Physiology of Exercise

Inquiry-based, Learning Cycle Unit for Middle School Students
This classroom unit was developed as part of The American Physiological Society's Frontiers in Physiology program by members of the Vermillion, South Dakota Local Outreach Team, June 1999

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# Physiology of Exercise

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**Appendix - National Science Education Standards**
Looking for More K-12 Science Education Resources?

www.the-aps.org/education.htm

K-12 Activities

Frontiers in Physiology and Explorations in Biomedicine. These programs offer fellowships for teachers to spend a summer working full time on a research project in physiology and to attend a Summer Retreat. It also supports inservice workshops by physiology departments nationwide for middle and high school science teachers.

Women Life Scientists: Past, Present, and Future. The APS developed and field-tested a book of modules for middle/high school life sciences classes that infuse female role models into the curriculum while incorporating hands-on and inquiry learning approaches.


Physiology Workshops for High School Teachers and Students. At the annual spring meeting of the APS (Experimental Biology), area high school teachers and their students are invited to attend a one-day workshop on physiology.

International Science and Engineering Fair Awards. The APS makes special awards to participants for outstanding projects in physiology.

Information Via the Internet. The programs and resources listed here are described in detail on the APS website. This includes free samples of resources, teacher-developed classroom activities, program descriptions, applications, resource order forms, links to other sites, and more. Go to http://www.the-aps.org/education.htm

K-12 Educational Resources

K-12 Resource Packets. These packets assist physiologists who visit K-12 classrooms. Includes suggestions for age-appropriate activities and discussion, teacher materials, and student resources.

Careers in Physiology. This full-color brochure and web site describes physiology research, physiology careers, and educational requirements for physiologists. Go to http://www.the-aps.org and click on “Careers.”

The Science of Life: Physiology Research in Action. This full-color comic book teaches students how physiology research touches their lives. Order a classroom set for FREE!

Reflecting On Effective Teaching Practices. This video illustrates and discusses teaching techniques for middle and high school science teachers.

List of Institutions Awarding Degrees in Physiology. The list contains over 200 institutions awarding undergraduate and/or graduate degrees in physiology.

Archive of Teaching Resources
A repository of teaching resources including power point presentations, animations, links to course syllabi, slides, case studies, etc. Go to http://www.apsarchive.org
About Inquiry-Based Learning

This activity has been designed within the guidelines of the National Science Education Standards (NSES) in both content and pedagogy for students in grades 5-8. More information about the NSES is available in Appendix A, located at the back of this unit. Below is a table you can use to assess the inquiry level of activities/labs.

Assessing the Inquiry Level of an Activity/Lab

<table>
<thead>
<tr>
<th>Points</th>
<th>Prelab</th>
<th>Lab</th>
<th>Postlab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proposal of problem or the issue to be explored</td>
<td>Plans the procedure to be used</td>
<td>Carries out the procedure</td>
</tr>
<tr>
<td>0</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
</tr>
<tr>
<td>1</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
</tr>
<tr>
<td>2</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Teacher</td>
</tr>
<tr>
<td>3</td>
<td>Teacher</td>
<td>Teacher</td>
<td>Student</td>
</tr>
<tr>
<td>4</td>
<td>Teacher</td>
<td>Student</td>
<td>Student</td>
</tr>
<tr>
<td>5</td>
<td>Student</td>
<td>Student</td>
<td>Student</td>
</tr>
</tbody>
</table>

Level 4 is “Guided Inquiry:” Teacher generates the question(s) Student designs the experiment. Level 5 is “Open Inquiry:” Student generates the question(s) and designs the experiment.

What is the Learning Cycle?

The Learning Cycle\(^2\) approach (Karplus & Thier, 1967; Lawson, 1988), structures activities/labs by integrating key modules, each designed to address a component of the activity, as follows:

The Five Modules are designed to:
1. **Engage** students in thinking about the topic(s);
2. offer them opportunities to **Explore** via hands-on and inquiry approach activities;
3. **Explain** their findings and how they relate to the concepts included in the unit;
4. **Elaborate** on the concepts; and
5. assist teachers to **Evaluate** students’ understanding of the unit concepts.

See Appendix B at the back of this unit for more information on the Learning Cycle.

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The American Physiological Society

Learning Cycle Units

Full Learning Cycle of Activities (*Engage, Explore, Explain, Elaborate, & Evaluate*)
Hands-on, inquiry-approach activities with authentic assessment suggestions
Activities are coordinated with the National Science Education Standards
Field-tested in both classroom and workshop settings

Note: All Units are available from The American Physiological Society (APS) in print version upon request, or as downloads in an Adobe PDF File format from the APS website at: http://www.the-aps.org/education.
**The American Physiological Society**  
**Physiology Learning Cycle Units**

<table>
<thead>
<tr>
<th>Unit Title</th>
<th>Grade Level</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye to Eye*</td>
<td>ES MS</td>
<td>This unit is designed to provide students with a scientific basis for the understanding of vision in humans and animals living in different environments. It includes a vision obstacle course, an exploration of the anatomy of compound and camera-like eyes, dissection of a cow eye, inquiry-based comparison of nocturnal and diurnal eyes, and exploration of the relationship of structure to organism visual needs and functions.</td>
</tr>
<tr>
<td>Cell-ebration*</td>
<td>MS</td>
<td>This unit extends the basic principles of cell structure and function to include what makes the organelle and the cell membrane only selectively permeable to molecules. Activities include an “alphabet review” of cell structure and function, exploration of a special Internet website designed specifically for this unit, and hands-on exploration of diffusion (guided inquiry), and or semi-permeable membranes (open inquiry). Companion Internet Activities Website Included</td>
</tr>
<tr>
<td>Physiology of Exercise</td>
<td>MS</td>
<td>This unit covers aspects of cardiovascular and respiratory physiology that are important in exercise and fitness. It includes a lifestyles inventory, exploration of biological variability and experimental variation using heart and respiratory rates, a demonstration of oxygen supply and demand during rest and exercise, and inquiry-based explorations of the baroreflex and responses to exercise.</td>
</tr>
<tr>
<td>A Kidney Under Pressure*</td>
<td>MS HS</td>
<td>This unit is designed to provide an active learning experience in problem-solving by introducing eight patients, all of whom suffer from kidney disorders, and asking students to experiment, collect data, and perform differential diagnoses to determine the source of their patient’s problem.</td>
</tr>
<tr>
<td>Human Lever Systems: A Biomechanical Evaluation*</td>
<td>MS HS</td>
<td>This unit explores the biomechanics of levers in the human body through the building and use of hands-on lever models and the use of a special Internet web site designed specifically for this unit.</td>
</tr>
<tr>
<td>Neural Networks</td>
<td>MS</td>
<td>This unit covers aspects of neurophysiology and neural responses that are important to the functioning of many body systems. It is designed to provide students with a scientific basis for understanding “reflexes,” especially why reflexes are special types of responses and how they can/cannot be modified. The modules are designed to teach students general physiological principles that are based on physical and biochemical principles. An important educational objective of the unit is that students should be able to relate what they learn about the nervous system to its many important interactions with other systems in the body.</td>
</tr>
<tr>
<td>Physiology of Fitness*</td>
<td>HS</td>
<td>This unit covers aspects of cardiovascular and respiratory physiology that are important in exercise and fitness. It is designed to provide students with a scientific basis for understanding “fitness” – especially why it varies between individuals, and how one can improve their fitness. This unit can be used as an integrative review of these topics, or selected activities cab be used to introduce some of the topics.</td>
</tr>
</tbody>
</table>

*Available soon at: [http://www.the-aps.org/education/lot/lotunits.htm](http://www.the-aps.org/education/lot/lotunits.htm)*
What is Physiology?

**Physiology is the study of life.**
Physiologists answer key questions ranging from the workings inside single cells to the interactions between human populations and our environment here on earth, the moon, and beyond. To answer these questions, physiologists work in laboratories, libraries, in the field, and in space. For example, a physiologist may study how a particular enzyme contributes to the functions of a specific cell or subcellular organelle. Other physiologists may use the simple nerve networks found in marine snails to answer questions about the fundamental mechanisms of learning and memory. Many physiologists investigate the cardiovascular system of animals to answer questions about heart attacks and other human diseases. And physiologists may study how the body adapts to temperature and environmental extremes encountered on earth, or the microgravity encountered in space flights to learn how life processes cope with these environmental stresses.

**Physiology is important because it is the basis upon which we expand our knowledge of what "life" is, how to treat disease, and how to cope with stresses imposed upon our bodies by new environments.**

**Some physiological questions:**

- Why does blood clot in a wound but not while flowing through blood vessels?
- Can we prevent loss of bone mineral during space flights or during long illnesses in bed?
- How does the nervous system convert stimuli into memories?
- Why is the immune system unable to defend the body from certain viruses?
- What factors limit human athletic performance?
- What makes one cell become cancerous while another does not?
Introduction

This unit covers aspects of cardiovascular and respiratory physiology that are important in exercise and fitness. It is designed to provide middle school students with a basic understanding of how the heart and the lungs work together when someone exercises. The unit can be used as an integrative review of these topics, or selected activities from the unit could be used to introduce some of the topics. The original module was designed by a team of high school teachers and research physiologists. This version has been modified by another teacher/physiologist team, experienced in middle school life science education. However, the unit does assume a basic knowledge of the cardiovascular and respiratory systems.

The unit utilizes the Learning Cycle approach (Karplus & Thier, 1967; Lawson, 1988), where various modules can be used to engage students in thinking about the topic(s); offer them opportunities to explore via hands-on and inquiry approach activities; to explain their findings and how they relate to the concepts included in the unit; to elaborate on the concepts; and to assist teachers to evaluate students' understanding of the unit concepts. The modules are designed to teach middle school students general physiological principles that are suitable for science or health classes. Although the curriculum is based on the life sciences, the activities could also be appropriate in general science, with an integrative unit, or when use of an inquiry-based approach is desirable.

Suggestions for Teachers are provided for each module and provide the information necessary to teach the units. Boldfaced terms typically can be found in the index of a life science or physiology textbook or in other references. The relationship of the unit activities to the National Science Education Standards (1996) for content and teaching is outlined on the following page.

This unit was developed as part of an American Physiological Society program designed to form partnerships between scientists and teachers. Therefore, the units also can be used in consultation with research scientists, such as a university faculty member or a pharmaceutical company researcher. The Education Office of The American Physiological Society can assist you in making connections with physiologists in your area (301-530-7132; educatio@aps.faseb.org).

References

Summary
Physiology of Exercise Unit

Unit concepts:
1) Lack of exercise can promote heart disease. When someone is overweight and/or does not perform "aerobic exercise" regularly, the muscle tone in the heart muscle may diminish.
2) Exercise increases the number of calories we burn. We utilize the nutrients in food (carbohydrates, proteins, and fats) to make energy.
3) Exercise improves the circulation of the blood. Muscles in the extremities aid in pumping the venous blood back to the heart.
4) Exercise improves a person's mental outlook on life by helping to relieve stress, through the release of pain-killing and euphoric chemicals from the brain.

What do you know about the effects of exercise?
Use the lifestyle inventory.
Use video clips of someone exercising and brainstorm observations.
Use KWL or T-chart for groups of three to four students.

How do your heart and lungs work together compared to those of your classmates?
Explore the resting responses of the heart and lungs, including individual and experimental variation in data by:
- Measuring pulse;
- Counting the rate of breathing.

How does exercise affect the cardiovascular and respiratory systems?
Demonstrate oxygen demand, supply, and delivery with egg carton activity.

Is heart rate constant?
Develop, design, and carry out experiments about positional changes in heart rate.
Develop, design, and carry out experiments about how strenuous exercise affects the cardiovascular and respiratory systems.

The cardiovascular and respiratory system and exercise - what do you know?
Re-evaluate lifestyle inventory and KWL/T-chart.
Analyze information learned.
Review concepts.
Relationship of *Physiology of Exercise* Unit to National Science Education Standards for Content and Pedagogy

<table>
<thead>
<tr>
<th>Selected Content Standards</th>
<th>Physiology Of Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grades 5-8</strong></td>
<td></td>
</tr>
<tr>
<td>Structure and function in living systems</td>
<td>✓</td>
</tr>
<tr>
<td>Regulation and behavior</td>
<td>✓</td>
</tr>
<tr>
<td>Personal health</td>
<td>✓</td>
</tr>
<tr>
<td>Risks and benefits</td>
<td>✓</td>
</tr>
<tr>
<td>History and nature of science</td>
<td>✓</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activities</th>
<th>Pedagogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module #</td>
<td>Title</td>
</tr>
<tr>
<td>1</td>
<td>What Do You Know About the Effects of Exercise?</td>
</tr>
<tr>
<td>2</td>
<td>How Do Your Heart and Lungs Work Together Compared to Those of Your Classmates?</td>
</tr>
<tr>
<td>3</td>
<td>How Does Exercise Affect the Cardiovascular and Respiratory Systems?</td>
</tr>
<tr>
<td>4</td>
<td>Is Heart Rate Constant?</td>
</tr>
<tr>
<td>5</td>
<td>Cardiovascular and Respiratory System and Exercise - What Do You Know Now?</td>
</tr>
</tbody>
</table>

**Reference**
Background Information

Themes and required student background
With the exception of Module #1, these modules assume that students have already been introduced to the basic structures and functions of the cardiovascular and respiratory systems. Students should understand the pumping of the heart and the function of the blood vessels and capillaries in distributing blood to all of the tissues and cells of the body. Students should also understand that, by breathing, the lungs are able to provide oxygen and remove the carbon dioxide waste product. Students should know that cells need oxygen to be able to take nutrients (fats, proteins, and carbohydrates) and make energy and that active cells (like those in exercising muscle) need more oxygen and nutrients than do less active cells. For both gas exchange at the lungs and gas exchange at the tissues, the size of the transfer surface area is important. There is a large surface area between the smallest air spaces (alveoli) in the lungs and the pulmonary capillaries that make the diffusion of oxygen into the blood and the diffusion of carbon dioxide into the exhaled air occur faster. In fact, the surface area of this blood-gas barrier in the lungs of one adult human is about the size of the playing surface on a tennis court!

What is the autonomic nervous system?
There is a part of the nervous system that is called the autonomic nervous system. “Autonomic” means that most of the time it acts by itself, without someone consciously trying to control it.

As an example, the autonomic nervous system determines how fast the heart beats (heart rate or pulse). If someone measured his or her heart rate at different times during the day, the values would vary. Sometimes heart rate is higher, while at other times, it is lower. For example, you may have noticed that your heart beats faster after you have just walked from one classroom to another, especially if you had to walk up some steps. You don’t have to think about raising your heart rate when you climb steps; the autonomic nervous system takes care of adjusting the rate.

There are areas in the central nervous system (the brain and the spinal cord)
that determine how fast the heart should beat. There are also nerve connections going both ways between these areas and the heart. It is along these nerves that messages are sent to speed up or slow down the heart. These nerve connections are part of the autonomic nervous system. Not only the heart, but also all of the organs and blood vessels in the body receive messages from the brain and the spinal cord and send messages back along nerves that are part of the autonomic nervous system. The autonomic nervous system helps set the rate of breathing based on chemical detection of carbon dioxide and/or oxygen in the blood. After someone eats a meal, the stomach and intestines receive messages to begin working or to work harder so that the food can be digested and absorbed.

**Autonomic reflexes**

The **autonomic nervous system** is made up of the sympathetic and parasympathetic nervous systems. The **sympathetic nervous system** is involved in the **fight or flight response**, for example, getting the body ready to react to or run away from a grizzly bear. The **parasympathetic nervous system** controls the "housekeeping" functions of the body, such as regular breathing, resting heart rate, and digestion. Heart rate is one example of a body function that is controlled by both the sympathetic and parasympathetic nervous systems. How high the heart rate is at any particular time depends upon many factors. For example, how much oxygen the body needs and how nervous or how calm someone feels are factors that influence heart rate. Heart rate also plays a role in regulating blood pressure. When you visit a doctor, s/he or the nurse will almost always measure your blood pressure to make sure it is not too low or too high. It is very important that your blood pressure remain close to normal. If blood pressure suddenly falls, heart rate will quickly increase and the contraction of the heart will become stronger so that the heart pumps more blood and increases blood pressure until it is normal again. This response is an example of a reflex involving the autonomic nervous system called the **baroreceptor reflex**.

How does the baroreceptor reflex work? Some large blood vessels near the heart contain blood pressure sensors that measure blood pressure. Physiologists call these sensors **baroreceptors** (**baro** means “pressure”). The blood pressure signal is sent via nerves to an area of the brain where it is compared to a normal blood pressure. For example, if the blood pressure is too low, this area of the brain will send a message via sympathetic nerves back to the heart to increase the heart rate. In this way the blood pressure will be brought back up to normal. You can test the baroreflex yourself; see “**An experiment and its explanation**” on the next page.
An experiment and its explanation
Two students should work together. First the subject lies down in a relaxed, inactive manner on the floor or a table for three minutes. Then the other person measures the subject’s heart rate and records it. The subject stands upright, relaxed and inactive for three minutes. At the end of these three minutes, the other person measures the subject’s heart rate and records it. The students compare the two heart rates.

After standing for three minutes, a person’s heart rate will normally be higher than heart rate while lying down. The reason is that as a result of standing up, blood temporarily pools in the legs and therefore less blood is in the heart. If you looked at an x-ray you would see that the heart is actually smaller when a person stands up. As a result, the heart pumps less blood volume with every beat, causing the blood pressure to fall slightly. Thus, the baroreceptor reflex increases the heart rate to bring the blood pressure back to normal. That is why heart rate is higher when a person stands upright. The baroreceptor reflex can also help bring sudden increases in heart rate back down.

The cardiovascular system -- transport and mechanisms
The cardiovascular system is the integral link among oxygen transport across the blood-gas barrier of the lungs, oxygen delivery to the cells of the body by the blood vessels, and oxygen utilization by the cells for energy. The cardiovascular system is therefore essential for life in multicellular organisms. The heart plays an important role in moving blood loaded with oxygen throughout the body. This oxygen is then used by the cells and tissues to provide energy (known as cellular respiration). The response of the human body to exercise offers an excellent opportunity to observe and learn about the physiology of oxygen transport, and the utilization and integration of the cardiovascular and respiratory systems. In this module, students can observe the effects of exercise both on heart rate and respiration.

Oxygen transport
Oxygen is the fuel of life, and more oxygen is needed by cells during increased activity such as exercise. An important function of the cardiovascular and respiratory systems is to supply oxygen to metabolically active tissues, including: contracting muscles, including the heart, brains processing information, and kidneys actively pumping salts and waste products into and out of the blood. The total amount of oxygen in the blood is greatly enhanced by the protein molecules (hemoglobin) found in red blood cells. Oxygen is carried in the blood both as a
physically dissolved gas (normally only 1.5% of blood oxygen) and in chemical combination with the hemoglobin inside the red blood cells (normally 98.5% of blood oxygen). Cardiac output (see below) is a measure of how much blood is available to the body every minute. If we had no hemoglobin in the blood, we would need a cardiac output of almost 1000 liters/minute to deliver enough physically dissolved oxygen to the muscles to support high rates of exercise! For a 90-pound middle school student, the normal maximum cardiac output is about 17.85 liters/min and the normal resting cardiac output is about 4.5 liters/min.

The chemical binding properties of oxygen with hemoglobin are advantageous for delivering oxygen to the cells of the tissues and organs in the body. As it leaves the lungs, hemoglobin in the arterial blood is about 97% saturated with oxygen, while in the venous blood entering the right side of the heart, hemoglobin is still about 70% saturated with oxygen. It is advantageous to keep capillary oxygen levels high because then more oxygen can leave the capillaries to enter cells by diffusion, that is, moving from a high concentration of oxygen in the blood to a low concentration of oxygen in active cells.

The heart as a pump
Many physiological transport systems involve muscular pumps. These include cardiac muscle in the heart, skeletal muscles for breathing, and smooth muscle in the stomach and intestine. The amount of materials these pumps can move depends upon: 1) how much pressure they can generate to pump materials; and 2) how much resistance to flow they must overcome in blood vessels, airways, etc.

The circulatory system works to provide cells throughout the body with the oxygen they need to function. How can we estimate how much oxygen is used by the body’s cells? One analogy is how much money you use during a trip. At the beginning of the trip, you put $20 in your pocket. At the end of the day you have $3 left in your pocket. Therefore, you know your trip required $17. Similarly, if we want to know how much oxygen a group of cells (tissue) used, we would look at the difference between the amount of oxygen entering the tissues with the arterial blood and the amount of oxygen leaving the tissue with the venous blood. How does the body control the supply of oxygen to the cells in our body’s tissues? The important variables for supplying oxygen to the tissues are the cardiac output (pump output) and the arterial-venous oxygen concentration difference (input-output difference).

Most physiological pumps like the heart can increase the rate of delivery (or output) by increasing the frequency of contractions and/or by increasing the
volume pumped with each contraction. In the cardiovascular system, **cardiac output** (or blood flow to the body) depends upon two variables: **heart rate** (number of beats/min) and **stroke volume** (ml/beat of volume of blood pumped by one ventricle during a contraction). A balance between nervous inputs from the sympathetic and parasympathetic branches of the autonomic nervous system sets the heart rate. The volume of blood in the ventricle before contraction and the strength of the heart muscle contraction determine the stroke volume. Increasing blood returning to the heart (**venous return**) so that there is more blood in the ventricle before contraction both increases the volume that can be pumped and changes the mechanical properties of the heart muscle fibers. Thus, the heart can contract more forcefully during subsequent contractions.

In addition, the sympathetic branch of the autonomic nervous system and the epinephrine it releases from the adrenal glands into the blood can increase the force of the heart’s contractions. Cardiac output may increase more or less than the increase in heart rate, because stroke volume may increase more or less. For example, during exercise, stroke volume increases progressively until about 60% of the maximum rate for oxygen utilization and further increases in cardiac output are achieved mainly by increasing the heart rate.

Therefore:

\[
\text{Cardiac output} = \text{(heart rate)} \times \text{(stroke volume)}
\]

A typical resting cardiac output would be 4.5 liters/minute for middle school students and their typical resting heart rate would be 60-100 beats/minute. Therefore, a typical stroke volume in a middle school student would be:

\[
\begin{align*}
\text{Cardiac output} &= \text{(heart rate)} \times \text{(stroke volume)} \\
4.5 \text{ liters} &\div \text{minute} = \frac{80 \text{ beats}}{\text{minute}} \times \text{stroke volume} \\
4.5 \text{ liters} &\div \text{minute} \times \frac{\text{minute}}{80 \text{ beats}} = \text{stroke volume} \\
\frac{.056 \text{ liters}}{\text{beat}} &= \text{stroke volume} \\
\frac{56 \text{ ml}}{\text{beat}} &= \text{stroke volume}
\end{align*}
\]
A resting adult average heart rate is about 72 beats/minute, about 50 beats/minute in trained athletes, and > 125 beats/minute in someone who is excited or anxious. Children generally have higher average heart rates than adults do. The adult normal stroke volume is 70 ml/beat. Therefore, an average adult would have a resting cardiac output of about 5 liters/minute (72 beats/minute x 70 ml/beat = 5040 ml/minute = 5.04 liters/minute), and a maximum cardiac output of about 35 liters/minute.

**The flow of blood**
The flow of blood through the blood vessels is similar to the flow of current in an electrical system and follows the same principle known as Ohm’s Law:

In an electrical system:

\[ \text{voltage} = (\text{current}) \times (\text{resistance}) \]

For fluid flowing through a tube:

\[ \text{pressure difference} = (\text{flow}) \times (\text{resistance}) \]

Several factors contribute to the resistance to flow in such a system, including the radius (half of the diameter) of the tube, the length of the tube, and the viscosity (thickness) of the fluid in the tube.

Fluid viscosity can be understood by thinking of some common fluids:

<table>
<thead>
<tr>
<th>More Viscous</th>
<th>Less Viscous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gelatin</td>
<td>Honey</td>
</tr>
<tr>
<td>Pancake Syrup</td>
<td>Water</td>
</tr>
</tbody>
</table>

**Factors Contributing to Resistance to Flow**

<table>
<thead>
<tr>
<th>Flow through a tube increases when:</th>
<th>the pressure difference from one end of the tube to the other <strong>increases; and</strong> when the radius of the tube <strong>increases.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow through a tube will decrease when:</td>
<td>the length of the tube <strong>increases,</strong> or when the viscosity of the fluid in the tube <strong>increases.</strong></td>
</tr>
</tbody>
</table>

The American Physiological Society, Bethesda, MD

*Physiology of Exercise*, © 1999

15
Changes with exercise

The body’s response to exercise involves simultaneous coordination of multiple systems in the body. Obviously, chemical sensing of the oxygen and carbon dioxide in the blood is important for increasing breathing. In addition, a cardiovascular control center in the brain uses the sympathetic nervous system to increase heart rate and reset the baroreceptors to a higher level; they sense a higher blood pressure than the normal blood pressure. Also, changes in oxygen or other chemicals cause the blood vessels to dilate (increase in diameter), in the active muscle, thereby decreasing the resistance and enhancing blood flow to that muscle. With more intense exercise, the sympathetic nervous system further increases cardiac output by increasing heart rate and contractility (force of contraction) of the heart and by redirecting blood flow to essential systems (the brain, the heart, or the working skeletal muscle). Blood vessels that serve nonessential systems constrict (decrease in diameter), leading to reduced blood flow (and an increase in vascular resistance) during exercise in some vascular beds. For example, the gut, which is not needed in the “fight or flight” response, has decreased blood flow during exercise.

The exact stimuli sensed by the body to cause all of the changes in each of the various systems of the body during exercise are not yet known. Interestingly, changes in the cardiovascular and respiratory systems actually begin before the exercise has begun and, thus, before the sensors can detect any changes. Therefore, the body anticipates the coming exercise. If we think of the brain as a computer, it seems that a brain “software package” called exercise is inserted into the disk drive whenever someone plans to exercise.

Acute (immediate) cardiovascular responses to exercise include:
- increased blood flow to the working muscles (especially the skeletal muscles);
- increased blood flow to the heart muscle (increased coronary artery blood flow);
- increased heart rate (# beats/minute);
- increased stroke volume (volume of blood pumped with each heartbeat);
- increased cardiac output (volume of blood pumped each minute); and
- increased blood pressure.

Acute (immediate) respiratory responses to exercise include:
- increased rate of breathing (# breaths/minute);
- increased depth of breathing (tidal volume or volume of gas in with each breath);
- increased total ventilation (the volume of gas breathed each minute)
increased blood flow to the lungs (increased pulmonary artery blood flow); and
increased surface area for gas exchange in the lungs (due to recruitment of
new pulmonary capillaries so that more oxygen can diffuse into the blood
and more carbon dioxide can diffuse into the air).

Thus, the effects of exercise on the cardiovascular and respiratory systems are
complicated and varied. For example, an average middle school student can
increase his/her heart rate from about 80 to 210 beats/minute with extreme
exercise. He can also increase the stroke volume from a low of about 25 ml/beat
to 85 ml/beat. Thus, the student’s cardiac output can change from an average
of about 4.48 liters/minute to 17.85 liters/minute. This is an increase of about
four-fold (four times).

Simultaneously during exercise, the student can increase tidal volume (volume
of gas inhaled or exhaled by the lungs per breath) from about 0.2 ml/breath to
two liters/breath. They can also increase rate of breathing from about 12
breaths/minute to 40 breaths/minute. Thus, total ventilation (the volume of
air moved in and out of the lungs each minute) can increase from about 2.46
liters/minute to 80 liters/minute during heavy exercise. Therefore, since the respiratory system can work up to 32.5 times better
during exercise and the cardiovascular system can only work about four
times better during exercise, it must be the cardiovascular system that
limits how much exercise a human is able to perform. (See Table on the
Effects of Exercise below)

\[
\text{Total ventilation (volume/min)} = \text{rate of breathing (breaths/minute)} \times \text{tidal volume (volume/breath)}
\]

[Resting adult average breathing rate is about 12-20 breaths/min. The adult
average tidal volume is 0.5 liter/breath with a possible maximal breath of 3.5
liters/breath. Therefore, an average adult would have resting total ventilation of
about six liters/minute (12 breaths/minute x 0.5 liters/breath).]

<table>
<thead>
<tr>
<th>Effects of Exercise on the Cardiovascular and Respiratory Systems of an Average Middle School Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Cardiovascular</td>
</tr>
<tr>
<td>Heart Rate</td>
</tr>
<tr>
<td>Stroke Volume</td>
</tr>
</tbody>
</table>
While exercising, trained athletes, compared to sedentary people, tend to increase stroke volume more and heart rate less and increase tidal volume more and rate of breathing less. This training and conditioning occurs by long-term regular aerobic exercise. With training, an individual can increase the maximal level of oxygen available to the cells of the body due to an increase in maximal cardiac output by decreasing resting heart rate, increasing resting stroke volume, and/or increasing total blood volume. Skeletal muscles can also become more efficient in their use of oxygen. The strength and endurance of the respiratory system may also increase slightly.

**Medical focus**

Heart disease will **decrease exercise capacity** because it decreases the efficiency of the pump. A **heart attack** may damage cardiac muscle so that stroke volume is diminished. However, cardiovascular disease frequently starts in the blood vessels outside the heart (peripheral circulation), such as, atherosclerosis, or clogging of the arteries with cholesterol and fat. This serves to increase resistance to flow through the arteries, similar to a clog in a drain. Chronic increases in vascular resistance, termed high-blood pressure (**hypertension**), can eventually lead to heart failure.

Interestingly, the heart may actually **hypertrophy** (become larger) in an attempt to pump through the vessels that have greater resistance, but the heart actually becomes less efficient and ultimately fails from such enlargement. A weak heart cannot pump blood effectively so that blood backs-up in the circuit, causing blood pressure to increase in the veins. This can lead to leakage of fluid out of the capillaries into the air spaces of the lungs (**pulmonary edema**) or into the body tissues (**tissue edema**, like the swelling of the ankles in the elderly or during pregnancy). This increase in blood volume also stretches the heart and increases the length of the individual heart muscle cells, making them less efficient, and can lead to **congestive heart failure**. High salt intake can cause water retention and also increase blood volume, which can further stretch the heart muscle.

The most common cause of increased blood viscosity is an increased **hematocrit**, that is, increased percentage of the blood cells in the blood.
Increased production of red blood cells by the bone marrow (erythropoiesis) occurs in response to low levels of oxygen in the blood. Increased production of red blood cells occurs normally when the body is adjusting to the lower oxygen levels at high altitudes. It also occurs in patients with lung diseases, often caused by smoking. It is also one of the adverse side effects of blood doping, that is, attempts by athletes to increase their hematocrit quickly before a race. This can temporarily increase their oxygen supply to exercising muscle.

**Biological and experimental variability**

Finally, it is important to note that biological variability between different individuals and experimental variability due to imperfect measurement techniques, contributes to differences in measurement of heart rate, blood pressure, etc. Biological variability includes gender differences, genetic differences, and differences due to training. This is the kind of difference you look for when you grade tests on a normal curve. Experimental variability can occur, for example, when different periods of time are used to count heart rate.

Consider what would happen if you only counted heart rate for one second. Sometimes you'd get a beat, but other times you may not, and your calculated heart rate could vary from 0/minute to the true value (usually 50-70 beats/minute)! The longer the time period for data collection, the more likely one is to obtain an accurate measurement. A normal-shaped curve usually describes random variation of an experimental nature, too. This is known as the Gaussian curve, named after the astronomer and mathematician, Gauss. He noticed that the coordinates of stars on sequential nights seemed to fit a normal-shaped curve, and he explained this as a result of imperfections in his telescope sighting methods.
Suggestions for Teachers
Module #1
What Do You Know About the Effects of Exercise?

Purpose
Engage students in exploring the effects of exercise on the human body

Objectives
The student will be able to:
- Make observations about how strenuous exercise affects respiration, heart rate, and blood flow.
- Connect their own experiences with the effects of exercise on their cardiovascular and respiratory systems to the observations that they make.
- Convey their current understanding and possible misconceptions about the effects of exercise on the cardiovascular and respiratory systems via analysis of initial KWL/T-chart responses.

Materials and Methods
Copy of the My Health Lifestyle Inventory and Student Activity Sheet for each student
VCR and monitor
Clips from television, movies, interviews, etc. of persons at rest and persons engaged in heavy exercise (preferably aerobic exercise such as long-distance running, not short-term, anaerobic exercise such as the 100 meter dash -- good possibilities would be clips from the most recent Olympics, a school track meet or training session, or a movie with sports competition, such as a basketball game)
KWL/T-chart materials for groups of three to four students (poster board or roll paper, Post-It™ notes, markers, or pens...see Student Handout)

Procedure
1) Ask students to complete My Health Lifestyle Inventory at the beginning of the unit and to hold the Inventory for Module #5 (evaluate). We do not recommend collecting the inventory since it includes personal questions about the student. Encourage students to answer the questions honestly and inform them that it is for self-assessment.
2) To initially engage students in the unit, they will make some observations about differences they can see and/or hear between persons at rest and persons engaged in strenuous exercise. After you tell students to make observations, show a one to three minute video clip of persons at rest and then a one to three minute video clip of persons engaged in strenuous exercise. We have found that this works especially well if the clips are shown the first time without sound. Students are asked to jot down some of their observations as they watch the clip. Then the clips are again shown with sound to see if students can make any additional observations.

3) Divide students into groups of three to four to generate the KWL/T-chart described on the student handout. They should put their names on the back of the poster board. The KWL/T-chart can be used as an initial assessment tool to determine students' understanding of cardiovascular and respiratory responses to exercise and is an excellent way to identify students' misconceptions and questions. Posters can be displayed on bulletin boards so students can refer to them throughout the unit. NOTE: Concept maps can be substituted for KWL’s or T-charts.

**Safety Issues**
None.

**Suggestions for Assessment**
Use the KWL/T-charts to check for student misconceptions and to provide a baseline assessment of student understanding of the unit concepts.

**References and Resources**


Student Activity Sheet
Module #1
What Do You Know About the Effects of Exercise?

Materials
- Pen/pencil
- Poster board or roll paper (1 sheet per group)
- Post-It™ notes

Procedure
Using the poster board and Post-It™ notes, work with your group to develop a “KWL” chart (complete the first two columns only) describing what you know about how exercise affects the cardiovascular and respiratory systems (heart, blood, blood vessels, lungs, etc.), and what you would like to know. See the example below:

| How Exercise Affects My Heart, Blood, Blood Vessels, and Lungs |
|---|---|---|
| What I **Know** | What I **Want to Know** | What I **Learned** |
| | | |
Student Name: ____________________________________

My Health Lifestyle Inventory

Directions: Complete each section of the inventory. Circle the number that corresponds to the answer that BEST describes your behavior. Then add the numbers you have circled to determine your score for that section. Write the score on the line provided at the end of each section.

<table>
<thead>
<tr>
<th>My Health Lifestyle Inventory</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Cigarette Smoking, Drugs, and Alcohol</td>
<td>Almost Always</td>
<td>Sometimes</td>
<td>Almost Never</td>
</tr>
<tr>
<td>If you never smoke or use drugs or alcohol, enter a score of 10 for this section and go to section II.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. I avoid smoking cigarettes.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. I smoke only low tar and nicotine cigarettes (if you do not smoke, mark “2”).</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. I avoid drinking alcoholic beverages.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. I avoid using alcohol or other drugs (especially illegal drugs) as a way of handling stressful situations or the problems in my life.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5. I read and follow the label directions when using prescribed and over-the-counter drugs.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Cigarette Smoking, Drugs, and Alcohol Score:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

II. Eating Habits

<table>
<thead>
<tr>
<th>Eating Habits</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I eat a variety of foods each day, such as fruits and vegetables, whole grain breads and cereals, lean meats, dairy products, dry peas, and beans.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. I limit the amount of fat, saturated fat, and cholesterol I eat.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. I limit the amount of salt I eat by cooking with only small amounts, not adding salt at the table, and avoiding salty snacks.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. I avoid eating too much sugar (especially frequent snacks of sticky candy or soft drinks).</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Eating Habits Score:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

III. Exercise and Fitness

<table>
<thead>
<tr>
<th>Exercise and Fitness</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I maintain a desired weight</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. I do vigorous exercises for 13-30 minutes at least three times a week (such as running, walking, swimming, or aerobics).</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. I do exercises that enhance my muscle tone for 15-30 minutes at least three times a week (such as yoga).</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. I use part of my leisure time to participate in individual, family, or team activities that increase my level of fitness.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Exercise and Fitness Score:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Continued on following page
<table>
<thead>
<tr>
<th>IV. Stress Control</th>
<th>Almost</th>
<th>Sometimes</th>
<th>Almost Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I have a job, attend school, or do other work that I enjoy.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. I find it easy to relax and express my feelings freely.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. I recognize early, and prepare for, events or situations likely to be stressful for me.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. I have close friends, relatives, or others whom I can talk to about personal matters and call on for help when needed.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5. I participate in group activities (such as church and community organizations) or hobbies that I enjoy.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Stress Control Score:**

<table>
<thead>
<tr>
<th>V. Safety and Health</th>
<th>Almost</th>
<th>Sometimes</th>
<th>Almost Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I wear a seat belt while riding in a car.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. I avoid riding with anyone under the influence of alcohol and other drugs.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3. I only ride with persons who obey traffic rules and the speed limit when driving.</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. I am careful when using potentially harmful products or substances (such as household cleaners, poisons, and electrical devices).</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5. I get at least 7-8 hours of sleep a night</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Safety and Health Score:**
My Health Lifestyle Inventory

What Your Scores Mean to You

Section Scores of 9 and 10 - Excellent! Your answers show that you are aware of the importance of this area to your health. More importantly, you are putting your knowledge to work for you by practicing good health habits. As long as you continue to do so, this area should not pose a serious health risk. It’s likely that you are setting an example for your family and friends to follow. Since you got a very high score on this part of the test, you may want to consider other areas where your scores indicate room for improvement.

Section Scores of 6-8 - Good. Your health practices in this area are good, but there is room for improvement. Look again at the items you answered with a “Sometimes” or “Almost Never.” What changes can you make to improve your score? Even a small change can often help you achieve better health.

Section Scores of 3 to 5 - Your health risks are showing! Would you like more information about the risks you are facing and about why it is important to change these behaviors? Perhaps you need help in deciding how to successfully make the changes you desire.

Scores of 1 to 2 - Obviously you were concerned enough about your health to take the test, but your answers show that you may be taking serious unnecessary risks with your health. Perhaps you are not aware of the risks and what to do about them. You can easily get the information and help you need to improve, if you wish.

Suggestions for Teachers
Module #2
How Do Your Heart and Lungs Work Together Compared to Those of Your Classmates?

Purpose
To explore “resting” responses of the heart and lungs. Exercise (skeletal muscle contraction) is such a common physiological state that true physiologic “rest” is rarely achieved during the day.

Objectives
Students will be able to:
- Take a pulse
- Measure the rate of breathing

Materials
Copy of Student Activity Sheets #2a and #2b for each student

Procedure
1) Students should work in groups of three or four.
2) Have students practice taking their pulse before the lesson (see diagram on page 23).
3) Have students practice counting their classmate’s rate of breathing (number of breaths in one minute).
4) You will find that it is easier for students to take pulse and breathing readings if all groups start and stop at the same time. The room must be quiet while readings are being taken.

Safety
Students should NOT take the pulse at the carotid artery in the neck because too much pressure may cause lack of oxygen to the brain, resulting in unconsciousness. Also, mechanical pressure on the carotid artery can be sensed by the baroreceptors there as high blood pressure, which will cause the autonomic nervous system to adjust the heart rate to lower the blood pressure.
Suggestions for Assessment
Groups can turn in the answers to their analysis questions.

References and Resources

Student Activity Sheet
Module #2a
How to Measure Your Pulse or Heart Rate

Method
1) Feel at your ankle, elbow, or wrists (see diagram below) with the fingertips of your index and middle fingers for your pulse point until you detect pulsations.
2) Keep yourself as still as possible while you are taking your heart rate. Do not hold your breath.
3) Count the number of heartbeats you feel in the time periods on your data chart on the next page. Record the results.
4) Try repeating steps 1-3, measuring your heart rate at different pulse points.

- Anterior Tibial Artery on the front of the ankle
- Brachial Artery in the inside of the elbow
- Radial Artery in the wrist

Cartoid artery in the neck (DO NOT use this for today’s experiment)
## Resting Pulse

<table>
<thead>
<tr>
<th>Pulse Point</th>
<th>15 seconds</th>
<th>30 seconds</th>
<th>60 seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse - Brachial Artery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse - Radial Artery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse - Anterior Tibial Artery</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reference:
Student Activity Sheet
Module #2b
How Do Your Heart and Lungs Work Together Compared to Those of Your Classmates?

Background Information
Different people have different heart rates (pulse) and different rates of breathing while they are in a relatively quiet state (resting). These differences are known as biological variability. Sometimes scientific measurements are improperly made or are not made in the best way to have results that are about the same from one measurement to another. This is called experimental variability. In this experiment, you will measure your pulse and rate of breathing and compare your measurements to those of your classmates. Finally, you will think about why there might be differences in heart rate and rate of breathing among middle school students.

Procedure
1) Do these activities in groups of three to four. Each student should participate as an experimental “subject.”

2) Each subject should stand quietly at rest for a minute or two before you measure his/her pulse. Find your partner’s radial pulse (on the thumb side of the inner wrist). Count and record the pulse for 6, 10, 15, 30, and 60 seconds. Then use the multiplication factor found in the table to calculate the number of beats/minute. If you have difficulty finding the pulse in the wrist, try the other arm and or the ankles. **DO NOT take the pulse from arteries in the neck area.**

Radial Artery in the wrist
<table>
<thead>
<tr>
<th>Count pulse for:</th>
<th>Record the count:</th>
<th>Multiply by:</th>
<th>Heart beats per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 seconds</td>
<td></td>
<td>x 1 =</td>
<td></td>
</tr>
<tr>
<td>30 seconds</td>
<td></td>
<td>x 2 =</td>
<td></td>
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<tr>
<td>15 seconds</td>
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<td>x 4 =</td>
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<tr>
<td>10 seconds</td>
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<td>x 6 =</td>
<td></td>
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<tr>
<td>6 seconds</td>
<td></td>
<td>x 10 =</td>
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</tbody>
</table>

3) During the 60-second pulse recording (or another 60-second period), have one student count the number of breaths that the subject takes during the whole minute. Each breath involves BOTH inhaling and exhaling the air (chest moving up AND down). The subject should try to breathe normally and quietly. Record your data here:

**Resting rate of breathing (breaths/min) __________________________**

4) Add your data to the charts that your teacher has provided and to the chart on the next page.
<table>
<thead>
<tr>
<th>Number of Students</th>
<th>40-45</th>
<th>46-50</th>
<th>51-55</th>
<th>56-60</th>
<th>61-65</th>
<th>66-70</th>
<th>71-75</th>
<th>76-80</th>
<th>81-85</th>
<th>86-90</th>
<th>91-95</th>
<th>96-100</th>
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<tbody>
<tr>
<td>12</td>
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<td>1</td>
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Number of beats/minute
## Histogram - Resting Breathing Rates

<table>
<thead>
<tr>
<th>Number of Students</th>
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<tbody>
<tr>
<td>12</td>
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<td>11</td>
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<td>10</td>
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<td>2</td>
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<td>1</td>
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<table>
<thead>
<tr>
<th>Number of breaths/minute</th>
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<tr>
<td>5-10</td>
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<td>11-15</td>
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<td>16-20</td>
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<td>21-25</td>
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<td>31-35</td>
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<tr>
<td>36-40</td>
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<td>41-45</td>
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</tbody>
</table>
Analysis

1) Is the resting pulse (in beats/minute) the same for each measurement? Why could you get different answers for different measurement times?

2) Not everyone has the same resting heart rate. Add your data to a bar graph (histogram) of resting heart rate for everyone in the class. What might explain the variability (differences) in heart rate between individuals?

3) Can you change your pulse by thinking about it? Describe how you could test this.

4) Not everyone has the same resting breathing rate. Add your data to a bar graph of resting breathing rate for everyone in the class. What might explain the variability (differences) in breathing rate between individuals?

5) Can you change your breathing rate by thinking about it? Describe how you could test this.
Suggestions for Teachers
Module #3
How does exercise affect the cardiovascular and respiratory systems?

Purpose
Explain the relationship between exercise and the needs of body tissues for oxygen and how the cardiovascular and respiratory systems respond to meet that need.

Objective
Students will be able to:
- Describe how increases in heart rate contribute to increases in the blood and oxygen going to the cells of the body to be used by the muscles for exercise.

Materials
- Egg carton
- Bag of marbles, candies, or other small hard objects
- Overhead transparencies

Procedure
Demonstration #1:
1) Recruit six students to assist with this demonstration. We suggest that each student be given a sign to indicate what role they are playing in the demonstration. Each student has a specific role:

   Student #1 = Lungs, supplying blood with oxygen
   Student #2 = Oxygen-measuring machine placed in an artery
   Student #3 = Muscle tissue which is using oxygen
   Student #4 = Oxygen-measuring machine placed in a vein
   Student #5 = Blood carrying oxygen
   Student #6 = Heart, driving the blood through the system

   Marbles = Oxygen molecules

2) Position students around the room as shown in Transparency Master 3.1
3) Give the empty carton to Student #5 (Blood).
4) Give the bowl or bag of marbles to Student #1 (Lungs).
5) Student #5 (Blood) begins at the Lungs (#1) and places one marble in each cup of the carton.

6) Heart (#6) pushes (gently!) the Blood toward the monitor in the Artery (#2).
7) Monitor (artery) (#2) counts the total number of marbles in the egg carton and remembers the number.
8) Heart (#6) pushes (gently!) the Blood toward Muscle Tissue (#3).
9) Muscle Tissue (#3) takes a few oxygen molecules from the egg carton and does not reveal the number. Note: They should only take a few pieces the first time (1-6 pieces).
10) Heart (#6) pushes (gently!) the Blood toward the monitor in the Vein (#4).
11) Monitor (vein) (#4) counts the total number of marbles left in the egg carton and remembers the number.
12) Heart (#6) pushes (gently!) the Blood back to the Lungs (#1).
13) Blood replenishes its supply of oxygen at the Lungs.
Work through the following questions with the class:

- How many marbles were in the carton at the artery? (Artery monitor #2 should report)
- How many marbles were in the carton at the vein? (Vein monitor #4 should report)
- Therefore, how many marbles did the muscle tissue use? (Class should calculate; muscle tissue should confirm).

If we want to know how much oxygen is used by the tissues, we can measure the concentration of oxygen in the artery and in the vein and calculate the difference.

**Demonstration #2: Responses to exercise**

Continue with the following questions:

1) If you begin to exercise, what happens to the muscle tissues’ need for oxygen? (*Answer: It increases*).

2) What are some ways that you could increase the amount of oxygen available to the tissues? Write them on the board or on an overhead transparency. *Encourage many answers, including:* 1) increase the amount of oxygen each red blood cell (RBC) carries; 2) increase the number of red blood cells in the circulatory system; 3) increase the heart rate so that more red blood cells go by the tissues in the same amount of time. *Answers:* 1) is not feasible...normal RBCs generally already carry their capacity of O₂; 2) actually occurs in many animals including horses and dogs. They have a reserve of RBCs in the spleen, which are released during exercise for just this purpose. This does not happen in humans; and 3) this is the response seen in most animals, including humans.

**Now demonstrate this process:**

Repeat steps 1-13 in Demonstration #1 several times, each time modeling one of the ways students proposed in the above question to increase the supply of oxygen to the muscle tissue. With each pass the muscle tissue should take more of the oxygen than they did in the first demonstration. After each demonstration, give feedback on whether the system works this way in humans or other animals. Give students the opportunity to take theatrical license if possible, during this part of the demonstration! Use Transparency Masters 3.2 and 3.3 to review the process after students act it out.
Blood picks up oxygen at the lungs

Heart pushes blood through the system

Tissues, such as muscle, use oxygen

Monitor to check concentration of oxygen in artery

Monitor to check concentration of oxygen in vein
1. At Rest

Lightly exercising muscle

Flow = 1 box per 20 seconds = 3 boxes per minute
Arterial-Venous Difference = 12 - 8 = 4 O₂
Oxygen consumption = 4 O₂ per 20 seconds = 12 O₂ per minute

Oxygen consumption = (A-V) x Flow *

2. Increase in Oxygen Extraction

Strenuously exercising muscle

Flow = 1 box per 20 seconds = 3 boxes per minute
Arterial-Venous Difference = 12 - 4 = 8 O₂
Oxygen consumption = 8 O₂ per 20 seconds = 24 O₂ per minute

* This is known as Fick's principle.
3. Increase in Heart Rate

Strenuously exercising muscle

Flow = 1 box per 10 seconds = 6 boxes per minute
Arterial-Venous Difference = 12 - 4 = 8 O₂
Oxygen consumption = 8 O₂ per 10 seconds = 48 O₂ per minute

4. Increase in Stroke Volume

Strenuously exercising muscle

Flow = 2 boxes per 10 seconds = 12 boxes per minute
Arterial-Venous Difference = 24 - 8 = 16 O₂
Oxygen consumption = 16 O₂ per 10 seconds = 96 O₂ per minute

Diagrams courtesy of Richard W. Carruba, Brackenridge High School, San Antonio, TX, and San Antonio Local Outreach Team.

The American Physiological Society, Bethesda, MD

*Physiology of Exercise*, © 1999

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Safety
Students should walk quickly during the demonstration, but not run. The Heart should gently push the Blood along; jerking, dragging, and shoving are not allowed.

Suggestions for Assessment
Ask students to explain how the muscles can get more oxygen when they exercise and what method their body normally uses. Students can demonstrate this using egg cartons or diagrams.

Note: There is no student handout for Module #3.
Elaborate

Suggestions for Teachers
Module #4
Is Heart Rate Constant?

Purpose
Explore further the concepts of changes in heart rate and breathing rate via a hands-on, inquiry–based laboratory by designing an experiment on the effect of a stimulus on heart rate. Note: There are two experimental questions in this activity. The teacher may choose to have all students explore one or both questions or divide the class and explore both simultaneously.

Objectives
Students will be able to:
- Make active observations about the baroreflex response and how it can be stimulated; AND/OR
- Make active observations about how strenuous exercise affects respiration and heart rate.
- Demonstrate improved skills in the scientific method of developing experimental questions, designing experiments, collecting and analyzing data, and drawing conclusions.

Option #1: Baroreflex Experiment (Module #4a)
Materials for Baroreflex Experiment
- Stopwatches (one per group)
- Pulse or heart rate monitors (desirable, but optional)
- Stethoscopes (desirable, but optional)

Procedure for Baroreflex Experiment (Module #4b)
1) Ask the class whether heart rate is constant. Obviously, it is not, but what sort of stimuli might raise or lower blood pressure?
2) Students should work in groups of 2-4.
3) Ask each group to design an experiment to test the effect of a stimulus on heart rate. Examples of stimuli could include standing from a prone or supine position (with or without the feet elevated) or standing from a sitting position. They will need a way to measure heart rate. The pulse is an obvious method, but it is not necessarily the most accurate. If possible, have stethoscopes and/or heart or pulse monitors available.
4) Each group should present their experimental design to the teacher for approval before the experiment is conducted.
Have students share their experimental design, results, and analysis.

**Safety issues for the Baroreceptor Experiment**
Students should design experiments that will not harm the subject. Extremely loud noises may damage hearing, and any stimulus that results in pain must be avoided. This is a good opportunity to discuss the need for human and animal protocol approval before experimentation. **All experiments and data tables must be approved by the teacher before the experimentation begins.**

**Option #2: Exercise Experiment (Module #4b)**

**Materials for exercise experiment**
- Stopwatch or metronome (one per class)
- 16” high bench or step

**Procedure for exercise experiment**
1) Now that the students are good at finding and recording the pulse rate and counting the number of breaths in one minute, they can now design and carry out an experiment to test the effects of exercise on the cardiovascular and respiratory systems. Students should design their experiment, including a description of the methods to be used and a data table ready for data entry, and then submit to the teacher for approval before any experimentation begins.

One option for exercise is the Step Test (see box below), but this is a very strenuous exercise and may not be appropriate for all groups. NOTE: Step Test is used for the whole class; data comparisons among groups may be more valid. However, the trade-off is the loss of student opportunity to increase their experimental design skills. The teacher should decide which format to use based on the needs of his/her students.
Physical Fitness Step Test.
The subject should do the Step Test in the following way:

1. The subject steps at a rate of 22 steps per minute (female) or 24 steps per minute (males) for 3 minutes total. The other team members should spot for the subject in case the subject stumbles during the test.

2. After exercise, the subject remains standing. Wait 5 seconds (find the pulse during this time) and then begin counting a 15-second heart rate count at the radial artery (as before). The students should be prepared to count quickly because the rate will be faster than before! Also have someone count the number of breaths in one minute (wait the 5 seconds and count the breaths for the next 60 seconds). Record the exercise data on the chart.

3. You may modify the step test to fit your particular situation. For example, we have done the step test on choir risers, bleachers, and building steps. If the step test is not feasible, an alternate exercise can be substituted.

Safety issues for the exercise experiment
You may want to get parental permission slips for students participating in the Step Test. This is a relatively strenuous activity in which all students may be unwilling or unable to participate. The more athletic students in the class should have no difficulty with the activity. Be sure to have at least one student in each group designated as a spotter in case the step tester stumbles. All experiments and data tables must be approved by the teacher before the experiment begins.

Suggestions for assessment of exercise experiment
Groups can turn in the answers to their analysis questions or can write a complete laboratory report. The students in each group should participate in presenting their experiments, results, and conclusions either orally or by a poster. Develop a rubric for evaluation of group activities.

You may choose to have the students follow procedures similar to research scientists and either write a complete laboratory report or prepare a visual poster presentation of their experiment. One of the objectives of a scientific paper or poster is to explain to people who were not present when they did the experiments what they did and why.

References and Resources
Textbooks on anatomy and physiology.
Background information for baroreceptor experiment
How does the baroreceptor reflex work? Since the baroreceptor reflex controls blood pressure (baro means pressure), you might expect that there will be something that monitors blood pressure, comparing your current blood pressure to a normal value. Indeed, some large blood vessels near the heart contain blood pressure sensors that measure blood pressure. Physiologists call these sensors baroreceptors. The blood pressure signal is sent via nerves to an area of the brain, where it is compared to a normal blood pressure. For example, if the blood pressure is too low, this area of the brain will send a message via nerves back to the heart to increase the heart rate. In this way, the blood pressure will be brought back up to normal.

Materials for Baroreflex Experiment
- Stopwatches
- Pulse or heart rate monitors (desirable, but optional)
- Stethoscopes (desirable, but optional)

Procedure for baroreflex experiment
1) Design an experiment to test the effect on heart rate of a stimulus, such as standing up from a prone (lying flat on your stomach) or supine (lying flat on your back) position (with or without the feet elevated) or standing from a sitting position.
2) Before you begin your experiment, your teach must approve your methods (what you plan to do). Share your experimental design, results, and analysis with the rest of the class.

Your scientific laboratory report or your poster presentation of a scientific report should include:
An introduction that includes the question to be answered (purpose);
Your hypothesis (what you think will happen) -- then your results will either agree or disagree with your hypothesis;
**Materials** that you used in the experiment;
Detailed **methods** including how you did the experiment, how many times you did the experiment, and how many subjects you studied;
Chart to record your **data**;
**Results** including a numerical or graphical presentation of your data;
**Conclusion** (based upon the results - did your results agree or disagree with your hypothesis and what did you conclude in answer to your question); and
Additional **questions** you’d like to explore (where would you go from here?).
Background information for exercise experiment
The cardiovascular system is the important link between the transport of oxygen from the lungs to other parts of the body: its delivery to tissues and its use by those tissues. It is essential for life in ALL animal species. In humans, the heart plays an important role in moving blood that is loaded with oxygen, so that it is provided to the cells for making energy. The response to exercise offers an excellent opportunity to observe and learn about how oxygen is transported and used by the body. In this laboratory, you will be able to study the response of the heart and lungs to exercise.

Materials for exercise experiment
Stopwatch or metronome
16” high bench or step (if doing the Step Test)

Procedure for exercise experiment
1) Now that you are good at finding and recording the pulse rate and counting the number of breaths in one minute, you can now design and carry out an experiment to test the effects of exercise on the cardiovascular and respiratory systems. You should design your experiment, including a description of the methods to be used and a data table ready for data entry, and then submit to the teacher for approval before any experimentation begins. One option for exercise is the Step Test (see box below), but this is a very strenuous exercise and may not be appropriate for all groups. NOTE: Step Test is used for the whole class; data comparisons among groups may be more valid.
**Physical Fitness Step Test.**
The subject should do the Step Test in the following way:

4. The subject steps at a rate of 22 steps per minute (female) or 24 steps per minute (males) for 3 minutes total. The other team members should spot for the subject in case the subject stumbles during the test.

5. After exercise, the subject remains standing. Wait 5 seconds (find the pulse during this time) and then begin counting a 15-second heart rate count at the radial artery (as before). The students should be prepared to count quickly because the rate will be faster than before! Also have someone count the number of breaths in one minute (wait the 5 seconds and count the breaths for the next 60 seconds). Record the exercise data on the chart.

6. You may modify the step test to fit your particular situation. For example, we have done the step test on choir risers, bleachers, and building steps. If the step test is not feasible, an alternate exercise can be substituted.

**Analysis questions for the exercise experiment**

1) What happens to the heart rate when you exercise? Why do you think it is important for this to occur?

2) Divide your post-exercise heart rate by your resting heart rate. How many times faster was your heart beating after exercise? (Example: If your resting heart rate=72 and your post-exercise heart rate=154, then: \( \frac{154}{72} = 2.1 \), or your heart was beating more than two times faster after exercise).
3) As you look at your data, what other questions come to mind about how the cardiovascular system responds to exercise? Write your questions down.

4) What happens to the breathing rate when you exercise? Why do you think it is important for this to occur?

5) Divide your post-exercise breathing rate by your resting breathing rate. How many times faster did you breathe after exercise? (Example: If your resting breathing rate=15 and your post-exercise breathing rate=45, then: 45/15 =3.0, or you were breathing three times faster after exercise).

6) As you look at your data, what other questions come to mind about how the respiratory system responds to exercise? Write your questions down.
Your scientific laboratory report or your poster presentation of a scientific report should include:

An introduction that includes the question to be answered (purpose); Your hypothesis (what you think will happen) -- then your results will either agree or disagree with your hypothesis; Materials that you used in the experiment; Detailed methods including how you did the experiment, how many times you did the experiment, and how many subjects you studied; Chart to record your data; Results including a numerical or graphical presentation of your data; Conclusion (based upon the results - did your results agree or disagree with your hypothesis and what did you conclude in answer to your question); and Additional questions you’d like to explore (where would you go from here?).
Suggestions for Teachers

Module #5
Cardiovascular and Respiratory System and Exercise. What Do You Know Now?

Purpose
To evaluate students’ acquisition of the concepts and skills developed through Modules #1-4.

Objectives
Student will be able to:
1) Clarify areas of understanding and identify misconceptions.
2) Apply their knowledge to a real-life problem (My Health Lifestyle Inventory).

Materials
- KWL/T-charts or concept maps completed by groups during Module #1 (have additional Post-It™ notes available)
- My Health Lifestyle Inventory (previously completed by student), p. 16.

Procedure
1) Each group should re-assess their KWL/T-chart. Are the concepts listed in column 1 correct? What have they learned in Modules 1-4?
2) Each group should finalize their chart for presentation to the whole class and/or submission to the teacher.
3) Each student should review their My Health Lifestyle Inventory and write down at least two things they are doing which contribute to his/her good health. Next, they should write down at least two things they could do to improve their good health (that is, to increase their overall score on the Inventory). These can be submitted to the teacher, if preferred.

Safety
None

Suggestions for Assessment
The KWL/T-chart can be used for assessment. Complete a My Health Lifestyle Inventory for a fictitious student. Ask students to note at least two things this student could do to improve his/her health (that is, to increase his/her overall
score on the Inventory) and two things the student is currently doing that contribute to his/her good health. Students should be able to relate one of these items to something they know/learned about the cardiovascular or respiratory systems and/or exercise.

**References and Resources**


**Note: There is NO student handout for Module #5.**
Appendix

National Science Education Standards
Teaching Standards

Complete information about the NSES may be obtained from contacting the National Academy Press, 2101 Constitution Avenue, N.W., Box 208, Washington DC 20055, 1-800-624-6242 or 1-202-334-331, or on the web at http://www.nap.edu. (Text below from: http://books.nap.edu/html/nses/html/overview.html#teaching)

The science teaching standards describe what teachers of science at all grade levels should know and be able to do. They are divided into six areas:

A. The planning of inquiry-based science programs.

B. The actions taken to guide and facilitate student learning.

C. The assessments made of teaching and student learning.

D. The development of environments that enable students to learn science.

E. The creation of communities of science learners.

F. The planning and development of the school science program.
TEACHING STANDARD A:
Teachers of science plan an inquiry-based science program for their students. In doing this, teachers:

- Develop a framework of yearlong and short-term goals for students.
- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.
- Select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners.
- Work together as colleagues within and across disciplines and grade levels.

TEACHING STANDARD B:
Teachers of science guide and facilitate learning. In doing this, teachers:

- Focus and support inquiries while interacting with students.
- Orchestrate discourse among students about scientific ideas.
- Challenge students to accept and share responsibility for their own learning.
- Recognize and respond to student diversity and encourage all students to participate fully in science learning.
- Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

Coordinating people, ideas, materials, and the science classroom environment are difficult, continual tasks. This standard focuses on the work that teachers do as they implement the plans of Standard A in the classroom.

TEACHING STANDARD C:
Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers:

- Use multiple methods and systematically gather data about student understanding and ability.
- Analyze assessment data to guide teaching.
- Use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice.
- Use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policy makers, and the general public.

The word "assessment" is commonly equated with testing, grading, and providing feedback to students and parents. However, these are only some of the uses of assessment data. Assessment of students and of teaching--formal and informal--provides teachers with the data they need to make the many decisions that are required to plan and conduct their teaching. Assessment data also provide information for communicating about student progress with individual students and with adults, including parents, other teachers, and administrators.
**TEACHING STANDARD D:**
Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers:

- Structure the time available so that students are able to engage in extended investigations.
- Create a setting for student work that is flexible and supportive of science inquiry.
- Ensure a safe working environment.
- Make the available science tools, materials, media, and technological resources accessible to students.
- Identify and use resources outside the school.
- Engage students in designing the learning environment.

Time, space, and materials are critical components of an effective science learning environment that promotes sustained inquiry and understanding. Creating an adequate environment for science teaching is a shared responsibility. Teachers lead the way in the design and use of resources, but school administrators, students, parents, and community members must meet their responsibility to ensure that the resources are available to be used. Developing a schedule that allows time for science investigations needs the cooperation of all in the school; acquiring materials requires the appropriation of funds; maintaining scientific equipment is the shared responsibility of students and adults alike; and designing appropriate use of the scientific institutions and resources in the local community requires the participation of the school and those institutions and individuals.

**TEACHING STANDARD E:**
Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers:

- Display and demand respect for the diverse ideas, skills, and experiences of all students.
- Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community.
- Nurture collaboration among students.
- Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.
- Model and emphasize the skills, attitudes, and values of scientific inquiry.

The focus of this standard is the social and intellectual environment that must be in place in the classroom if all students are to succeed in learning science and have the opportunity to develop the skills and dispositions for life-long learning. Elements of other standards are brought together by this standard to highlight the importance of the community of learners and what effective teachers do to foster its development. A community approach enhances learning: It helps to advance understanding, expand students' capabilities for investigation, enrich the questions that guide inquiry, and aid students in giving meaning to experiences.

An assumption of the Standards is that all students should learn science through full participation and that all are capable of making meaningful contributions in science classes. The nature of the community in which students learn science is critical to making this assumption a reality.
TEACHING STANDARD F:
Teachers of science actively participate in the ongoing planning and development of the school science program. In doing this, teachers:

- Plan and develop the school science program.
- Participate in decisions concerning the allocation of time and other resources to the science program.
- Participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.