Name: ____________________________

Staying Warm in the Extreme: Metabolism of Baby Seals

Scenario: You have been hiking and wandered off the trail, and now you are lost! Immediately you reach for your phone, but you have no service. You look in your backpack to find you have a bottle of water, a chocolate protein bar, and a down jacket.

1. You are starting to get cold; the temperature is dropping below freezing. What item(s) do you use from your bag to stay warm and why?

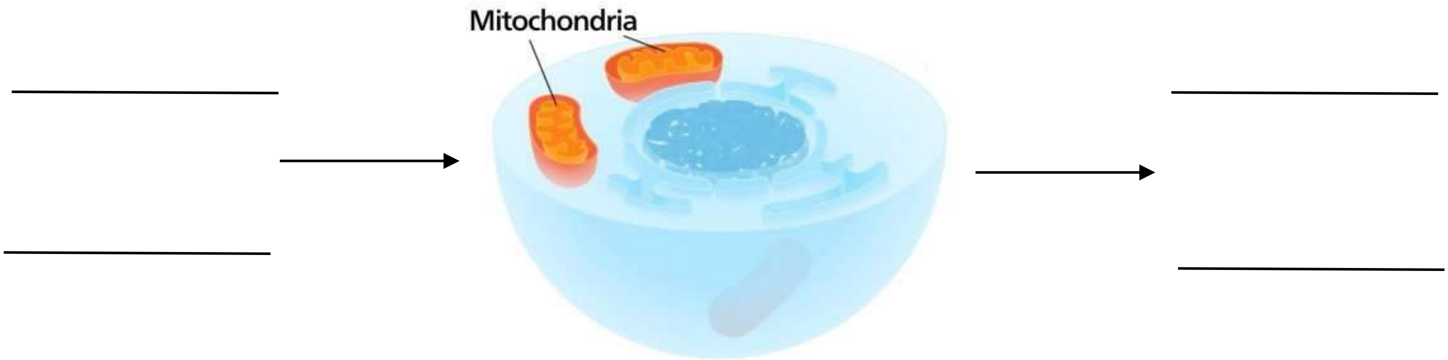
Students' answers will vary and may include the following. You will want to discuss how each method helps an individual maintain body heat.

Down jacket – Insulation, traps body heat.
Run around – Movement, using skeletal muscle produces heat.
Hunker down and shiver – Movement, using skeletal muscle produces heat.
Eat Protein bar – Metabolic rate increases (heat is produced as a result of digestion)

Why do we need to stay warm?
Humans, along with other mammals and birds, are ***homeotherms***, animals that maintain a constant body temperature; humans maintain a body temperature of 37°C (98.6ºF). The term ***homeostasis*** means maintaining constant internal conditions, such as body temperature. If our bodies do not maintain homeostasis, our cells do not work properly, and things start to shut down (cells and eventually organs will die) if we don't correct it. Homeostasis works well in our bodies under normal conditions, but in extreme conditions we need to take action to make sure we can survive. When it comes to body temperature, the human body works like a thermostat that turns on the air conditioning when it's too hot or turns on the heater when it's too cold.

Examples of "air conditioning" include sweating, panting (in animals), moving blood to the skin surface
Examples of "heaters" include turning up your metabolism, shivering, moving blood away from the skin surface

To aid in maintaining a stable body temperature, ***endothermic*** animals undergo the heat-producing reactions of ***metabolism***. One of the chemical reactions of metabolism is ***cellular respiration***, which breaks down glucose to generate heat. Using the word bank, label the reactants (going into the cell) and products (leaving the cell) in the process of cellular respiration in an animal cell: Glucose, Carbon Dioxide, Oxygen, Water (H_2O)



Scientists measure **metabolic rate** to understand how much energy an organism is using. One way to measure metabolic rate is to calculate the rate of cellular respiration,
Glucose ($C_6H_{12}O_6$) + Oxygen (O_2) $\longrightarrow$ Carbon dioxide (CO_2) + Water (H_2O) + HEAT + Energy.

2. If you were a scientist and wanted to measure the metabolic rate of an organism, which do you think is the easiest molecule in the cellular respiration equation to measure: Glucose, Oxygen, Carbon Dioxide, or Water? Explain how you would measure it.

Glucose – measure how much food they take in (and subtract out undigested food – poop!)
Oxygen consumption – measure how much oxygen the animal takes from the air (can use an oxygen sensor for this). Note: An animal extracts only some of the oxygen from the air that it inhales.
Carbon dioxide production – measure how much carbon dioxide the animal exhales (can use carbon dioxide sensor for this).
Water – Students may refer to how much water you drink, but in this equation water is a product, not a reactant. This one is harder (though possible) to measure in wild animals. Water is produced by many chemical reactions in the body, including cellular respiration, and it involves some chemistry and mathematics to measure metabolism this way. Note that measuring urine output is not a way to get at cellular respiration, because urine has to do with the kidneys filtering the blood.
Conclusion: Measuring oxygen consumption or carbon dioxide production are the easier ways to measure metabolic rate in whole organisms.

Though we don't have the equipment to measure your oxygen consumption in class, we can use ***respiration rate*** as a ***proxy*** for metabolic rate. When your metabolic rate increases, your respiration rate also increases to deliver oxygen to the body faster.

During exercise you use more energy, increasing your metabolic rate, and as a result you need to consume more oxygen. In this activity you will record data on your respiration rate before and after exercising, in Table 1 (below).

1) Record the number of times you inhale for **60 seconds** while sitting still in your chair (at rest). Do **NOT** look at the timer during the 60 seconds, you may use a timer with a beeper or have a partner tell you when to begin and end counting.

2) Repeat step 1 two additional times, and record the data in Table 1.
3) Do 20 jumping jacks.
4) Record the number of times you inhale for **60 seconds** while continuing to stand, immediately after you complete your jumping jacks. Do **NOT** look at the timer during the 60 seconds, you may use a timer with a beeper or have a partner tell you when to begin and end counting.
5) Repeat steps 3 and 4 two additional times and record the data in Table 1.
6) Calculate your mean number of inhales for both at rest and after exercise, and record those values in Table 1.

Table 1:

Trial Number	Number of inhales at rest	Number of inhales after exercise
1		
2		
3		
Mean (average of 3 trials)		

3. Under which condition, at rest or after exercise, did you have a higher number of inhales?

4. Circle the correct terms to make the following a correct statement:

When organisms increase physical activity the amount of oxygen cells require increases, because the rate of cellular respiration **increases/decreases**. As the rate of cellular respiration **increases/decreases**, an organism's metabolic rate **increases/decreases,** and more heat is produced.

Weddell seals are the southernmost born mammals. They live in Antarctica, the coldest, driest continent on the planet. Weddell seals must survive in extreme weather conditions, including cold air temperatures and strong winds. Like humans, baby seals (pups) must maintain homeostasis with a body temperature around 37°C (98.6°F). Unlike humans, Weddell seal pups cannot put on a down jacket, eat a chocolate protein bar, or run around to stay warm. Instead, they have fur and blubber for insulation; they consume milk from their mom, which is really fatty (50% fat vs. 4% for whole cow's milk; heavy whipping cream is 30%); and they do not move around to stay warm, because they stay close to their mothers.

Starting at around 3 weeks old, Weddell seal pups start to face an additional extreme condition: they begin to learn to swim in not-quite-frozen ocean water, which is about -2.8°C (27°F; note that seawater freezes at a colder temperature than freshwater). Scientists wondered which is more challenging for the pups to maintain homeostasis of body temperature, on top of the sea ice or in ocean water?

5. Do you think it requires more, less, or the same amount energy for Weddell seals to stay warm in ocean water (-2.8°C) compared to being on top of the ice, where temperatures can range from -40°C to +10ºC? Why?

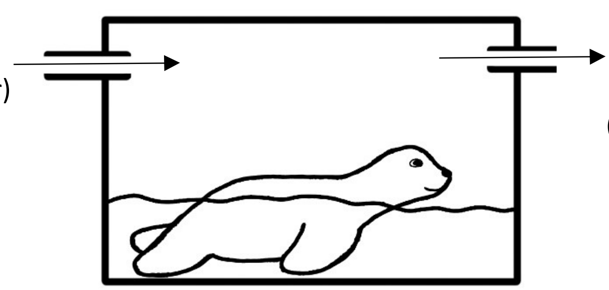
Student answers will vary, and we don't want to give the answer away at this stage.

6. Which additional variables do scientists need to control or account for to make sure they are only comparing the amount of energy being used by the seal pup in water versus air?

Possible answers: Environmental temperature, wind, whether the pup has eaten, age of the pup, body size, whether or how much the pup is moving around

To determine if you were using more energy at rest or during exercise, you recorded your number of inhales, to reveal under which condition your body required more oxygen. To evaluate if Weddell seal pups were using more energy to stay warm in the water or air, the researchers also measured how much oxygen that the seals used. Instead of counting inhales, scientists used a device called a metabolic chamber.

The metabolic chamber is connected to sensors that record the following:
- The **flow rate** of air moving through chamber (500 L/min)
- Fraction of O_2 in ambient (incoming) air = 20.95% = 0.2095
  (which is the same as the air around you!)
- Fraction of O_2 in air exiting chamber (after animal consumes some O_2)



Using the collected data, scientists can calculate the **oxygen consumption rate**, also referred to as **metabolic rate**, using the equation below:

$$\text{Metabolic Rate} = \begin{matrix}\text{Flow rate of air}\\ \text{through chamber}\\ \text{(500 L/min)}\end{matrix} \times \left[\begin{matrix}\text{Fraction of } O_2\\ \text{in ambient (incoming air)}\\ (0.2095)\end{matrix} - \begin{matrix}\text{Fraction of } O_2\\ \text{In air exiting chamber}\\ \text{(after animal consumes}\\ \text{some } O_2)\end{matrix}\right]$$

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Option: Teacher provides images of 6 Weddell seal pups either on board, in digital notebook, or physically

Below are the data scientists recorded for six 3-week-old Weddell seal pups. Using the equation above, you will be calculating their metabolic rates, both in and out of water, to determine if these pups use more energy to stay warm submerged in the cold ocean water or on the sea ice exposed to the Antarctic air.

Calculate the metabolic rate of the Weddell seal pups, using the equation above, when exposed to air. After you calculate the metabolic rate for each pup, calculate the mean metabolic rate.

Weddell Seal Pup	Fraction of O_2 exiting Chamber	Calculated Metabolic Rate (L/min)
Mr. Goodbar	0.2085	0.5036
Twix	0.2081	0.6814
Smartie	0.2078	0.8388
Macaroni	0.2083	0.5818
King	0.2084	0.5601
Little Blue	0.2083	0.5686
Mean		0.6224

Calculate the metabolic rate of the Weddell seal pups, using the equation above, when submerged in water. After you calculate the metabolic rate for each pup, calculate the mean metabolic rate.

Weddell Seal Pup	Fraction of O_2 exiting Chamber	Calculated Metabolic Rate
Mr. Goodbar	0.2080	0.7517
Twix	0.2080	0.7290
Smartie	0.2072	1.1526
Macaroni	0.2081	0.7000
King	0.2075	0.9934
Little Blue	0.2073	1.0888
Mean		0.9026

7. In which condition, exposed to air or submerged in water, do Weddell seal pups have a higher metabolic rate? Use data as evidence to support your answer

The mean metabolic rate in water is higher than it is in air.

8. During this experiment you analyzed data of oxygen consumption because oxygen is required for cellular respiration, which is a chemical reaction of metabolism. Explain the pathway oxygen travels to get to cells to be used for cellular respiration.

Air is inhaled into the lungs (respiratory system), and the oxygen moves from the lungs to the blood (circulatory system). The protein **hemoglobin** carries the oxygen in the red blood cells. The circulatory system delivers the oxygen to the cells, where it gets used in cellular respiration.

9. Returning back to the scenario at the beginning of the lab: How would eating a chocolate protein bar help you generate heat to stay warm?

The glucose supplied in the chocolate protein bar is used as a chemical reactant in cellular respiration heat is generated as a product of cellular respiration.

Glossary:

Cellular Respiration – a set of reactions and processes in living cells, which convert chemical energy from oxygen and nutrients into other forms of energy
Endotherm – animal that uses its metabolism (internal energy) to maintain its body temperature (Mammals and birds are homeothermic endotherms.)
Flow Rate – movement of a fluid (air or water) per unit time
Homeostasis – maintaining constant internal conditions (**body temperature**, pH, water balance)
Homeotherm – animal that maintains ~constant body temperature
Metabolic Rate – energy expenditure per unit time in an organism
Metabolism – the sum of all chemical reactions in an organism
Oxygen Consumption Rate – the amount of oxygen (usually measured in liters or milliliters) an organism brings into its cells per unit time
Proxy – a measurement or process used in place of another
Rate – the measurement of something with respect to time elapsed
Respiration Rate – the rate at which breathing occurs, often measured as breaths per minute

Teacher Note:

Air temp at 3 weeks: 4.69°C
Water temp at 3 weeks: -1.59°C
* water is more conductive than air (even at the same temperature)