their environment. For example, people in the Polar Bear Club choose to jump into and swim in very cold water in the winter. People often enjoy relaxing in a hot tub. Hot tubs can be very warm and may have water that reaches up to 100ºF (37.8ºC).

Members of the Polar Bear Club swimming in icy water

Free-standing outdoor hot tub

New Visions for Public Schools 1

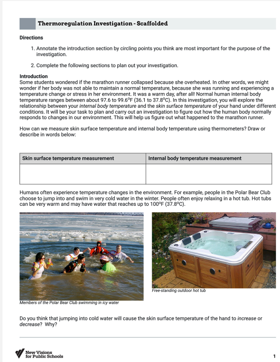
Look & Listen For

At this point the class has surfaced some ideas around what our bodies do in terms of shivering or sweating, but students are still figuring whether internal body temperature changes in relation to external temperature changes, and how this regulation happens.
As groups prepare to plan their investigations, make sure they have an understanding of why we are doing this investigation and where it fits into the unit. These points should be reflected in their research questions and hypotheses.

Differentiation Point

Support with Investigation Design: For small group instruction, there is a version of the lab with a procedure already designed, *Thermoregulation Investigation - Scaffolded*. This can be used for students who still need support with experimental design, to give them a starting point in this work.

Assign roles to students, based on readiness and interest



Thermoregulation Investigation - Scaffolded

Directions

1. Annotate the introduction section by circling points you think are most important for the purpose of the investigation.
2. Complete the following sections to plan out your investigation.

Introduction
Some students wondered if the marathon runner collapsed because she overheated. In other words, we might wonder if her body was not able to maintain a normal temperature, because she was running and experiencing a temperature change or stress in her environment. It was a warm day, after all! Normal human internal body temperature ranges between about 97.6 to 99.6ºF (36.1 to 37.8ºC). In this investigation, you will explore the relationship between your *internal body temperature* and the *skin surface temperature* of your hand under different conditions. It will be your task to plan and carry out an investigation to figure out how the human body normally responds to changes in our environment. This will help us figure out what happened to the marathon runner.

How can we measure skin surface temperature and internal body temperature using thermometers? Draw or describe in words below:

Skin surface temperature measurement	Internal body temperature measurement

Humans often experience temperature changes in the environment. For example, people in the Polar Bear Club choose to jump into and swim in very cold water in the winter. People often enjoy relaxing in a hot tub. Hot tubs can be very warm and may have water that reaches up to 100ºF (37.8ºC).

Members of the Polar Bear Club swimming in icy water

Free-standing outdoor hot tub

Do you think that jumping into cold water will cause the skin surface temperature of the hand to *increase* or *decrease*? Why?

New Visions for Public Schools 1

Investigation: Human Thermoregulation

1. Have groups carry out the agreed-upon procedure for investigating thermoregulation.

Lab Safety Note: To avoid transmission of infectious diseases, ensure that students are sanitizing oral thermometers with soap and water and / or isopropyl alcohol before each student uses an oral thermometer.

2. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Conferring Prompts

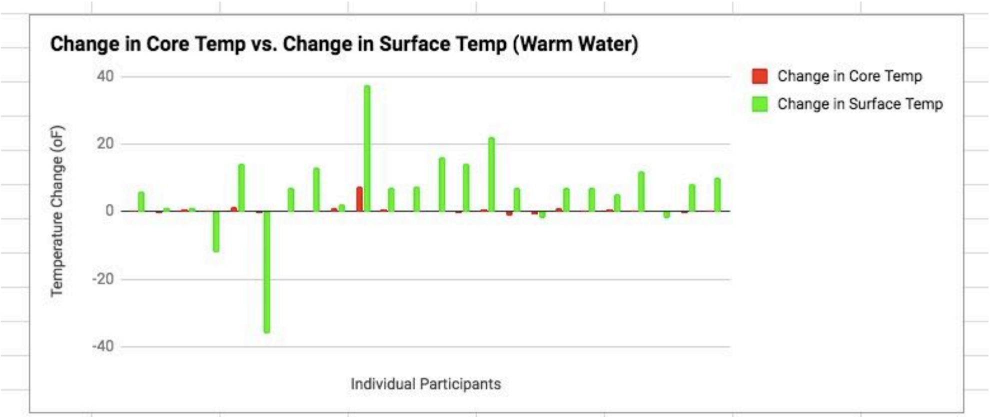
Suggested conferring questions during investigation:

- What are the variables we are testing?
- What is the control in this experiment?
- What was your prediction when we started?
- Why are we aggregating all the data from the class, instead of looking at just one group's data?

Suggested post-investigation conferring questions:

- What is the trend you observed?
- What do you predict is going on inside the body to create this trend?

3. Create a class-wide data table for students to use.



Example thermoregulation data

Implementation Tip

You can set up a Google Form to collect groups' data, or simply collect in a table on a class marker board or poster. In either case, the point is to make the trends in the data easily visible, without requiring a lot of additional mathematical analysis.

Whole-Class Investigation Summary

1. Have students work in lab groups to record their ideas about the data in the Investigation Summary section of *Making Sense of Thermoregulation*.

Look & Listen For

While students work on the Investigation Summary:

- Every group or individual will have slight variations in data.
- Some variation is normal between individuals, but there may be inconsistencies in how individuals are collecting data.
- Generally, internal (core) temperature does not change in response to external temperature changes.
- Students may wonder if the body reacts differently if temperature change is generated from body heat (internal source of heat) versus external temperature changes.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.
3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the phenomenon.

Look & Listen For

Possible student ideas from the Summary page:

- There is variation in individual data, but the trend shows that internal temperature does not change in response to external temperature changes (in this investigation).
- Our bodies attempt to maintain a stable body temperature; this may happen by shivering, sweating, or other mechanisms.
- The data generated from this investigation would be more accurate if many more trials, with a wider range of individuals, were conducted and if there were greater attempts to keep a consistent water temperature across all groups.
- We do not know all of the mechanisms and variables involved in thermoregulation. For example, does body heat generated from exercise impact the body differently?

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Access for Multilingual Learners

MLLs, especially students who are **emerging** and **transitioning** language learners, may struggle with the task of describing trends in the data.
The following sentence frames may support students with this need.
As people's temperatures at their extremities get colder, _________.
As people's temperatures at their extremities get warmer, _________.
OR
When skin temperature rises, core temperature __________. I know this because ____________.
When skin temperature falls, core temperature __________. I know this because ____________.

Routine

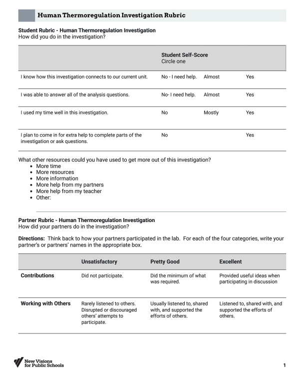
This Domino Discover routine is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Read more about **Domino Discover** in the Biology Course Guide.

> **Integrating Three Dimensions**
>
> Each question in the Investigation Summary targets a different element in the standards for this unit, so make a determination about the ideas that are most important to surface in the classroom, to set the stage for the Explain phase.

Self and Peer Assessment

1. Ask students to work independently to complete the *Human Thermoregulation Investigation Rubric* prompts, then discuss the findings with their group.

2. Provide time for students to use the *Human Thermoregulation Investigation Rubric* to reflect on their own participation in the investigation, and that of their peers.



Human Thermoregulation Investigation Rubric

Student Rubric - Human Thermoregulation Investigation
How did you do in the investigation?

	Student Self-Score Circle one		
I know how this investigation connects to our current unit.	No - I need help.	Almost	Yes
I was able to answer all of the analysis questions.	No- I need help.	Almost	Yes
I used my time well in this investigation.	No	Mostly	Yes
I plan to come in for extra help to complete parts of the investigation or ask questions.	No		Yes

What other resources could you have used to get more out of this investigation?
- More time
- More resources
- More information
- More help from my partners
- More help from my teacher
- Other:

Partner Rubric - Human Thermoregulation Investigation
How did your partners do in the investigation?

Directions: Think back to how your partners participated in the lab. For each of the four categories, write your partner's or partners' names in the appropriate box.

	Unsatisfactory	**Pretty Good**	**Excellent**
Contributions	Did not participate.	Did the minimum of what was required.	Provided useful ideas when participating in discussion
Working with Others	Rarely listened to others. Disrupted or discouraged others' attempts to participate.	Usually listened to, shared with, and supported the efforts of others.	Listened to, shared with, and supported the efforts of others.

New Visions for Public Schools 1

Explain

How do humans maintain a dynamic equilibrium through thermoregulation?

Students use a three-level guide to interpret a complex diagram demonstrating how **feedback mechanisms** enable the human body to **thermoregulate**. Using this new learning, students **construct a scientific explanation** of the **data collected** in the Explore phase.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs or table groups	❏ Class Consensus Discussion	❏ Three-Level Guide ❏ Claim-Evidence-Reasoning (CER)

Materials

Handouts	Lab Supplies	Other Resources
❏ Homeostasis and Thermoregulation in Humans ❏ Three-Level Guide ❏ Developing a Scientific Explanation ❏ Scientific Explanation (CER) Rubric ❏ Summary Task	None	❏ Resources on supporting scientific explanation in the Biology Course Guide

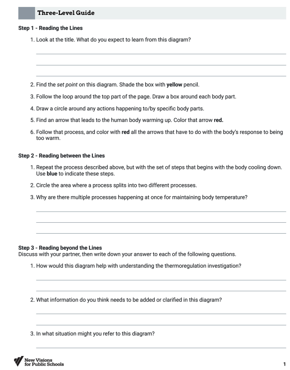
Interpreting a Complex Diagram

1. Prompt students to reflect on unanswered questions from the Explore phase. Students have surfaced that the body appears to maintain a consistent core temperature, even when external temperatures change. Additionally, students have ideas that the body regulates internal temperatures through actions such as shivering, and they have previous experience discussing feedback mechanisms. They may, however, still wonder how this is happening in the body. What is the mechanism?

2. Provide students with the handouts *Homeostasis and Thermoregulation in Humans* and *Three-Level Guide*. Frame the rationale for reading this visual text by naming their remaining questions, for example:

    - "At the end of the Explore phase, we saw that our internal temperatures stayed fairly constant, even when external temperatures at our extremities changed. Many of you wondered how our bodies do that, how do they *know* to shiver or when to stop when we are cold? Let's figure that out next."

3. Prompt students to complete the *Three-Level Guide*. Confer with pairs as they complete the **Three-Level Guide**, making sure to leave the sense-making and questioning to the students at this stage.



Three-Level Guide

Step 1 - Reading the Lines

1. Look at the title. What do you expect to learn from this diagram?
2. Find the *set point* on this diagram. Shade the box with **yellow** pencil.
3. Follow the loop around the top part of the page. Draw a box around each body part.
4. Draw a circle around any actions happening to/by specific body parts.
5. Find an arrow that leads to the human body warming up. Color that arrow **red.**
6. Follow that process, and color with **red** all the arrows that have to do with the body's response to being too warm.

Step 2 - Reading between the Lines

1. Repeat the process described above, but with the set of steps that begins with the body cooling down. Use **blue** to indicate these steps.
2. Circle the area where a process splits into two different processes.
3. Why are there multiple processes happening at once for maintaining body temperature?

Step 3 - Reading beyond the Lines
Discuss with your partner, then write down your answer to each of the following questions.

1. How would this diagram help with understanding the thermoregulation investigation?
2. What information do you think needs to be added or clarified in this diagram?
3. In what situation might you refer to this diagram?

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Implementation Tip

Here are some tips to support students with three-level guides strategy:

- Encourage students to stick with the color coding, even if it seems tedious. This supports the work in level 2 and 3 of the guide.
- Don't get hung up on having students use colors in the same way. This is a tool for *them* to make sense of a complex visual text!

Differentiation Point

The **Three-Level Guide** supports all students in slowing down and deeply noticing different portions of a visual text. To further support students, here are more options:

1. Shared reading group: support students by having them read the text along with a teacher, in a small group setting.
2. Instruct students to fold the diagram in half, and work on each side individually before interpreting the diagram as a whole.

Integrating Three Dimensions

The **Three-Level Guide** builds on the type of representations students created using **Sequence Charts** in the last 5E. This is the second time in this unit that students are working with a Three-Level Guide for interpreting visuals.

Tell students "This is a complicated sequence chart that is already created for you. Do you notice any similarities between the layout of this chart and the one you created about gas exchange?"

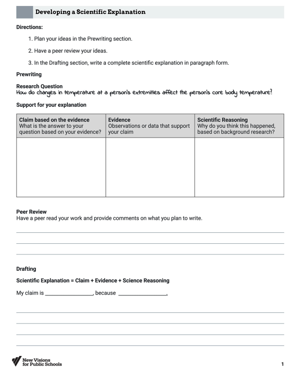
Noticing the similar structures will help students develop an understanding of how *feedback mechanisms* tend to be represented, which is a key part of working towards high school level elements in **CCC #7 - Stability and Change.**

Access for Multilingual Learners

Three-level guides provide access to students who are **emerging** and **transitioning** language learners. Engaging with a visual text through a three-level guide gives students a chance to hear and think about concepts alongside vocabulary.

Constructing a Scientific Explanation

1. Confer with students as they develop a scientific explanation in response to the following prompt:
    - Does a human's body temperature change due to temperature changes at the extremities or changes in ambient temperature? Develop a claim in response to this question, and support your claim with evidence from the lab and sufficient reasoning.
2. Provide students with the handout *Developing a Scientific Explanation*, to generate their initial scientific explanation draft (#1 - Pre-writing).
3. Students switch papers with a partner, and use *Scientific Explanation (CER) Rubric* to provide peer review (#2 - Peer Review).
4. Provide time for students to use peer feedback to draft their explanation (#3 - Drafting).


Developing a Scientific Explanation

Directions:

1. Plan your ideas in the Prewriting section.
2. Have a peer review your ideas.
3. In the Drafting section, write a complete scientific explanation in paragraph form.

Prewriting

Research Question
How do changes in temperature at a person's extremities affect the person's core body temperature?

Support for your explanation

Claim based on the evidence What is the answer to your question based on your evidence?	**Evidence** Observations or data that support your claim	**Scientific Reasoning** Why do you think this happened, based on background research?

Peer Review
Have a peer read your work and provide comments on what you plan to write.

Drafting

Scientific Explanation = Claim + Evidence + Science Reasoning

My claim is ________________, because ________________.

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Integrating Three Dimensions

This is the first time students have constructed a scientific explanation in this unit. The Biology Course Guide has further resources to support students in using the **Claim-Evidence-Reasoning (CER)** framework for constructing scientific Explanations.

Note: SEP #6 - Constructing Explanations, is not a foregrounded practice in this unit. This CER is a great opportunity to do a formative assessment of your students' middle school experience with CER, to use in the upcoming units which foreground this SEP. However, if unit pacing is a concern, this step can be shortened or because students will have more opportunities to engage with the CER framework and SEP #6 in Unit 2.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this: “We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to some decisions about how the human body thermoregulates, or maintains a stable body temperature, even when external temperatures change.”

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three student explanations to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of thermoregulation. The decision about which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.
   For example, if you find in your class that students are grappling with the idea that you may decide to select the following two groups to share their data.
   - Group 1 determined that the external temperature does have an effect on core temperature, because they observed some tiny shifts in core temperature in the data set.
   - Group 2 determined that the external temperature does not have an effect on core temperature, because they averaged the numbers and determined there is little change.

3. Ask the first students to share their explanation. You can do this by:
   - Projecting using a document camera; OR
   - Copying the written explanation to be shared and passing them out to the class; OR
   - Taking a picture of each explanation and projecting them as slides.

4. Proceed through the steps in the Consensus Discussion Steps. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get “buried” in student talk.

5. Return to student questions that bring up lingering issues not yet resolved, such as:
   - If we are able to regulate our temperature, why do people die of hypothermia or hyperthermia?
   - Why are people sometimes deliberately chilled to save their lives?

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Refer to the Biology Course Guide for support with this routine.

Integrating Three Dimensions

The depth of this discussion will really depend on what you’ve observed in the room and how you respond. Be sure to make CCC #7 - Stability and Change explicit for students by elevating and probing for ideas related to feedback mechanisms and how they can stabilize or destabilize a system. This is an important element CCC # 7 - Stability and Change at the high school level.

- Did the marathon runner overheat? Or was her body unable to properly regulate her temperature?

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- Humans are able to maintain *homeostasis*, in this case a stable body temperature, through *feedback mechanisms*.
- An example of a feedback mechanism is blood vessels dilating to facilitate the dissipation of body heat in response to increasing temperatures; returning to normal when body temperatures return to the set point.
- Internal body temperatures slightly fluctuate around a set point, this is called *dynamic equilibrium*.
- Multiple body systems interact at the system, organ, tissue, and cellular levels to thermoregulate; with the nervous system playing a key role in determining how to respond to temperature changes.
- Note: The CER prompt does not address the issue of body heat (which is important for our discussion on the marathon runner). Be sure to surface the connection (from bullet point #2) that through sweating and blood vessel dilation, body heat is dissipated to the environment (even if it internally generates heat).

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about how the body regulates body temperature.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas:
1) understanding how they are using the three dimensions, including the concept of thermoregulation, to make sense of a phenomenon, tolerating extreme temperatures; 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

How can humans outrace faster animals, like horses and antelopes?

Students bring together their ideas and conceptions about **thermoregulation** by applying their thinking to a new way to model it, and use that model to explain why human thermoregulation allows them to outrun horses and antelopes. Using a template, and their understanding of **feedback systems**, students **construct a model** demonstrating the interactions and transfer of energy between systems of the human body. Students determine where animal thermoregulation differs from human thermoregulation and how that impacts racing ability.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Consensus-Building Share	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Homeostasis Model	None	❑ A 50-mile race of a lifetime: Girl vs. horse ❑ The Intense 8 Hour Hunt

Constructing a Model

1. Organize students into pairs. Highlight for students that in the previous Explore & Explain, they figured out that humans regulate body temperature even when external temperatures change, or we generate excess heat through exercise. They also figured out how this happens, through a complex set of feedback mechanisms.

Differentiation Point

□↔○
○↔□
□↔○

In the Explain phase, you were able to assess student learning around how the human body regulates body temperature. This phase of the 5E allows for students who are still unsure of that idea to develop it further through visually modeling these processes in a new way.

2. Ask students if they have any ideas about how human thermoregulation might be different from thermoregulation in other mammals. Students may know that dogs pant because they do not sweat as well as humans do.

3. Tell students that sweating is a bit of a superpower, which contributes to our amazing ability to run marathons and ultramarathons. Show students one or both of the videos: A 50-mile race of a lifetime: Girl vs. horse , The Intense 8 Hour Hunt .

4. Tell students that we will figure out how humans are able to accomplish these feats by constructing a model of feedback mechanisms using a graph of body temperature over time, similar to the ones they've already seen for oxygen levels during exercise and glucose levels.

5. Provide the handout *Homeostasis Model*, and facilitate students working in pairs to construct models of how temperature changes during thermoregulation after exposure to extreme heat or cold. Help students focus on how information and energy are transmitted through different systems and subsystems.

6. Prompt students to consider how thermoregulation is different in horses than in humans, and how that impacts the ability of the body to dissipate heat energy between systems.

7. Use the group learning routine **Consensus-Building Share** to facilitate the sharing of ideas from groups to explain how humans can outrun horses under specific conditions.

Look & Listen For

Students may generate ideas such as:

- When body temperature moves away from baseline, the body responds and uses feedback mechanisms to move body temperature back to baseline
- Feedback mechanisms work by the nervous system detecting a change in the body, and then telling body systems, including the circulatory system and muscular systems, to react. Information travels between different body systems.
- Body heat is generated from heat released during cellular respiration, especially in muscle cells; the heat is transported by the circulatory system to spread it evenly throughout the body; heat is then dissipated into the air
- Animals that sweat less well than humans, or that have less surface area to sweat through, are less able to dissipate heat from the body into the air, so more heat is conserved within the body
- If heat is retained in the body, it increases overheating in the animal, and the animals have to stop running

Evaluate

How does the body thermoregulate during exercise?

Students consider both internal and external sources of heat, and demonstrate their understanding of how an exercising person **regulates body temperature** by **evaluating the importance of body temperature data** on the Marathon Runner problem.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Domino Discover	None

Materials

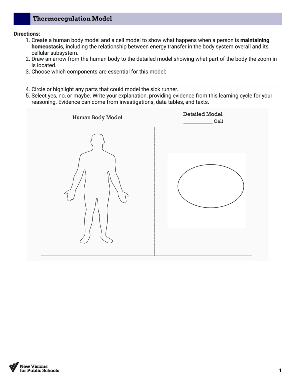
Handouts	Lab Supplies	Other Resources
❑ Thermoregulation Model from Performance Task Organizer ❑ Human Thermoregulation Model Rubric	None	❑ Class wide scientific model characteristics ❑ Driving Question Board from the start of the unit should be available

Revisit the Performance Task

1. Prompt students to consider where they currently stand on the question category from the Driving Question Board that they have been investigating throughout this 5E instructional sequence. This will be something like: Did the marathon runner overheat?

2. Students work individually on the Human Thermoregulation section of their Performance Task Organizer, *Thermoregulation Model*. They should make choices about how to represent their ideas using the model they are developing. In the models, students are representing how a human normally regulates body temperature.

3. Confer with students while they are working.


Thermoregulation Model

Directions:
1. Create a human body model and a cell model to show what happens when a person is **maintaining homeostasis,** including the relationship between energy transfer in the body system overall and its cellular subsystem.
2. Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3. Choose which components are essential for this model:
4. Circle or highlight any parts that could model the sick runner.
5. Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Conferring Prompts

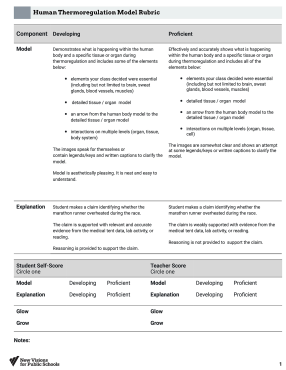
Confer with students as they work to develop their models. Prompt students to return to the class wide scientific model characteristics, posted in the room. Suggested conferring questions:

- Can you confirm, contradict, or modify anything on the list based on your interactions with models throughout these investigations on human thermoregulation?
- How can you use the characteristics on the list to inform the development of your own model?

4. Provide students with the normal human body temperature, 37°C. This information should be recorded in their organizer.

5. Students individually use their models to evaluate a claim about whether or not the runner failed to regulate body temperature, and collapsed because of overheating. This is a response to the question: Did the runner overheat? Prompt students to use the medical tent data to support their claim. They should also consider data and evidence gathered during the investigations completed during this instructional sequence, as well as their new understandings.

6. Use the *Human Thermoregulation Model Rubric* for students to self-reflect on their progress and to provide individual feedback towards the final task.


Human Thermoregulation Model Rubric

Component	Developing	Proficient
Model	Demonstrates what is happening within the human body and a specific tissue or organ during thermoregulation and includes some of the elements below: • elements your class decided were essential (including but not limited to brain, sweat glands, blood vessels, muscles) • detailed tissue / organ model • an arrow from the human body model to the detailed tissue / organ model • interactions on multiple levels (organ, tissue, body system) The images speak for themselves or contain legends/keys and written captions to clarify the model. Model is aesthetically pleasing. It is neat and easy to understand.	Effectively and accurately shows what is happening within the human body and a specific tissue or organ during thermoregulation and includes all of the elements below: • elements your class decided were essential (including but not limited to brain, sweat glands, blood vessels, muscles) • detailed tissue / organ model • an arrow from the human body model to the detailed tissue / organ model • interactions on multiple levels (organ, tissue, cell) The images are somewhat clear and shows an attempt at some legends/keys or written captions to clarify the model.
Explanation	Student makes a claim identifying whether the marathon runner overheated during the race. The claim is supported with relevant and accurate evidence from the medical tent data, lab activity, or reading. Reasoning is provided to support the claim.	Student makes a claim identifying whether the marathon runner overheated during the race. The claim is weakly supported with evidence from the medical tent data, lab activity, or reading. Reasoning is not provided to support the claim.

Student Self-Score Circle one			Teacher Score Circle one		
Model	Developing	Proficient	Model	Developing	Proficient
Explanation	Developing	Proficient	Explanation	Developing	Proficient
Glow			Glow		
Grow			Grow		

Notes:

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Implementation Tip

When returning to the Driving Question Board, be sure to change these suggested teacher notes so that they match your class' actual questions!

Document Class Thinking

1. Prompt students to discuss with their groups their decision regarding the question: Did the marathon runner overheat? Students can use the notes in their performance task organizers in these discussions.

2. Each group comes to a consensus answer to the question—*Yes, No, or Maybe*—and articulates their reasoning.

3. Use the *Human Thermoregulation Model Rubric* and *Thermoregulation Model* for students to self-reflect on their progress and to provide individual feedback towards the final task.

4. Facilitate the group learning routine **Domino Discover** to hear from each group, and tally the responses on chart paper. It is not necessary to discuss all the positions or get to class consensus at this point. Based on the investigations in this 5E instructional sequence, most groups will say No. Groups that

shared *Yes or Maybe* may need some additional support during the next 5E instructional sequence when ideas related to homeostasis and feedback mechanisms are explored in a different context.

Revisit the Driving Question Board

1. Use the **Driving Question Board** routine to discuss which of the class's questions have been answered.
2. Have students identify which categories or questions they have not figured out yet. Prompt students to share out these questions, and document new questions that arise based on what they have been learning.
3. Add new questions to the Driving Question Board.
4. One question category still unanswered relates to questions about dehydration. Students may ask, for example: Did the marathon runner dehydrate? or Did the marathon runner not drink enough water? Tell students that, in the next sequence of lessons, they will investigate what it means when we get thirsty, dehydrated, or have a problem with regulating our water balance.

Implementation Tip

Use the **Driving Question Board** unit routine to document students' evolving questions.

Performance Expectations

HS-LS1-2 **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.**
Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.
Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.

In NYS the clarification statement has been edited as follows: Emphasis is on functions at the organism's system level such as nutrient uptake, water delivery, immune response, and organism response to stimuli.

HS-LS1-3 **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.**
Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.
Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3) Planning and Carrying out Investigations • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. SEP3(2) Constructing Explanations and Designing Solutions • 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. SEP6(2)	LS1.A Structure and Function • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. LS1.A(3) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. LS1.A(4) LS1.C Organization for Matter and Energy Flow in Organisms • As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. LS1.C(4)	Systems and Systems Models • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. CCC4(3) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

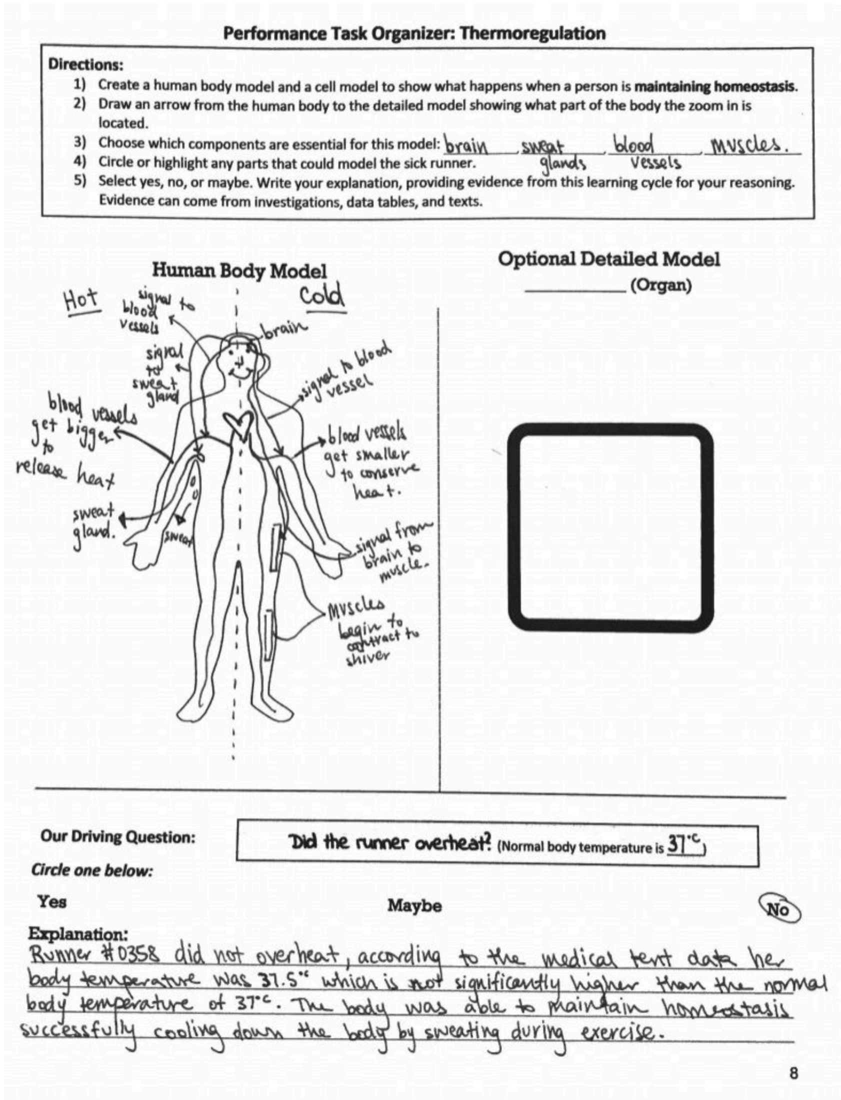
	Engage	Explore	Explain	Elaborate	Evaluate
Developing and Using Models			*Three-Level Guide*; *Summary Task*		Human body and organ model in *Thermoregulation Model* *Human Thermoregulation Model Rubric*
Planning and Carrying out Investigations		*Human Thermoregulation Investigation*; *Making Sense of Thermoregulation*			
Constructing Explanations and Designing Solutions				*Homeostasis Model*	
LS1.A Structure and Function	Domino Discover	*Human Thermoregulation Investigation*; *Making Sense of Thermoregulation*	*Three-Level Guide*; *Developing a Scientific Explanation*; *Summary Task*	*Homeostasis Model*	Yes-no-maybe explanation in *Thermoregulation Model* *Human Thermoregulation Model Rubric*
LS1.C Organization for Matter and Energy Flow in Organisms			*Three-Level Guide*		
Systems and Systems Models			*Three-Level Guide* *Summary Task*	*Homeostasis Model*	Human body and organ model in *Thermoregulation Model* *Human Thermoregulation Model Rubric*
Stability and Change	Domino Discover		*Three-Level Guide*; *Developing a Scientific Explanation*; *Summary Task*; Class consensus discussion	*Homeostasis Model*	Yes-no-maybe explanation in *Thermoregulation Model* *Human Thermoregulation Model Rubric*

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics		HSF-IF.B.5	MP2 MP3	MP2	MP2
ELA/Literacy		RST.9-10.7 WHST.9-10.2 WHST.9-10.9	RST.9-10.7 WHST.9-10.2 WHST.9-10.9 SL.9-10.4 SL.9-10.5	WHST.9-10.9 SL.9-10.4	WHST.9-10.2 WHST.9-10.9 SL.9-10.4

Student Work for Human Thermoregulation 5E

Example Student Model



Performance Task Organizer: Thermoregulation

Directions:

1) Create a human body model and a cell model to show what happens when a person is **maintaining homeostasis**.
2) Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3) Choose which components are essential for this model: brain, sweat glands, blood vessels, muscles.
4) Circle or highlight any parts that could model the sick runner.
5) Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Human Body Model

Optional Detailed Model

__________ (Organ)

Our Driving Question: Did the runner overheat? (Normal body temperature is 37°C)

Circle one below:

Yes   Maybe   No

Explanation: Runner #0358 did not overheat, according to the medical tent data her body temperature was 37.5°C which is not significantly higher than the normal body temperature of 37°C. The body was able to maintain homeostasis successfully cooling down the body by sweating during exercise.

8

Student work for thermoregulation section of the performance task organizer

Implementation Notes from Field Test Teachers:

- Some classes may still be struggling with the SEP of modeling at this point. Remember this may be their first time experiencing modeling and probably their first time experiencing modeling on a high school level. It might be helpful to pause and reflect on their modeling practice. You could take pictures of two to three different mini-models students have created in their first two attempts. Prompt students to state glows and grows about each of the models—push students to use language from the mini-rubric to help them with their feedback. You can then give students the opportunity to revise one of their previous models taking account the feedback their just gave to the examples or you can create an exemplar mini-model as a class. Make sure you highlight the things you want to see in the model—connections between body systems, interactions on multiple levels, scientifically accurate. If you haven't already, introducing the idea of a key/legend could be really helpful.
- Students should be prompted to fill in the components they think need to be included based on their learning in this 5E instructional sequence. You could also give students components if you do not feel they are ready (brain, sweat glands, muscles, blood vessels are some options).
- Students should be able to show the interactions between the nervous system, the integumentary system, the circulatory system, and the muscular system in this mini-model.
- The detailed model is optional in this case and is based on an organ.
- Students may try to incorporate all of their previous modeling work (cellular respiration and glucose regulation) into this new model. Encourage them to focus only on thermoregulation as it will get too overwhelming to include their learning from all of the 5E instructional sequences.
- To break down some barriers, it may be useful to provide students will pictures of the body systems for them to see the location of different organs in the body. You will also need to encourage students to just draw boxes with labels if they are concerned about their artistic ability.
- Students may ask where are sweat glands? Help students to develop their problem solving skills by asking, "where do you sweat? Do you think there could be sweat glands there?"

Water Balance 5E	Was the marathon runner dehydrated? How do our bodies maintain water balance?	**Performance Expectations** HS-LS1-2, HS-LS1-3	**Investigative Phenomenon** Humans sweat during exercise, losing water and salts.	**Time** 4-6 days

In this 5E instructional sequence, students are investigating the questions about water balance surfaced during the Driving Question Board launch: Did the marathon runner run dehydrate? Did the marathon runner get too much or not enough fluid? This leads to questions about why humans sweat when exercising, how our bodies maintain water balance during exercise, and how much fluid (and what type) we should drink during exertion. Students investigate the interaction between the excretory and circulatory systems that are required to work properly, as well as the feedback mechanisms that regulate all of this, to ensure that we can maintaintain water and salt balances and keep exercising. Students figure out that the marathon runner was not dehydrated, but rather consumed too much water during the race, causing a disorder called hyponatremia.

ENGAGE	Why do we get sweaty when we exercise? How does sweat help?	Connecting to their earlier questions about the marathon runner's use of water, students share their initial ideas about which type of fluid is better to drink during exercise: water or a sports drink. This helps with surfacing students' prior knowledge about processes surrounding **osmoregulation** in the human body.
EXPLORE	How does the body osmoregulate?	Students **conduct two investigations,** in order to learn about **osmoregulation**. Students **generate observations** on **osmosis**, using an onion cell; and use data on solute concentrations in the blood in order to **generate models demonstrating osmoregulation in the kidney.**
EXPLAIN	Developing an understanding of how the body osmoregulates during exercise.	Students engage with a complex text and visuals on **osmoregulation**, and use their understanding of **feedback mechanisms** in order to **construct a sequence chart to explain** how the body adjusts to changes during exercise.
ELABORATE	How do fish osmoregulate?	Students test out their ideas and conceptions about **osmoregulation** by investigating if goldfish can live in saltwater aquariums. Students **evaluate the models** used in the Explore phase, and **propose criteria they would use to develop a model** that could be used to represent whether or not freshwater goldfish can **maintain stability** when introduced into a saltwater environment.
EVALUATE	How does the body regulate water balance during exercise?	Students demonstrate their understanding of how an exercising person **osmoregulates** by **evaluating the importance of plasma sodium level data** on the Marathon Runner problem.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

Why do we get sweaty when we exercise? How does sweat help?

Connecting to their earlier questions about the marathon runner's use of water, students share their initial ideas about which type of fluid is better to drink during exercise: water or a sports drink. This helps with surfacing students' prior knowledge about processes surrounding **osmoregulation** in the human body.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	❏ Sticky notes ❏ Chart paper

Launch

1. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to dehydration. Students may have asked the following questions: Was sufficient water available to the runner? Did the marathon runner become dehydrated or get too much fluid? Ask students to share more about why they asked questions about dehydration. In the previous 5E, students learned that sweating helps us thermoregulate.

Look & Listen For

Students have background knowledge (and have thought about this using their body models during the Anchor Phenomenon Launch).
They may surface ideas such as:

- When running or exercising, sweating increases, and we get thirsty.
- When it's hot out, we sweat, and that can make us thirsty.
- The idea that sweat is salty; we lose salt when we sweat.

Access for All Learners

All students have some background knowledge on the topic of sweating and feeling thirsty after sweating. However, not all students may know the composition of sweat (water and salts) or why water is an essential component of our bodies. Be sure to provide opportunities for these ideas to surface if students are not generating those ideas initially.

2. Use students' questions and observations about sweating to transition to the guiding question: When we are exercising, should we drink water or sports drinks?

3. Provide students with bottles of different sports drinks (for example, Gatorade) so that they can look at the contents of the drink. Prompt students to consider the body models they generated during the

anchor phenomenon launch and their own experiences running or exercising heavily. If students need support generating ideas, provide a brief video, image, or GIF of an athlete sweating heavily.

4. Individually, students respond to the prompt, brainstorming as many ideas as possible

Surface Student Ideas

1. Each student writes their response to the prompt (water or sports drink) on a sticky note, along with a brief rationale of their thinking.
2. Students share their ideas, using the group learning routine **Rumors**.
3. Categorize student ideas, and surface patterns in student thinking. If you hear students bringing up the idea of substances dissolved in water, introduce the term *solute* as the term for matter dissolved in water.

Look & Listen For

- Sports drinks have substances (sugar, salt, electrolytes) dissolved in water. Why is that?
- Pure drinking water does not have anything dissolved (solutes).
- Sweat has solutes (like salt).
- We need to find out more about the importance of solutes.
- We need to understand more about how our bodies use and regulate water to understand hydration and dehydration.

Classroom Supports

Create a poster or space on a whiteboard for categories of student ideas that have come up. Use the title: Why do we get sweaty when we exercise?
You can refer back to the poster throughout this 5E plan.

Routine

The **Rumors** routine has appeared many times at this point in the unit. By now, students should be able to run this routine seamlessly!

Explore

How does the body osmoregulate?

Students **conduct two investigations,** in order to learn about **osmoregulation**. Students **generate observations** on **osmosis**, using an onion cell; and use data on solute concentrations in the blood in order to **generate models demonstrating osmoregulation in the kidney.**

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Consensus-Building Share	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Osmosis in Onion Cells Investigation ❑ Making Sense of Osmosis in Onion Cells Investigation ❑ Osmoregulation in the Kidney Investigation ❑ Making Sense of Osmoregulation in the Kidney Investigation	❑ Red onion slices ❑ Cover slips ❑ Microscope slides ❑ Water ❑ Scalpel or knife ❑ Dropper or pipette ❑ Distilled water ❑ Colored pencils ❑ Salt solution ❑ Paper towels	❑ Computer access (with Internet)

Launch

1. Ask students to remind us what we are trying to figure out. They will bring up ideas related to whether the marathon runner became dehydrated or did not drink the right amount or type of fluid.

2. Tell students that, so far, we have a lot of ideas about how humans sweat, what sweat is made up of, and how sweating might contribute to dehydration. Students may have also noticed that sports drinks, often used during excessive exercise to reduce dehydration, include both water and solutes -- such as salts and sugars. Point to the poster from the Engage phase, if it is still visible in the classroom.

3. Have students recall their earlier discussion about how we often study how something works in other organisms, model organisms, before trying to understand how it works in humans.

4. Using the class consensus chart about models, prompt students to recall how we used yeast as model organisms in an earlier lesson.

Class Consensus List:
Characteristics of a Scientific Model

It is a picture/representation/drawing of the thing we are studying.

It helps us see or visualize something.

It lets us think about impacts of actions/cause & effect.

It is a 'testable' version of something.

We can (more) easily manipulate variables

Difficult to see or experiment on human cells

Cheaper, simpler, faster, more efficient

5. Explain that, in the same vein, we are going to investigate how water responds to changes in solute concentrations in onion cells, before investigating this phenomenon in humans.

Investigation: Part 1

1. Provide students with *Osmosis in Onion Cells Investigation* handout, and the appropriate materials for each group.

Lab Safety Note: Do not assume all students know how to use a scalpel safely. Demonstrate how to safely cut a sample of onion, or consider pre-cutting the samples for students to avoid any possible injuries.

2. Students work in table groups to complete the investigation.

Conferring Prompts

Confer with students during and after the lab. Encourage students to use new terminology and science vocabulary from this unit to discuss what they are doing.

Suggested during-lab conferring questions:
- What is the job of the cell membrane?
- What do you notice about the cytoplasm? How does it change?
- What is distilled water? How is it different from salt solution? Regular tap water?

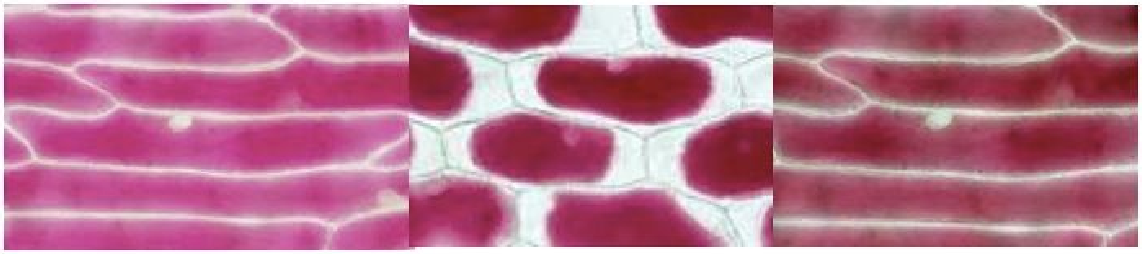
Suggested post-lab conferring questions:
- How does water move in response to hypotonic solutions? Hypertonic?
- When a cell is submerged in salt solution, where is the higher concentration of water? Of salt?
- What happens when a human cell is submerged in distilled water?

Access for Multilingual Learners

Since this investigation can involve observing, drawing, and annotating, it is very supportive of language learners at all levels, particularly **emerging** and **transitioning** learners. Prompt students to use detailed drawings and figures as a way to make sense of the movement of water.

Implementation Tip

The micrographs show the sorts of differences students may see when looking at cells in hypertonic vs. hypotonic solutions. These are meant as a reference for you as you support students to interpret what they see in the microscope.



Initial view of onion cells under the 40X

View of onion cells after 20% salt solution was added

View of onion cells after flushed with distilled (100%) water.

View of onion cells in hypertonic and hypotonic environments

Differentiation Point

The DCI addressed in the *Movement of Water in Onion Cells* investigation is at the middle school level; however, teachers may have noticed in the first 5E instructional sequence (Gas Exchange & Cellular Respiration) that students struggled with the concept of diffusion. This lab provides support for students that may need review of the concepts of diffusion, osmosis, and the function of the cell membrane. These concepts are vital in understanding osmoregulation at the body system level, and in understanding what caused the marathon runner to collapse. If students are well-versed in these concepts, and can respond to prompts such as Summary Question #1 from the investigation, it is appropriate to skip the first part of this Explore phase, and move directly into the *Osmoregulation in the Kidney Investigation*

Whole Class Investigation Summary

1. Ask students to work independently to complete the *Making Sense of Osmosis in Onion Cells Investigation*, then use the completed prompts to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

3. Use the group learning routine **Consensus-Building Share** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated.

Look & Listen For

Possible student ideas from the analysis questions in *Making Sense of Osmosis in Onion Cells Investigation*:

Analysis Q#2
- Water moves along a concentration gradient (moves towards a lower concentration of water); this is called osmosis
- Water moves towards where there is a higher solute concentration.
- Water can move in and out of a cell, across the cell membrane.

From the summary page:
- If submerged in a hypertonic solution, human cells would shrink as water moves out of the cell.
- If submerged in a hypotonic solution, human cells would swell as water moves into the cell.
- If submerged in an isotonic solution, humans cells would stay the same with no net movement of water.
- We figured out that water moves towards a higher concentration of solute, but how does the **body** maintain a stable level of solutes and water to keep enough water in the cells?
- Should we drink water or sports drinks during exercise? Why or why not?

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Integrating Three Dimensions

Each question in the Summary targets a different element in the standards for this unit, so make a determination about the ideas that are most important to surface in the classroom, to set the stage for the Explain phase.

Routine

Facilitate this **Consensus-Building Share** carefully! There is no need to move too quickly here. It is important to get students to build on one another's ideas well; we are building a case here for how important it is for water between cells to have the right amount of solute. This will need to translate to students' thinking about the human body after this!

Investigation: Part 2

1. In question # 2 in *Making Sense of Osmosis in Onion Cells Investigation* students surfaced additional questions they have about how our bodies maintain homeostasis in terms of water and salts (as they only investigated the cellular level in onions). Highlight these questions to transition to looking at data taken from a person exercising and drinking different amounts of water. Provide students with *Osmoregulation in the Kidney Investigation*.

2. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Conferring Prompts

Confer with students during and after the investigation. Encourage students to use new terminology and science vocabulary from this unit to discuss what they are doing.
Suggested during-lab conferring questions:

- What do you notice about which substances are reabsorbed and which are excreted by the kidney?
- What do you notice about sodium (salt)?
- How does the kidney know to increase or decrease the amount of urine produced?
- How is the movement of substances into and out of the blood at the kidney similar or different to how water moved into and out of the onion cell?

Whole Class Investigation Summary

1. Ask students to work independently to complete *Making Sense of Osmoregulation in the Kidney Investigation* then use these completed prompts to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their notes.

3. Use the group learning routine Consensus-Building Share to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated.

Look & Listen For

Possible student ideas to surface and build on in the Consensus-Building Share::

- The kidneys help the body regulate water and solutes in the blood.
- Urine is the primary way we excrete urea (nitrogenous waste).
- Some substances in the blood are reabsorbed, some are excreted, and some substances are both reabsorbed and excreted.
- Concentrated urine indicates lower levels of water in the blood.
- Dilute urine indicates higher levels of water in the blood.
- How does exercise impact how our body osmoregulates?

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

5. Provide students with *Osmoregulation in the Kidney Investigation Rubric*. Ask students to use the investigation rubric to self and peer assess their progress on engaging with the investigation individually and as a group.

Integrating Three Dimensions

Each question in *Making Sense of Osmoregulation in the Kidney Investigation* targets a different element in the standards for this unit, so make a determination about the ideas that are most important to surface in the classroom, to set the stage for the Explain phase.

Access for Multilingual Learners

MLLs, especially students who are **emerging** and **transitioning** language learners, may struggle with the task of describing trends in the data.

The following sentence frames may support students with this need.

- As water in the blood increases, water ____________.
- As water in the blood decreases, water____________.

Explain

Developing an understanding of how the body osmoregulates during exercise.

Students engage with a complex text and visuals on **osmoregulation**, and use their understanding of **feedback mechanisms** in order to **construct a sequence chart to explain** how the body adjusts to changes during exercise.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	❑ Idea Carousel ❑ Class Consensus Discussion	❑ Sequence Chart ❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ Osmoregulation at the System Level Text ❑ Osmosis in Red Blood Cells Text ❑ Summary Task	None	❑ Chart paper ❑ Markers

Generating an Initial Sequence Chart

1. Prompt students to reflect on unanswered questions from the Explore phase. In the first investigation, students noted that cells in the body should generally be in an isotonic solution or that blood should be isotonic with cells; this maintains an environment in which cells neither shrivel or swell. In the second part of the Explore, students surfaced that the kidney works with the circulatory and nervous system to maintain solute concentration in the blood (isotonic with cells). However, they may still wonder how intense exercise impacts osmoregulation, and if the marathon runner had difficulty due to a fluid imbalance, or an imbalance in blood sodium.

2. Prompt students to work in small groups to outline an initial sequence chart that represents their thinking on how the human body carries out osmoregulation in response to exercise. If you have sequence charts from previous 5Es on chart papers or in slides, this is a good time to bring them up for students to review.

Integrating Three Dimensions

Throughout this Explain phase, students are addressing and making sense of data using **CCC #7 - Stability and Change**; at the high school level this CCC addresses feedback mechanisms, which are an underlying way of thinking about biological systems that cuts across topics and is explicitly taught as a lens in this 5E.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points related to osmoregulation:

- cells should be isotonic with their surroundings (blood or intracellular fluid) and the kidney
- The kidneys work with other body systems to maintain that isotonic environment in the blood.

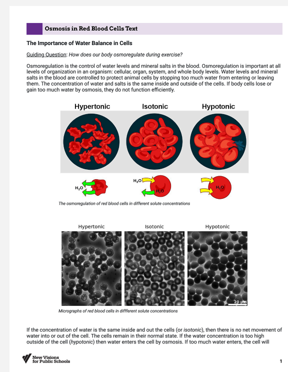
Note: This point about isotonic solutions is a key understanding for figuring out the phenomenon. It is worth taking time to support students in piecing this together for themselves.

Implementation Tip

Students have had many opportunities in this unit to work with sequence charts. In addition to being a support for reading, they are an ideal support for developing and refining an understanding of feedback mechanisms. When coaching groups through this work, prompt them to remember how they worked through other sequence charts in this unit, so that they can explicitly build on that idea.

Differentiation Point

If students are struggling to visualize why blood cells should be generally isotonic with the surrounding fluid, provide students with *Osmosis in Red Blood Cells Text* (or just the visual provided in the text) to surface the importance of regulating solute concentrations in the blood.


Osmosis in Red Blood Cells Text

The Importance of Water Balance in Cells

Guiding Question: *How does our body osmoregulate during exercise?*

Osmoregulation is the control of water levels and mineral salts in the blood. Osmoregulation is important at all levels of organization in an organism: cellular, organ, system, and whole body levels. Water levels and mineral salts in the blood are controlled to protect animal cells by stopping too much water from entering or leaving them. The concentration of water and salts is the same inside and outside of the cells. If body cells lose or gain too much water by osmosis, they do not function efficiently.

The osmoregulation of red blood cells in different solute concentrations

Micrographs of red blood cells in diffferent solute concentrations

If the concentration of water is the same inside and out the cells (or *isotonic*), then there is no net movement of water into or out of the cell. The cells remain in their normal state. If the water concentration is too high outside of the cell (*hypotonic*) then water enters the cell by osmosis. If too much water enters, the cell will

New Visions for Public Schools 1

Accessing a Complex Text

1. Provide students the *Osmoregulation at the System Level Text*. Frame the rationale for reading this text by naming some specific point(s) that you noticed as you viewed their draft sequence charts. For example:
    - "When your groups were talking just now, I noticed that some groups were trying to figure out how much we sweat, and how that might impact our water-sodium balance during exercise. This is a really great question! As we read this, we can try and fill in gaps or problems with our group sequence chart."
2. Prompt students to read and use **text annotation** individually for the following, using the annotation guide in their handouts:
    - Points that confirm your group's sequence chart
    - Points that contradict your group's sequence chart
    - Points that help to modify or add to your group's sequence chart
3. Ask students to return to their group sequence chart, to add or modify components that were not in the earlier version.

Implementation Tip

Reading a complex text after making predictions (in the form of a sequence chart) provides all students with a reason to read, allowing them to engage with the same complex text, but with different sets of reading priorities.

Access for Multilingual Learners

Annotating texts is a strategy that many students find helpful. For **transitioning** and **expanding** language learners, you can tailor the annotation guide to focus only on points that confirm their group's sequence chart.

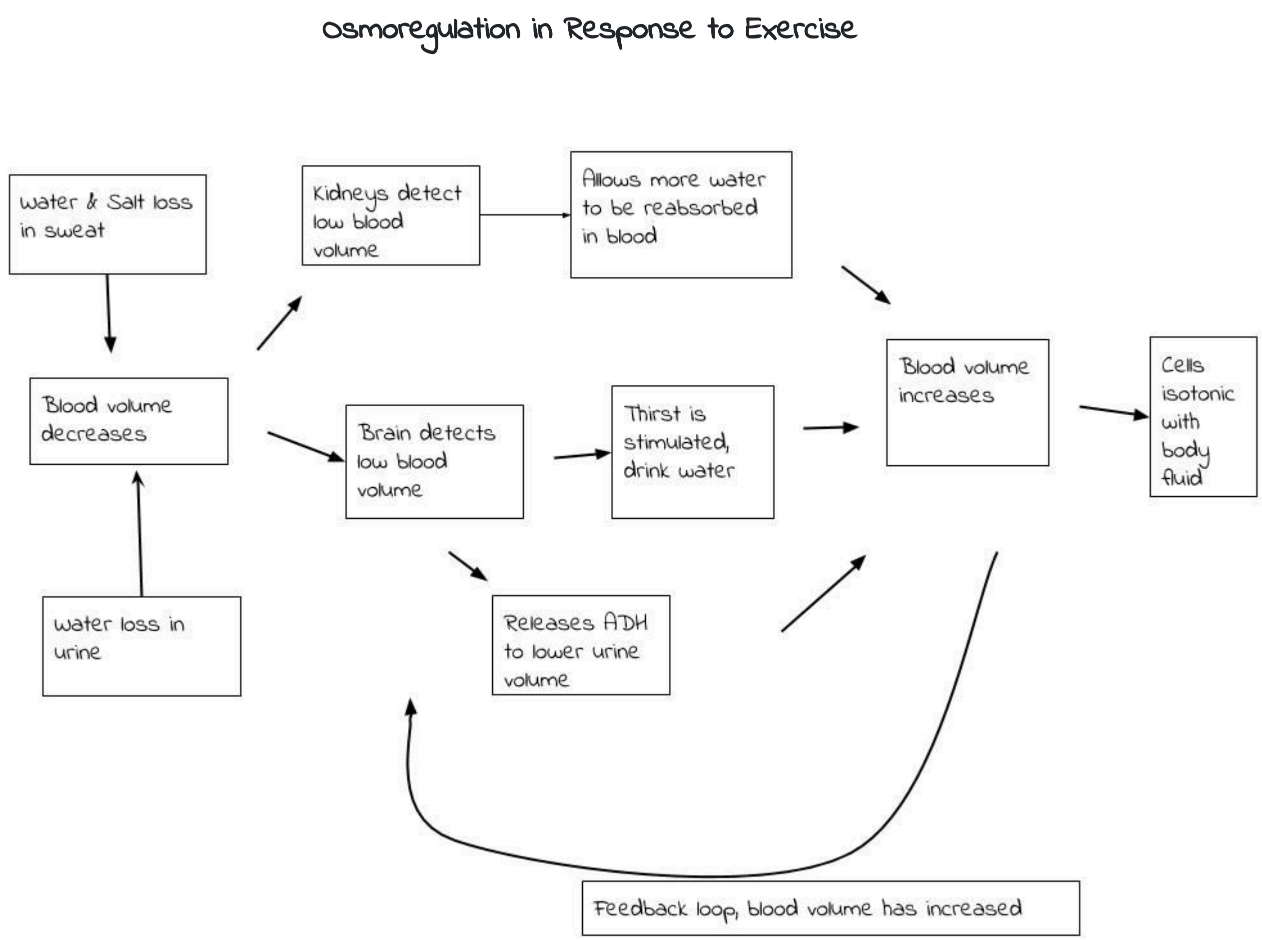
Surfacing Student Ideas

1. Provide students with chart paper and markers, to generate a group sequence chart they will use to share their ideas with the class. This is the starting point for the group learning routing **Idea Carousel**.
2. Remind students of the shared question everyone is trying to address in their sequence charts: How does the body osmoregulate during exercise?
3. Post chart papers around the room, or in the hallway if needed. You need to provide enough space that students can talk and circulate.
4. Launch the group learning routine Idea Carousel, to engage students in sharing then discussing their sequence charts. Groups come to consensus at the end of the routine when they return to their own work and read the annotations provided from other groups.
5. At the end of the routine, each group revises and finalizes their sequence chart. If necessary, they can use new chart papers to do this.

Routine

This is the first time the routine **Idea Carousel** appears in this unit! Please read the Biology Course Guide for detailed steps about this routine. For this implementation, focus on having students

Example Student Poster



An example of a group poster. There are multiple ways in which a group could represent this flowchart.

Conferring Prompts

Confer with students as they are working on their sequence charts. While you should not strive to have all of the charts look the same (that would make for a boring Idea Carousel!), it is important that students produce a thorough record of their current thinking. Use the example sequence chart below to guide your questions.

In addition, here are some suggested conferring questions
- Did you consider what happens when people sweat?
- Do people usually take in water or food while exercising? Where did you include that?
- Are there other ways water leaves the body?

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
    - "We have a lot of different ideas circulating in the room right now, and they are in the form of different sequence charts. It is really important for us to get to some agreement on how we represent what we know about osmoregulation, and how the body maintains homeostasis during exercise, so that we have a shared understanding to build upon as we move ahead. In order to do this we are going to do something called a **Class Consensus Discussion**. First I will select a few different groups to share their ideas. Then, we will let each group share their chart, and discuss what we can agree to as a class."

Implementation Tip

Class Consensus Discussions are so important for the Explain phase across this unit. It provides an opportunity for groups to share out around their sensemaking and for other groups to list, summarize, and ask questions after each share.

2. You may decide to walk students through the entire poster, or take them through the steps as you facilitate it. Alternatively, if you have collected helpful feedback points from students after past consensus discussions, you can share those ideas with the class.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Refer to the Biology Course Guide for support with this routine.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #7 - Stability and Change** explicit for students by elevating and probing for ideas related to feedback mechanisms and how they can stabilize or destabilize a system. This is an important element **CCC # 7 - Stability and Change** at the high school level.

3. Select two or three groups' charts to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of osmoregulation during exercise. The decision about which models to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

4. Ask the first group to share their chart. You can do this by:
   - Projecting using a document camera; OR
   - Copying the charts to be shared and passing them out to the class; OR
   - Taking a picture of each model and projecting them as slides.

5. Proceed through the steps in the Consensus Discussion Steps. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk; use the guidelines below to ensure the class focuses on ideas that will drive the lesson and unit forward.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:
- Multiple body systems (circulatory, nervous, excretory, endocrine) work together at the cellular, organ, and system levels to maintain *homeostasis* in terms of water and salt balance during exercise
- Osmoregulation is maintained through *feedback mechanisms*, an example is the release of ADH to decrease urine in order to increase blood volume (or reduce solute concentration); once blood volume increases, ADH release is stopped
- Osmoregulation functions to maintain the proper osmolarity (solute/water balance) so that cells are generally *isotonic* with body fluids; cells in *hypertonic* solutions shrink and are dehydrated, cells in *hypotonic* solutions swell

Summary

1. Students individually complete *Summary Task* This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about how the body regulates water and salt balances.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's individual thinking at this point in the unit, in a few different areas:
1) understanding how they are **using the three dimensions to make sense of a phenomenon,** human sweat during exercise; 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

How do fish osmoregulate?

Students test out their ideas and conceptions about **osmoregulation** by investigating if goldfish can live in saltwater aquariums. Students **evaluate the models** used in the Explore phase, and **propose criteria they would use to develop a model** that could be used to represent whether or not freshwater goldfish can **maintain stability** when introduced into a saltwater environment.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Individual or pairs	❏ Domino Discover	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ Goldfish Scenario ❏ Osmoregulation in Fish Text	None	❏ Mashable article: Goldfish, released into the wild, are somehow surviving in saltwater

Text Based Task

1. Organize students into pairs. Highlight for students that in the Explore & Explain, they figured out how humans osmoregulate during exercise.

2. If this question has not surfaced yet, prompt students to consider how other organisms osmoregulate, especially aquatic organisms that are entirely surrounded by water. Ask them to list reasons why this might be helpful to figure out.

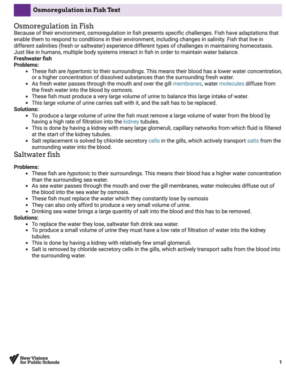
Differentiation Point

In the Explain phase, you had a chance to assess student learning around how the human body osmoregulates. This phase of the 5E allows for students who are still unsure of that idea to develop it further through learning how fish osmoregulate, and are able to live in different types of environments. This phase also provides students an opportunity to extend their thinking on developing and using scientific models.

3. Provide students with the *Goldfish Scenario*. Students must decide if a goldfish can live in a saltwater tank. Students read *Osmoregulation in Fish Text*, and annotate the text for evidence to inform their decision and to provide a rationale.

4. Students must decide on the best way to represent what they think will happen to the goldfish in saltwater. To do that, they evaluate the models they have interacted with in this 5E instructional sequence, including the onion cell, and diagrams or models they have used throughout the unit (such as the input-output model). They identify positive characteristics (i.e. what was useful about the model in helping them understand the phenomenon) and limitations of each model. Using what surfaces in that task, students generate their own model to explain why (why or why not) a goldfish can survive in a saltwater aquarium.

5. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from students. Plan forward based on the various understandings that students or student groups have articulated.



Osmoregulation in Fish Text

Osmoregulation in Fish

Because of their environment, osmoregulation in fish presents specific challenges. Fish have adaptations that enable them to respond to conditions in their environment, including changes in salinity. Fish that live in different salinities (fresh or saltwater) experience different types of challenges in maintaining homeostasis. Just like in humans, multiple body systems interact in fish in order to maintain water balance.

Freshwater fish

Problems:

- These fish are *hypertonic* to their surroundings. This means their blood has a lower water concentration, or a higher concentration of dissolved substances than the surrounding fresh water.
- As fresh water passes through the mouth and over the gill membranes, water molecules diffuse from the fresh water into the blood by osmosis.
- These fish must produce a very large volume of urine to balance this large intake of water.
- This large volume of urine carries salt with it, and the salt has to be replaced.

Solutions:

- To produce a large volume of urine the fish must remove a large volume of water from the blood by having a high rate of filtration into the kidney tubules.
- This is done by having a kidney with many large glomeruli, capillary networks from which fluid is filtered at the start of the kidney tubules.
- Salt replacement is solved by chloride secretory cells in the gills, which actively transport salts from the surrounding water into the blood.

Saltwater fish

Problems:

- These fish are *hypotonic* to their surroundings. This means their blood has a higher water concentration than the surrounding sea water.
- As sea water passes through the mouth and over the gill membranes, water molecules diffuse out of the blood into the sea water by osmosis.
- These fish must replace the water which they constantly lose by osmosis
- They can also only afford to produce a very small volume of urine.
- Drinking sea water brings a large quantity of salt into the blood and this has to be removed.

Solutions:

- To replace the water they lose, saltwater fish drink sea water.
- To produce a small volume of urine they must have a low rate of filtration of water into the kidney tubules.
- This is done by having a kidney with relatively few small glomeruli.
- Salt is removed by chloride secretory cells in the gills, which actively transport salts from the blood into the surrounding water.

New Visions for Public Schools 1

Class Consensus List: Characteristics of a Scientific Model

It is a picture/representation/drawing of the thing we are studying.

It helps us see or visualize something.

It lets us think about impacts of actions/cause & effect.

It is a 'testable' version of something.

We can (more) easily manipulate variables

Difficult to see or experiment on human cells

Cheaper, simpler, faster, more efficient

Look & Listen For

Students may generate ideas such as:

- Just like human cells, goldfish cells should generally be isotonic with their surroundings.
- Goldfish do not have the adaptations to live in a saline environment.
- In a saltwater aquarium their environment would be hypertonic to the fish's cells.
- Cells would lose water to their environment and shrink.
- There are many ways to represent this concept in an explanatory model.
- Arrows, legend/labels, and diagramming the input-output of the process may be helpful in generating a clear model.

Differentiation Point

Based on student interest and readiness, provide the additional article, Mashable article: Goldfish, released into the wild, are somehow surviving in saltwater in order to spiral in the concepts of adaptation, natural selection, and invasive species!

Differentiation Point

This activity is designed to support students in generating their final explanatory model. Take this opportunity to review the models students have generated or interacted with through the unit. Remind students of their scientific model characteristic chart. Prompt students to modify the final list as they prepare to generate their final model in the Performance Task.

Evaluate

How does the body regulate water balance during exercise?

Students demonstrate their understanding of how an exercising person **osmoregulates** by **evaluating the importance of plasma sodium level data** on the Marathon Runner problem.

Preparation

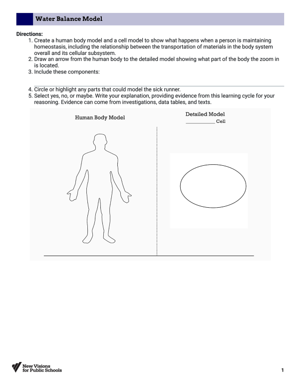
Student Grouping	Routines	Literacy Strategies
❏ Table groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Water Balance Model ❏ Water Balance Model Rubric ❏ Hyponatremia Text	None	❏ Class wide scientific model characteristics ❏ Driving Question Board from the start of the unit should be available

Revisit the Performance Task

1. Prompt students to consider where they currently stand on the question category from the Driving Question Board that they have been investigating throughout this 5E instructional sequence (for example, *Did the* marathon runner dehydrate or drink too much water?)



Water Balance Model

Directions:
1. Create a human body model and a cell model to show what happens when a person is maintaining homeostasis, including the relationship between the transportation of materials in the body system overall and its cellular subsystem.
2. Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3. Include these components:
4. Circle or highlight any parts that could model the sick runner.
5. Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Human Body Model

Detailed Model
_________ Cell

Implementation Tip

When returning to the Driving Question Board, be sure to change these suggested teacher notes so that they match your class' actual questions!

2. Students work individually on the Water Balance section of their performance task organizer. They should make choices on how to represent their ideas using the model they are developing. In the models, students are representing how a human normally regulates water and salt balance.
3. Provide students with the normal human plasma sodium levels, between 135 and 145 milliequivalents per liter (mEq/L). This information should be recorded in their organizer.
4. Confer with students while they are working.

Conferring Prompts

Confer with students as they work to develop their models. Prompt students to return to the class wide scientific model characteristics, posted in the room.
Suggested conferring questions:

- Can you confirm, contradict, or modify anything on the list based on your interactions with models throughout these investigations on water balance?
- How can you use the characteristics on the list to inform the development of your own model?

5. Students individually use their model to evaluate the claim on whether or not the runner was not able to regulate water balance, and collapsed because of dehydration (Did the runner not drink enough or drink too much water or other fluids?). Prompt students to use the medical tent data to support their claim. They should also consider data and evidence gathered during the investigations completed during this instructional sequence, as well as their new understandings.
6. Use the *Water Balance Model Rubric* and *Water Balance Model Student Work Example* for students to self-reflect on their progress and to provide individual feedback towards the final task.

Document Class Thinking

1. Prompt students to discuss with their groups their decision, on the question Did the marathon runner drink too much water? Students can use the notes in their performance task organizers in these discussions.

2. Each group comes to a consensus answer to the question -- Yes, No, or Maybe -- and should be able to articulate their reasoning.

3. Conduct a **Domino Discover** to hear from each group, and tally the responses on chart paper. It is not necessary to discuss all the positions or get to class consensus at this point. Based on the investigations in this 5E instructional sequence, most groups will say Yes.

Routine

This **Domino Discover** routine is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction.

Implementation Tip

The last body model is representing how humans osmoregulate normally when exercising. Depending on the exact questions your students asked, the class may be responding to the question, Did the marathon runner dehydrate? (no, she did not) instead of the question Did the marathon runner drink too much water? (yes, she did). This is ok, as long as students are thinking through if there was a disruption (in any way) of how she maintained water balance.

If your students respond that no, she did not dehydrate and respond to that prompt in their Water Balance Evaluate model, encourage them to think further about what could have gone wrong, based on the medical tent data. As the plasma sodium levels are lower than normal, prompt students to think about what might have gone wrong, as they transition to their final response to the Performance Task.

Differentiation Point

If students are struggling with making the connection between the runner's low sodium plasma levels and drinking too much water too fast, provide students with the optional *Hyponatremia Text* which may provide them with more guidance or ideas on how the runner's body failed to maintain homeostasis, resulting in her falling into a coma.

Standards in Water Balance 5E

Performance Expectations

HS-LS1-2 **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.**
Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.
Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.

In NYS the clarification statement has been edited as follows: Emphasis is on functions at the organism's system level such as nutrient uptake, water delivery, immune response, and organism response to stimuli.

HS-LS1-3 **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.**
Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.
Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3)	LS1.A Structure and Function • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. LS1.A(3) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. LS1.A(4)	Systems and Systems Models • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. CCC4(3) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Developing and Using Models		*Making Sense of Osmosis in Onion Cells Investigation* *Making Sense of Osmoregulation in the Kidney Investigation*	*Summary Task*	*Goldfish Scenario*	*Water Balance Model* *Water Balance Model Rubric*
LS1.A Structure and Function	Rumors: students' post-its and the emergent categories	*Making Sense of Osmoregulation in the Kidney Investigation*	Osmoregulation Sequence Chart *Summary Task*	*Goldfish Scenario*	*Water Balance Model* *Water Balance Model Rubric*
Systems and Systems Models		*Making Sense of Osmosis in Onion Cells Investigation* *Osmoregulation in the Kidney Investigation* *Making Sense of Osmoregulation in the Kidney Investigation*	*Summary Task*	*Goldfish Scenario*	
Stability and Change	Rumors: students' post-its and the emergent categories		Osmoregulation Sequence Chart *Summary Task*	*Goldfish Scenario*	*Water Balance Model* *Water Balance Model Rubric*

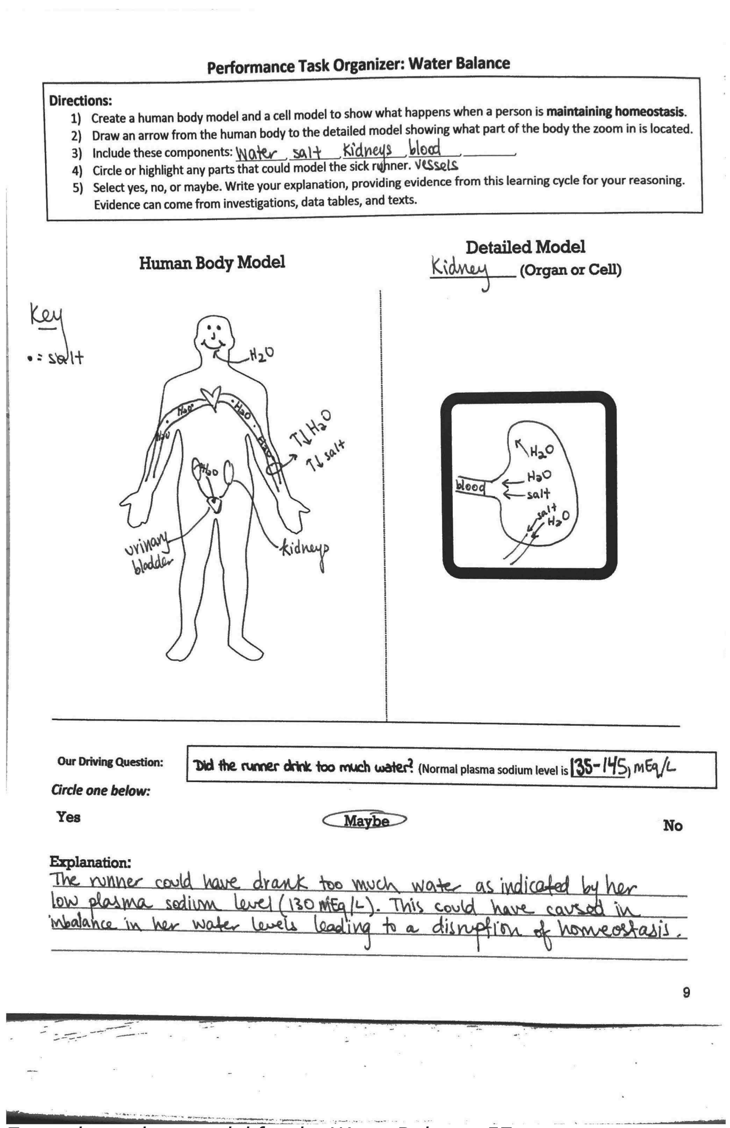
Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics	MP2	MP2	MP2 MP3	MP2	MP2
ELA/Literacy		RST.9-10.7 WHST.9-10.9 SL.9-10.5	RST.9-10.1 RST.9-10.7 WHST.9-10.9 SL.9-10.4 SL.9-10.5	RST.9-10.1 WHST.9-10.9 SL.9-10.4	WHST.9-10.2 WHST.9-10.9 SL.9-10.4 SL.9-10.5

Student Work for Water Balance 5E

Water Balance Model Student Work Example

Example Student Model


Performance Task Organizer: Water Balance

Directions:
1) Create a human body model and a cell model to show what happens when a person is **maintaining homeostasis.**
2) Draw an arrow from the human body to the detailed model showing what part of the body the zoom in is located.
3) Include these components: Water, salt, Kidneys, blood, vessels, ______
4) Circle or highlight any parts that could model the sick runner.
5) Select yes, no, or maybe. Write your explanation, providing evidence from this learning cycle for your reasoning. Evidence can come from investigations, data tables, and texts.

Human Body Model

Detailed Model
Kidney (Organ or Cell)

Our Driving Question: Did the runner drink too much water? (Normal plasma sodium level is 135-145 mEq/L

Circle one below:

Yes | Maybe | No

Explanation:
The runner could have drank too much water as indicated by her low plasma sodium level (130 mEq/L). This could have caused in imbalance in her water levels leading to a disruption of homeostasis.

9

Example student model for the Water Balance 5E

Implementation Notes from Field Test Teachers:

- You may be wondering- why would I have my students do this model if they are just gonna do it again for their final explanatory model?! Remember this model should be what is normally happening in the body!
- Remember to go back to your characteristics of models and have students reflect. In addition, prompt students to reflect on their practice of modeling as a whole- what is one thing they want to improve upon in this last model?
- Students should be prompted to fill in the components they think need to be included based on their learning in this 5E instructional sequence. You could also give students components if you do not feel they are ready (brain, kidney, blood, urinary bladder are some options).
- In the human body model students should be able to show the osmoregulatory functions in the body. This should include the interactions between the brain, kidney, and blood filtering.
- In the detailed model students can choose to show a detailed model of an organ or a cell. The organ could include the interactions happening in the kidney as learned through the simulation in the Explore phase of this instructional sequence. The cell can show a cell maintaining water balance with equal concentrations of solute inside and outside of the cell leading to a stable cell size.

Unit Closing	Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	**Performance Expectations** HS-LS1-2, HS-LS1-3	**Anchor Phenomenon** Marathon Runner Collapse: Why would a marathon runner become disoriented during the race, then go into a coma shortly after running the race?	**Time** 1-5 days

Based on the investigations and learning throughout the unit, students generate a final explanatory model that represents why the marathon runner collapsed.

ANCHOR PHENOMENON	Why would a marathon runner become disoriented during the race, then collapse afterward?	Based on the investigations and learning throughout the unit, students review their ideas for why the marathon runner collapsed.
DRIVING QUESTION BOARD	What questions have been answered? What have we not answered yet?	Based on the investigations and learning throughout the unit, students return to the Driving Question Board to reflect on questions generated throughout the unit.
PERFORMANCE TASK	Why would a marathon runner become disoriented during the race, then collapse afterward?	Based on the investigations and learning throughout the unit, students generate a final explanatory model that represents why the marathon runner collapsed.
UNIT REFLECTION	How can we evaluate our practice of modeling?	Students reflect on their use of scientific modeling throughout the unit.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

Why would a marathon runner become disoriented during the race, then collapse afterward?

Based on the investigations and learning throughout the unit, students review their ideas for why the marathon runner collapsed.

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Final Explanatory Model	None	

Generating Ideas about Anchor Phenomenon

1. Students return to the anchor phenomenon and review their ideas for why a marathon runner would collapse.

Driving Question Board

What questions have been answered? What have we not answered yet?

Based on the investigations and learning throughout the unit, students return to the Driving Question Board to reflect on questions generated throughout the unit.

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	❑ Class wide Driving Question Board

Revisit the Driving Question Board

1. Students return to the questions generated throughout the unit and reflect. What questions have been answered? Are there questions that we still need to investigate?

2. Note that not all of the students' questions will be answered at the end of the unit, and students may have generated entirely new questions. Depending on student interest and instructional time, prompt students to explore some of the unanswered questions independently.

Performance Task

Why would a marathon runner become disoriented during the race, then collapse afterward?

Based on the investigations and learning throughout the unit, students generate a final explanatory model that represents why the marathon runner collapsed.

Preparation

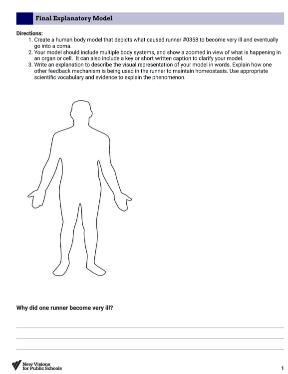
Student Grouping	Routines	Literacy Strategies
❏ Individual	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Final Explanatory Model	None	❏ *Final Explanatory Model* ❏ *Final Explanation* ❏ Runners World article: Pass The Salt? ❏ Hammer Nutrition text: Hydration - What do You Need to Know ❏ Scientific American article: Strange But True: Drinking Too Much Water Can Kill

Develop an Explanatory Model

1. Remind students of the ideas and questions surfaced at the end of the Water Balance 5E. Tell students that they will have an opportunity to demonstrate what they think happened to the marathon runner and why she collapsed at the end of the race.
2. The explanatory model should only demonstrate how runner #0358 failed to maintain homeostasis (why she collapsed and ended up in a coma) and should include multiple body systems and a zoomed in view of a cell or organ.
3. Provide students time to review the feedback from each of their body and cell models in their *Final Explanatory Model* and review the class list: Characteristics of Scientific Models.
4. Students individually generate their explanatory model.


Final Explanatory Model

Directions:
1. Create a human body model that depicts what caused runner #0358 to become very ill and eventually go into a coma.
2. Your model should include multiple body systems, and show a zoomed in view of what is happening in an organ or cell. It can also include a key or short written caption to clarify your model.
3. Write an explanation to describe the visual representation of your model in words. Explain how one other feedback mechanism is being used in the runner to maintain homeostasis. Use appropriate scientific vocabulary and evidence to explain the phenomenon.

Why did one runner become very ill?

Class Consensus List:
Characteristics of a Scientific Model

It is a picture/representation/drawing of the thing we are studying.

It helps us see or visualize something.

It lets us think about impacts of actions/cause & effect.

It is a 'testable' version of something.

we can (more) easily manipulate variables

Difficult to see or experiment on human cells

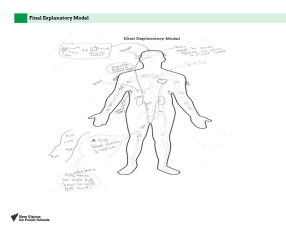
Cheaper, simpler, faster, more efficient

Can be used to explain or demonstrate a process or concept

Differentiation Point

If students are struggling to make the connections to hyponatremia, return to the medical tent data as a class, adding in the normal ranges for each. Facilitate discussion around the idea that the sodium plasma levels are below normal for runner #0358 (the one that collapsed), and what that could mean for her water-sodium balance and her cells -- especially those in her brain, as she did go into a coma. It is not necessary for students to use the term hyponatremia, but they should be able to demonstrate the concept in the model and written component. Additional articles on hyponatremia and the results of drinking too much water too fast, (such as Runners World article: Pass The Salt? , Hammer Nutrition text: Hydration - What do You Need to Know , and Scientific American article: Strange But True: Drinking Too Much Water Can Kill) can be used to further support students, or to extend the discussion based on student interest.

5. Use the *Final Explanatory Model* to provide feedback to students as they are working.



Construct an Explanation of the Phenomenon

1. Prompt students to provide a written explanation of their model in the *Final Explanatory Model* Remind students that It is especially important to clarify concepts in writing that might not be clear or entirely visible in their final model.

2. Students choose one example of a disruption that did not cause the marathon runner to collapse (a system that was most likely working normally to maintain homeostasis) to explain why that was not the cause of the collapse. Encourage students to think back to what they initially predicted was the cause of the collapse and to explain how their thinking has changed.

3. Use the *Final Explanation* to provide students with feedback as they work.

Differentiation Point

The cause behind the marathon collapse is unexpected, and students may not have ever heard of hyponatremia or have heard that it is possible to drink too much water (as we usually hear so much about hydration!). Students ready to extend the discussion can think through what the organizers of future races should do to avoid this type of issue. A final product could include a newspaper article, or a safety plan on how to change the race (or similar sporting events) to avoid hyponatremia in the future. The additional resources on hyponatremia (Runners World article: Pass The Salt? , Hammer Nutrition text: Hydration - What do You Need to Know , and Scientific American article: Strange But True: Drinking Too Much Water Can Kill) may be useful for students working on this extension.

Access for All Learners

Some students feel more confident first representing their ideas visually in their model and then writing the explanation. Other students prefer to write the explanation and then generate the model from their written ideas. Alternatively, some students draft both at the same time. All of these variations are fine. Encourage students to work on the performance task in that way that works best for them.

Unit Reflection

How can we evaluate our practice of modeling?

Students reflect on their use of scientific modeling throughout the unit.

Preparation

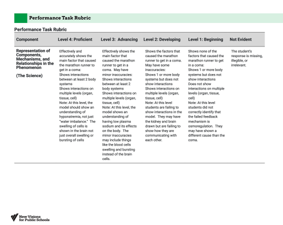
Student Grouping	Routines	Literacy Strategies
❏ Individual	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Self Evaluation	None	❏ *Performance Task Rubric*

Self-Evaluation in the Practice of Modeling

1. Remind students that at the start of the unit they generated an initial scientific model (using the human body outline) to represent what happens in the body during exercise and as a class, and they created an initial list of characteristics of a scientific model.
2. Prompt students to identify how their thinking has changed on what a scientific model is and what scientific models can be used for. Support student ideas by projecting the initial and final class lists on scientific model characteristics, and/or asking students to compare their initial model with their final model.
3. Students discuss ideas in their groups.
4. Provide students with the *Self Evaluation* to complete individually.
5. Use the *Performance Task Rubric* to provide feedback as students are working.



Performance Task Rubric

Performance Task Rubric

Component	Level 4: Proficient	Level 3: Advancing	Level 2: Developing	Level 1: Beginning	Not Evident
Representation of Components, Mechanisms, and Relationships in the Phenomenon **(The Science)**	Effectively and accurately shows the main factor that caused the marathon runner to get in a coma: Shows interactions between at least 2 body systems Shows interactions on multiple levels (organ, tissue, cell) Note: At this level, the model should show an understanding of hyponatremia, not just "water imbalance." The swelling of cells is shown in the brain not just overall swelling or bursting of cells	Effectively shows the main factor that caused the marathon runner to get in a coma. May have minor inaccuracies: Shows interactions between at least 2 body systems Shows interactions on multiple levels (organ, tissue, cell) Note: At this level, the model shows an understanding of having low plasma sodium and its effects on the body. The minor inaccuracies may include things like the blood cells swelling and bursting instead of the brain cells.	Shows the factors that caused the marathon runner to get in a coma. May have some inaccuracies: Shows 1 or more body systems but does not show interactions Shows interactions on multiple levels (organ, tissue, cell) Note: At this level students are failing to show interactions in the model. They may have the kidney and brain drawn but are failing to show how they are communicating with each other.	Shows none of the factors that caused the marathon runner to get in a coma: Shows 1 or more body systems but does not show interactions Does not show interactions on multiple levels (organ, tissue, cell) Note: At this level students did not correctly identify that the failed feedback mechanism is osmoregulation. They may have shown a different cause than the coma.	The student's response is missing, illegible, or irrelevant.

New Visions for Public Schools 1

Standards in Unit Closing

Performance Expectations

HS-LS1-2 **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.**
Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.
Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.

In NYS the clarification statement has been edited as follows: Emphasis is on functions at the organism's system level such as nutrient uptake, water delivery, immune response, and organism response to stimuli.

HS-LS1-3 **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.**
Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.
Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3)	LS1.A Structure and Function • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. LS1.A(3) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. LS1.A(4)	Systems and Systems Models • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. CCC4(3) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

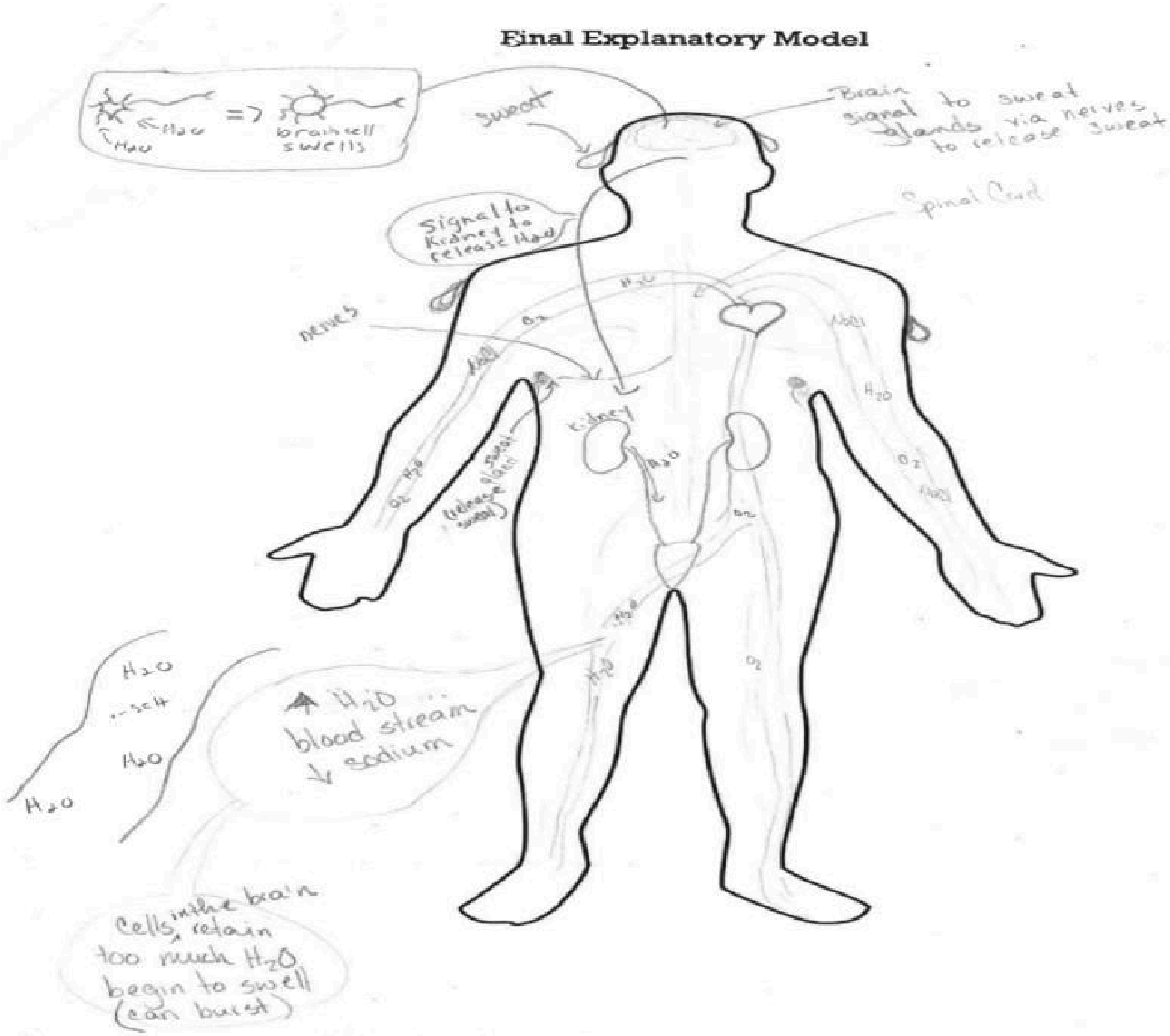
	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Developing and Using Models			*Final Explanatory Model*	*Self Evaluation*
LS1.A Structure and Function			*Final Explanatory Model*	
Systems and Systems Models			*Final Explanatory Model*	
Stability and Change			*Final Explanatory Model*	

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Mathematics				
ELA/Literacy			RST.9-10.7 WHST.9-10.2 WHST.9-10.9	RST.9-10.7 WHST.9-10.2 WHST.9-10.9

Student Work for Unit Closing

Final Explanatory Model



Implementation Notes from Field Test Teachers

- Encourage students to focus only on the failure of homeostasis. The other 5E-level models represented how a runner's body would normally maintain homeostasis in regard to each type of regulation.
- Attempting to represent too many components on the model makes the final product messy and unclear.
- In the previous body and cell models, students were given guidance on what they needed to include. In the final model, students should be making the decisions, including what they should zoom into (for the cellular or organ levels).
- Pus**h** students to think about what is essential (and not essential) to represent the phenomenon.

Final Explanation

Example Student Work

The following written explanation includes the components, relationships and mechanism represented in the model. Individual written explanation utilizes appropriate scientific terminology to develop an explanation of the phenomenon. Individual written explanation explains why at least one other feedback mechanism was not disrupted (level 4 on the rubric).

As shown in my model, runner 0358 went into a coma because of a disruption of homeostasis negatively impacted the interaction of two body systems: the nervous and excretory systems. Sodium levels in the nervous system is key to maintaining homeostasis in nerve impulse and cellular homeostasis. In order to maintain sodium levels in the normal range (135 - 145 mEq/L), water balance needs to be also maintained by the excretory system. When there is too much water in the body, the nervous system detects it and sends a signal to the kidney to excrete the excess water. This is an example of feedback mechanism. If this is not controlled, an increase in the water level in the body will result in a decrease in the solute (sodium) concentration in the cells. During the marathon, runner 0358 drank high level of water that were not filtered by the kidney in that short amount of time. The increase in water concentration in the body had a major impact on the brain cells causing hyponatremia (low level of salt). Indeed, the medical tent data showed that the sodium level dropped to 130 mEq/L. This also caused the brain cells to swell as a consequence of water moving inside the cell through osmosis. This means that water moves from high concentration outside the cells to an area of lower concentration inside the cell. On the contrary, the runner could not have ran out of oxygen because the oxygen levels were in the normal range (as shown by the medical tent data - 98%). The runner was able to successfully regulate gas exchange, so that enough oxygen was able to supply the muscle cells and generate ATP through cellular respiration.

The following written explanation includes some of the components, relationships and mechanism represented in the model. Individual written explanation has limited use of appropriate scientific terminology to develop an explanation of the phenomenon than can be represented on the model (level 2 on the rubric).

My model shows how runner 0358 became ill and went into a coma. During the marathon, this woman drank high amount of water. The higher water amount resulted in a lower blood sodium amount (as shown in the medical tent data with sodium at 130 mEq/L). Osmosis is the movement of water from an area of high amount to an area of low amount. After drinking high amount of water, the runner had high water levels in her body. This caused the water to move inside each cell of her body. However, when the water moved inside the brain cell this caused them to swell and burst. The swelling and bursting of neurons led the runner into a coma. However, the runner probably did not have an asthma attack or run out of oxygen. The medical tent data shows that she had a normal level of oxygen.

Why did one runner become very ill?

As shown in my model, runner 0358 went into a coma because of ~~a~~ disruption of homeostasis, negatively impacted the interaction of 2 body systems: the nervous and excretory systems. Sodium levels in the nervous system is key to maintaining homeostasis in nerve impulses and cellular homeostasis. In order to maintain sodium levels in the normal range (135-145 mEq/L) water balance needs to be maintained by the excretory system. When there is too much water in the body, the nervous system detects it and sends a signal to the kidney to excrete the excess water. This is an example of a feedback mechanism. If this is not controlled, an increase in the water level in the body will result in a decrease in the solute (sodium) concentration in the cells. During the marathon, runner 0358 drank high level of water that was not filtered by the kidney in that short amount of time. The increase in water concentration in the body had a major impact on the brain cells causing hyponatremia (low levels of salt). Indeed, the medical tent data showed that the plasma sodium level of runner 0358 dropped to 130 mEq/L. This caused the brain cells to swell as a consequence of water moving inside the cell through osmosis. This means that water moves from high concentration outside the cells to an area of lower concentration inside the cell. On the contrary, the runner could not have ran out of oxygen because the oxygen levels were in the normal range (as shown in the medical tent data - 98%).

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Why did one runner become very ill?

My model shows how runner 0358 became ill and went into a coma. During the marathon, this woman drank high amounts of water. The higher water amount resulted in a lower blood sodium amount (as shown in the medical tent data at 130 mEq/L). Osmosis is the movement of water from an area of high amount to an area of low amount. After drinking high amounts of water, the runner had high water levels in her body. This caused water to move into the cells in her body. When the water moved into her brain cells it caused them to swell and burst. The swelling and bursting of neurons led the runner into a coma.

Classroom Resources for Unit Closing

Performance Task Rubric

Performance Task Rubric

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Decision making about visual representation (The Model)	Used proper symbols/notations to demonstrate phenomenon components, relationships, and mechanisms. The images (for the most part) "speak for themselves." Or contains legends/keys and written captions to clarify the model.	Used some symbols/notations to demonstrate phenomenon components, relationships, and mechanisms. The images (for the most part) "speak for themselves." Or contains some legends/keys and written captions to clarify the model.	Limited use of symbols/notations to demonstrate phenomenon components, relationships, and mechanisms. The images are not clear and shows an attempt at some legends/keys or written captions to clarify the model.	No use of symbols/notations to demonstrate phenomenon components, relationships, and mechanisms. The images are not clear and does not show an attempt at some legends/keys or written captions to clarify the model.	The student's response is missing, illegible, or irrelevant.
Using the model to develop a written explanation or prediction (The Explanation)	Individual written explanation includes the components, relationships and mechanism represented in the model. Individual written explanation utilizes appropriate scientific terminology to develop an explanation of the phenomenon. Individual written explanation explains why at least one other feedback mechanism was not disrupted.	Individual written explanation includes the components, relationships and mechanism represented in the model. Individual written explanation utilizes some appropriate scientific terminology to develop an explanation of the phenomenon than can be represented on the model.	Individual written explanation includes some of the components, relationships and mechanism represented in the model. Individual written explanation has limited use of appropriate scientific terminology to develop an explanation of the phenomenon than can be represented on the model.	Explanation does not match the mechanism represented in the model. Individual written explanation has little to no use of appropriate scientific terminology to develop an explanation of the phenomenon than can be represented on the model.	The student's response is missing, illegible, or irrelevant.

Note: For this portion of the rubric make sure you are following what the students showed in their model. It is important that we don't dock students a second time for stating the wrong feedback mechanism failed. For example, if they think the runner overheated and that is what they represented in their model their written explanation should follow that disruption of homeostasis.

Evaluate the model	In self-evaluation student mentions: Limitations of their model Purpose of decision-making	In self -evaluation student fails to mention one of the following: Limitations of their model Purpose of decision-making	In self-evaluation student in-accurately explains the following: Limitation of their model Purpose of decision making	No idea why we made the model Focused on appearance ("colorful" or "neat") as opposed to characteristics or decisions	The student's response is missing, illegible, or irrelevant.