Lung Capacity

SC Academic Standards:

NGSS DCI:

Science and Engineering Practices: S.1A.1; S.1A.2; S.1A.4; S.1A.5; S.1A.7

Crosscutting Concepts: Patterns; Cause and Effect: Mechanism and Explanation; Systems and Systems Models; Energy and Matter: Flows, Cycles, and Conservation; and Stability and Change.

Focus Question(s): What is my lung capacity? What factors affect lung capacity?

Conceptual Understanding: Plants and animals have physical characteristics that allow them to receive information from the environment. Structural adaptations within groups of plants and animals allow them to better survive and reproduce.

Life is the quality that differentiates living things (organisms) from nonliving objects or those that were once living. All organisms are made up of cells, need food and water, a way to dispose of waste, and an environment in which they can live. Because of the diversity of life on Earth, scientists have developed a way to organize groups of organisms according to their characteristic traits, making it easier to identify and study them.

The Animal Kingdom includes a diversity of organisms that have many characteristics in common. Classification of animals is based on structures that function in growth, reproduction, and survival. Animals have both structural and behavioral adaptations that increase the chances of reproduction and survival in changing environments.

Multicellular organisms (including humans) are complex systems with specialized cells that perform specific functions. Organs and organ systems are composed of cells that function to serve the needs of cells which in turn serve the needs of the organism.

<u>Background:</u> **Lungs** are balloon-like structures in the chest that are used to exchange oxygen and carbon dioxide between your blood and the atmosphere. As you **inhale** (breathe in), air is drawn into your lungs. As you **exhale** (breathe out), you expel gases from your lungs. In the lungs, oxygen from inhaled air moves into your **blood** (the liquid in animals that carries nutrients and oxygen to cells and takes away wastes) and is carried to the cells throughout the body to produce energy. Also in the lungs, **carbon dioxide** (a gaseous waste) leaves the blood and enters tubes, then is expelled when you exhale. The breathing rate of a healthy adult at rest is about 12 times a minute. A baby breathes faster, about 30 times a minute.

Normally, you breathe through your nose. Air enters the nose and moves down the back of the **pharynx** (the throat), where it enters the **trachea** (the breathing tube). At the end of the trachea, the passage splits to form two tubes called **bronchi** that lead to the lungs. In the lungs, each bronchus divides many times, forming small tubes called **bronchioles.** At the end of each bronchiole is a balloon-shaped structure called an **alviolus** (air sac). The lungs contain millions of alvioli, and around each are many capillaries. A **capillary** is the body's smallest blood vessel. Through the capillaries, oxygen from inhaled air is transferred, by diffusion, to the blood, and waste from the blood is diffused into the lungs before being exhaled.

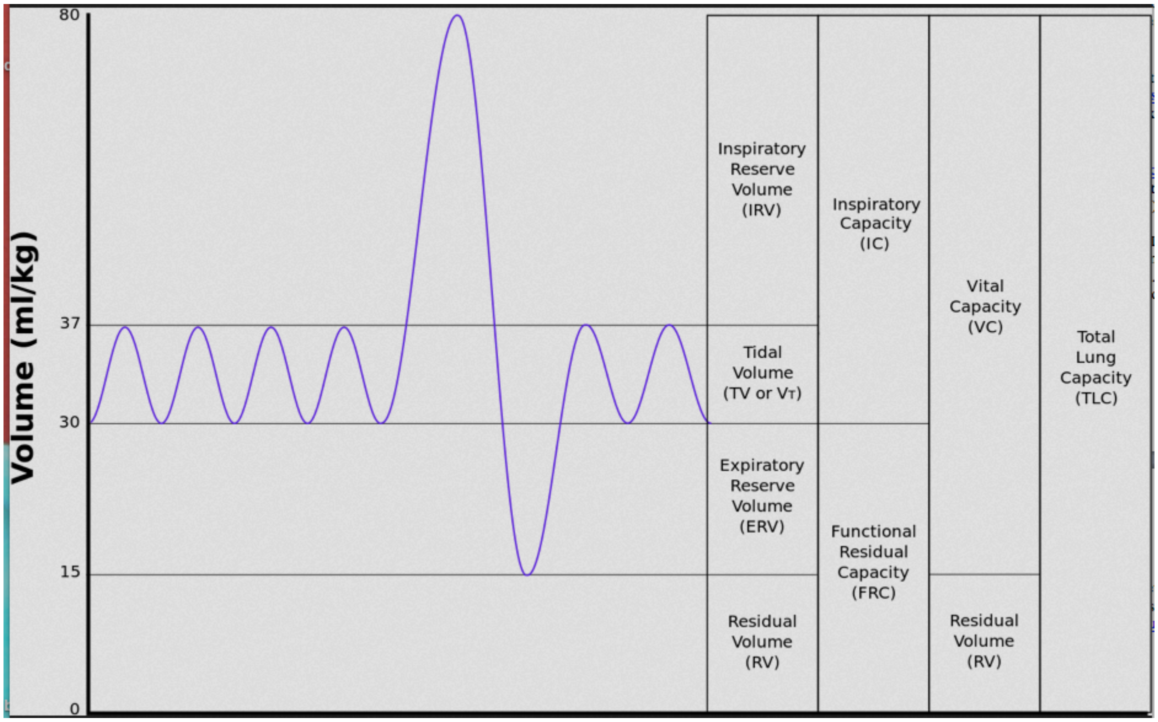
The average total lung capacity of an adult human male is about 6 liters of air but only a small amount of this capacity is used during normal breathing. The lung capacity of freediver and world record holder Herbert Nitsch is measured to be 10 Liters. The amount of air that you move in and out of your lungs while breathing normally is called TIDAL VOLUME. This amount of air provides enough oxygen for a person who is resting. Tidal volume is only a fraction of the total lung capacity, about 500 mL; it is possible to inhale and exhale more forcefully and blow out more than 500 ml.

In this activity, you will be measuring the vital capacity (the greatest volume you can force out in one deep breath) and the tidal volume (the normal amount of air expelled in one breath) of your own lungs, this actual number can then be compared with a number derived from an equation that measures vital capacity. In effect, you are measuring an actual number, based on laboratory measurements, to a theoretical number, based on an equation. If you have any breathing difficulties (asthma or other condition), you should not participate in this activity, instead only take the data on your lab partner or group. Breathing in very deeply (your **inspiratory reserve**), then exhaling as much as you can (contracting your thoracic and abdominal muscles), can increase tidal volume to about 1.4 liters – this is your **expiratory reserve volume**. The maximum amount of air moved in and out of the lungs is called your **Vital Capacity**.

Some air that we breathe never even reaches our lungs - instead it fills our nasal cavities, trachea, bronchi, and bronchioles. These passages aren't used in gas exchange so they are considered to be dead air space. To make sure that the inhaled air gets to the lungs, we need to breathe slowly and deeply. Even when we exhale deeply some air is still in the lungs (about 1,000 ml, or 1 Liter – this is called the **residual volume**). This air isn't useful for gas exchange. There are certain types of diseases of the lung where residual volume builds up because the person cannot fully empty the lungs. This means that the vital capacity is also reduced because their lungs are filled with useless air.

Many things may affect your vital capacity – including smoking, obesity, pregnancy, and how often you exercise. Fast-moving exercise causes your heart and breathing rates to increase, delivering fresh oxygen to your bloodstream and energy to your muscles. Your lung capacity can be increased through regular aerobic workouts, but only by a modest amount (5-15%). Specific changes in lung volumes also occur during pregnancy. Functional residual capacity drops 18–20% typically falling from 1.7 to 1.35 liters, due to the compression of the diaphragm by the uterus.

TLC	Total lung capacity: the volume in the lungs at maximal inflation, the sum of VC and RV.
TV	Tidal volume: that volume of air moved into or out of the lungs during quiet breathing (VT indicates a subdivision of the lung; when tidal volume is precisely measured, as in gas exchange calculation, the symbol VT or V_T is used.)
RV	Residual volume: the volume of air remaining in the lungs after a maximal exhalation
ERV	Expiratory reserve volume: the maximal volume of air that can be exhaled from the end-expiratory position
IRV	Inspiratory reserve volume: the maximal volume that can be inhaled from the end-inspiratory level
IC	Inspiratory capacity: the sum of IRV and TV
IVC	Inspiratory vital capacity: the maximum volume of air inhaled from the point of maximum expiration
VC	Vital capacity: the volume of air breathed out after the deepest inhalation.
V_T	Tidal volume: that volume of air moved into or out of the lungs during quiet breathing (VT indicates a subdivision of the lung; when tidal volume is precisely measured, as in gas exchange calculation, the symbol VT or V_T is used.)
	Functional residual capacity: the volume in the lungs at the end-expiratory position



Average lung volumes in healthy adults

Volume	Value (litres)	
	In men	In women
Inspiratory reserve volume	3.0	1.9
Tidal volume	0.5	0.5
Expiratory reserve volume	1.1	0.7
Residual volume	1.2	1.1
Vital Capacity	4.6	3.1
Total Lung Capacity	5.8	4.2

In this lab we will investigate how lung volume (expiratory reserve volume) might differ as a result of heavy exercise.

Materials: for each group: a two liter plastic soda bottle (clear, labels ripped off), 2 feet of aquarium tubing, plastic dishpan or shoebox, masking tape, pen.

Procedure:

1. Place a strip of masking tape down the side of the soda bottle.
2. Fill the soda bottle with water and screw the top on to bottle.
3. Fill dishpan ½ way full with water
4. Place soda bottle upside down in dishpan, so neck and opening are under water – then remove the cap (one student needs to keep ahold of the bottle so that it remains upright. DO NOT allow air bubbles to enter the bottle).
5. Place one end of the aquarium tubing inside the bottle opening (under water)
6. Take a normal breath and exhale through the tubing. Your breath should displace the water in the bottle.
7. Mark the water level on the tape after you are done breathing out.
8. Refill bottle and return it to dishpan.
9. Take a very deep breath and try to exhale all that you possibly can through the tubing – then mark the new water level on the tape.
10. Refill bottle and return it to dishpan.
11. Run up and down the stairs (or other physical cardio exercise) and then again take a deep breath and try to exhale all that you possibly can through the tubing – then mark the third water level on the tape.
12. Now, calculate your normal vital capacity (expiratory reserve before exercise) using a formula – you can then compare what you measured with the answer you get using just a formula.

Male Vital Capacity Calculation = Body Surface Area * 2500
Female Vital Capacity = Body Surface Area * 2000

Where Body Surface Area = (SQRT ((height in cm * mass in kg)/3600)

Student Name	Lung Capacity (normal: tidal volume)	Lung Capacity (expiratory reserve volume: before exercise)	Lung Capacity (expiratory reserve volume: after exercise)	Lung Capacity as calculated using formula
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
AVERAGE				

Table 1. Data on lung capacity (liters) before and after strenuous exercise.

Data Analysis: Make a bar graph of the average lung capacity (expiratory reserve) before and after heavy exercise. Are they different?
Estimated Vital Capacity: Research has shown that the capacity of a person's lungs is proportional to the surface area of his or her body. To find the surface area, you will need to know your height and weight. There are a couple of different ways to calculate your body surface area mathematically. Either use the equation
Body Surface Area = (SQRT ((height in cm * mass in kg)/3600) or go to a website that has an automatic calculator. Once you have calculated your surface area, a second equation will calculate your estimated vital capacity:

Vital Capacity - Males: SA x 2500
Vital Capacity - Females SA x 2000

Extensions: Have students research different lung diseases. Try to Measure Tidal Volume by stretching a round balloon several times. Then, Inhale normally and then exhale normally into the balloon. Do not force your breathing. Pinch the end of the balloon and measure its diameter at the widest point (place balloon on a table, and hold a ruler up to it). Repeat this so that you have 3 total measurements and can take the average and record in the data table. Then, to measure Vital Capacity, repeat, only this time inhale as much air as you can and exhale our forcefully into the balloon.

Reflection Questions:

- **How does lung capacity differ for people who live at high altitudes? (**A person who is born and lives at sea level will develop a slightly smaller lung capacity than a person who spends their life at a high altitude. This is because the partial pressure of oxygen is lower at higher altitude, which as a result means that oxygen less readily diffuses into the bloodstream. In response to higher altitude, the body's diffusing capacity increases in order to process more air. When someone living at or near sea level travels to locations at high altitudes (like Denver, Colorado!) that person can develop a condition called altitude sickness because their lungs remove adequate amounts of carbon dioxide but they do not take in enough oxygen. (In normal individuals, buildup of carbon dioxide (not lack of oxygen) is the primary determinant of respiratory drive.)

- **How does regular exercise change lung capacity? (**In general regular exercise does not substantially change measures of pulmonary function such as total lung capacity, the volume of air in the lungs after taking the largest breath possible (TLC), and forced vital capacity, the amount of air able to be blown out after taking the largest breath possible (FVC). Studies comparing TLC and FVC show little difference between regular exercisers and non-exercisers, in fact. So even though people often report feeling 'out of breath' or 'winded' during exercise, it is unlikely that pulmonary function limits their ability to exercise, unless they have a disease that specifically impairs lung function such as asthma, bronchitis or emphysema. What we might see in this lab is that immediately after exercising, the student is so out of breath that their expiratory reserve is smaller – but the amount of expiratory reserve you have should stay stable whether you are in shape or not).

- **How does exercise help you get oxygen to your cells? (**One of the largest differences between an exerciser and a nonexerciser concerns the heart's ability to pump blood and consequently deliver oxygen to working muscles. Cardiac output is a major limiting factor for prolonged exercise. In addition, an exerciser typically has a larger blood volume, is better able to extract oxygen from the air in the lungs and is better able to extract oxygen from the blood at the working muscles than a sedentary individual is. Gas exchange involves not only oxygen delivery but also the removal of carbon dioxide, which is a byproduct of energy metabolism, and this process is also more efficient in an exerciser. Fast-moving exercise causes your heart and breathing rates to increase, delivering fresh oxygen to your bloodstream and energy to your muscles.

Your lung capacity can be increased through regular aerobic workouts, but only by a modest amount. Regular aerobic exercise strengthens and tones the heart and lungs, enabling the pulmonary system to increase the maximum amount of oxygen that the lungs can handle. The average person's lung capacity can be improved only 5 percent to 15 percent even with frequent intense aerobic workouts).

- **What might make your lung volume change?** (Specific changes in lung volumes occur during pregnancy. Functional residual capacity drops 18–20% typically falling from 1.7 to 1.35 liters, due to the compression of the diaphragm by the uterus. During pregnancy, the mother's total lung capacity decreases and so does the expiratory reserve volume, though tidal volume increases about 30% - so enough oxygen reaches the fetus. Also, **? (**A person who is born and lives at sea level will develop a slightly smaller lung capacity than a person who spends their life at a high altitude. This is because the partial pressure of oxygen is lower at higher altitude, which as a result means that oxygen less readily diffuses into the bloodstream. In response to higher altitude, the body's diffusing capacity increases in order to process more air. When someone living at or near sea level travels to locations at high altitudes (like Denver, Colorado!) that person can develop a condition called altitude sickness because their lungs remove adequate amounts of carbon dioxide but they do not take in enough oxygen. (In normal individuals, buildup of carbon dioxide (not lack of oxygen) is the primary determinant of respiratory drive.)

- **Why is it important to measure tidal volume and vital capacity three times and then get an average?** (replication! - to be more confident in your data).

- **Compare your data to other members of the class. How can you account for differences?** (different sex, weight, height, some may exercise regularly, some may smoke, lung disease, genetics…**..)**

- **How does your measured vital capacity compare to the vital capacity you estimated using the formula? Which do you think is more accurate and why?** (probably what you measured is more accurate. You could calculate percent error too!).

How might an athlete's vital capacity compare to a non-athlete? Explain your reasoning. (Your lung capacity can be increased through regular aerobic workouts, but only by a modest amount. Regular aerobic exercise strengthens and tones the heart and lungs, enabling the pulmonary system to increase the maximum amount of oxygen that the lungs can handle. The average person's lung capacity can be improved only 5 percent to 15 percent even with frequent intense aerobic workouts).

Models and Explanations: In this lab we explored how heavy exercise might affect lung volumes, specifically expiratory reserve volumes. **A student who demonstrates understanding** of this concept can explain the difference between tidal volume, vital capacity, total lung volume, and inspiratory and expiratory reserve volumes and can explain several factors that might influence lung capacity (like sex, exercise, lung disease, height and weight, pregnancy, smoking….). This student will be able to discuss the results of his/her controlled experiment and reference the independent, dependent, and controlled variables.

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Student Worksheet:

Lungs are balloon-like structures in the chest that are used to exchange oxygen and carbon dioxide between your blood and the atmosphere. As you **inhale** (breathe in), air is drawn into your lungs. As you **exhale** (breathe out), you expel gases from your lungs. In the lungs, oxygen from inhaled air moves into your **blood** (the liquid in animals that carries nutrients and oxygen to cells and takes away wastes) and is carried to the cells throughout the body to produce energy. Also in the lungs, **carbon dioxide** (a gaseous waste) leaves the blood and enters tubes, then is expelled when you exhale. The breathing rate of a healthy adult at rest is about 12 times a minute. A baby breathes faster, about 30 times a minute.

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Height (cm)	
Mass (kg)	
Surface Area	
Vital Capacity	

Reflection Questions:

- **How does heavy exercise affect my lung volume (expiratory reserve)?**
- **How does lung capacity differ for people who live at high altitudes?**
- **What other factors might make your lung volume change?**
- **Why is it important to measure tidal volume and vital capacity three times and then get an average?**
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