Exercise, Energy Needs, and the Burning Reaction

TEACHER GUIDE

Instructional Goals

This exercise is not intended to be a formal lab, rather it is intended to provide the class with an easy-to-generate phenomenon that connects energy demand and the burning reaction we suspect to be involved in getting energy from food. We do this using the proxy of carbon dioxide. More CO_2 out means the reaction is running faster. That's the punchline, so we recommend not spending too much time on this lab.

Challenges

There are other reasons to move quickly through this activity and to not get too hung up on the details.

1. **Variance in the Data.** Some teachers have reported a lot of variance in the effect of exercise on the rate of CO_2 output. When comparing no exercise to degrees of exercise, the data is not as "clean" as they would have hoped. We've altered the procedure here so that we are only comparing a resting state with the output after two full minutes of exercise. Hopefully the effect will be clear. Do not worry if there is variance in the data. Real scientific data is often "noisy". Don't get hung up on this here unless you have a reason to teach stats in your course. This would be an opportunity to talk about a t-test and to have a conversation about why we run statistics to see if differences are significant.

2. **Titrating the Indicator Dye.** We have not specified a dye to use in this lab. Phenolphthalein, Phenol Red, and Bromothymol Blue can all work to detect the decrease in pH associated with CO_2 dissolved in water. If you would like to use Phenolphthalein, there are some guidelines provided at the end of these teacher notes. You will need to play with concentrations of whichever indicator you choose. A decent guideline is that the change to a "final color" should take about a minute or so in the "at rest" / no exercise condition. With BTB, the "final color" would be a tube with fully yellow liquid in it. You would need to similarly define the "final color" for any dye indicator for your students as they will be timing how long the color change takes as a proxy for CO_2 output (which then is our proxy for the rate of the reaction!)

3. **Understanding the Increased Rate.** It can be challenging to talk about the "rate" of a reaction in the context of this experiment. When we have an increase in energy demand, we do increase the rate of the "mystery reaction" (we know it's cellular respiration, but the students have not made it there yet). This increases the amount of CO_2 we need to get out of our bodies. This is accomplished mostly through an increase in our breathing rate, but it may also be that the volume of CO_2 we are able to push out in a <u>single</u> breath increases as well. There are two things that could contribute to this latter increase: (1) the concentration of CO_2 in that single breath, and (2) the volume of that single breath. So in truth, there are a few different measurements to consider. HOWEVER, they all contribute to the same end result: an increase in the amount of CO_2 your body puts out in a given amount of time- and that's the rate (amount per time) we're really interested in. Be sure you understand this before starting the lab.

Purpose
- To observe the effects of exercise on production on one of our outputs, carbon dioxide.
- To explore the relationships of carbon dioxide production, breathing rate, and heart rate.

Background Information
We think a reaction like burning is the way we get energy from our food. In burning, a fuel source made of carbon reacts with oxygen to produce the lower energy products carbon dioxide and water. As such, it releases a lot of energy.

$$\text{Fuel} + O_2 \rightarrow H_2O + CO_2 + \text{energy}$$

This simple lab will address how increased energy demand during exercise (increased muscle activity) affects the rate of carbon dioxide production. On the flip side of the reaction, you would expect increased demand for oxygen, which enters our body through the lungs and is carried to our muscles by the blood. You will measure 3 different indicators of an increase in the rate of our suspected chemical reaction: breathing rate, heart rate, and carbon dioxide production. The first two are indicators of demand for oxygen. Why? And the last is a direct measure of carbon dioxide production. You will measure these indicators at rest (with no exercise) and after 2 minutes of exercise. Breathing rate is measured in breaths per minute, heart rate in beats per minute, and carbon dioxide in the time it takes the sodium carbonate solution to change color. Carbon dioxide production can be measured by breathing through a straw into a solution of sodium carbonate combined with an indicator dye. (Ask your teacher which dye your class is using.)

Materials:
-Paper cup
-Straw
-Sodium carbonate solution
-Stopwatch/timer

Before beginning the experiment, students should practice finding a pulse on their participant. It is important that measurements are taken immediately after exercising and not after they've 'caught their breath'.

Procedure: PART A: Resting (no exercise)

Measuring Carbon Dioxide Production:
Using a straw, ***exhale*** into the solution. (CAUTION: Do not inhale the solution!)
In your data table, record the amount of time it takes to change the color of the solution.

Measuring Breathing Rate:
Count the number of breaths (1 breath = inhale + exhale) you take in 1 minute.
Record this in your data table.

Measuring Heart Rate:
1. While you calculate your breathing rate, have your partner take your pulse.
2. Count the number of beats in 30 seconds and multiply that number by 2.
   Record this in your data table

PART B: Increased Muscle Activity (Exercise)

1. Exercise for exactly 2 minutes by doing jumping jacks.
2. After 2 minutes of exercise, ***immediately*** exhale through the straw into the solution. Time how long it takes for the solution to turn clear. *Record this in your data table.*
   (Note: catching your breath before you start to exhale defeats the purpose).
3. Quickly calculate your breathing and heart rates as you did before. You only need to do this once.
4. *Record this in your data table.*
5. If there is time, get more of the sodium carbonate solution from the teacher and repeat the entire procedure for your lab partner.
6. Record your results on the class data table or be ready to share them with your teacher.

Data & Results:

	Student 1	Student 2
Heart Rate		
Resting		
Two Minutes		
Breathing		
Resting		
Two Minutes		
Time to Change		
Resting		
Two Minutes		

Analysis: Please answer the questions using complete sentences. *(Conclusions will be discussed as a class).*

1. Look at your data briefly. Are the results what you expected? Explain.

2. Did the class results agree with your results? Which might be more trustworthy, your results or the class results? Why?

Using Phenolphthalein…

The **sodium carbonate solution** is a large volume of water (1000 mL) with a small amount of Na2CO3 (~1 gram) and a few drops of phenolphthalein solution to turn the solution pink. Sodium carbonate, while commonly available in science labs, can also be found as washing soda or soda ash. Exact measurements are not important, but you will want to test your solution prior to the lab to ensure it will change color in the time needed. You can adjust the concentrations as needed.

Phenolphthalein is a bright fuchsia color when added to a basic solution (such as the sodium carbonate); it turns colorless when its pH drops below 8.2. Mentioning its prior use as a laxative typically discourages students from tasting or inhaling their solution. The phenolphthalein molecule is colorless; however, the phenolphthalein ion is pink. When a base is added to the phenolphthalein, the molecule $\rightleftharpoons$ ions' equilibrium shifts to the right, leading to more ionization as H^+ ions are removed. This is predicted by Le Chatelier's principle.

Possible Questions for a more formal Analysis & Conclusions:

1. How did exercise affect the time needed for the solution to change color? Explain why the color change occurred.

Exhaling carbon dioxide causes the basic solution to become more acidic (neutral). Increase in aerobic activity increases the rate of carbon dioxide production. This results in a quicker color change (to clear) as the pH dropped.

2. What can you conclude about the effect of exercise on the amount of carbon dioxide that is present in your exhaled breath? Why is this so?

When you exercise, the muscles you use require more energy. When exercise can be sustained, this demand is met primarily by aerobic means. Aerobic energy production in muscles results in increased gas exchange at the lungs, because more oxygen is taken in and more carbon dioxide is released. Your blood transports these metabolic gases to and from your tissues.

During exercise, your body needs more energy, which means your tissues consume more oxygen than they do at rest. Consuming more oxygen means you will also produce more carbon dioxide. Interestingly, the ratio of carbon dioxide produced per oxygen consumed also increases during exercise because a shift from fat to carbohydrate utilization takes place. At the most challenging work rates, you burn carbohydrates exclusively and produce 1.0 liter of carbon dioxide for every liter of oxygen you consume.

3. What can you conclude about the effect of exercise on breathing rate? Why is this so?

During exercise, your lungs are responsible for delivering more oxygen to your cells as they use up all available reources. Faster consumption of oxygen means faster (and often deeper) breathing to keep up with this deficiency.

4. What can you conclude about the effect of exercise on heart rate? Why is this so? What do your muscles need during exercise that the blood brings?

While you are exercising, as oxygen is entering the blood in the lungs and the cells are absorbing oxygen in the capillaries, blood is moving through the body to deliver the good and remove the bad. A faster heart rate means more blood is getting to the lungs and the tissues faster.