OBJECTIVES:

1. Understand the main function(s) of respiratory and circulatory systems.
2. Learn the major components of each system.
3. Examine how these systems and their components differ across taxa and their respective environments.

INTRODUCTION:

Circulatory systems provide a means of delivering oxygen, nutrients and hormones to the cells of an organism’s body, while removing the metabolic wastes (carbon dioxide and ammonia) produced by them. In homeotherms, i.e. warm-blooded animals (e.g. birds and mammals), the circulatory system also plays a vital role in the regulation of body temperature (thermoregulation) through a process referred to as countercurrent heat exchange (CCHE). When an organism is situated in an environment that is colder than its core body temperature, CCHE permits the transfer of heat from the warm blood (from the heart) flowing through the arteries of the extremities to the colder blood traveling in the veins, which run parallel to them (Fig. 1).

Figure 1. Countercurrent Heat Exchange

Circulatory systems differ significantly throughout the Animal Kingdom. The cells of unicellular organisms (e.g. protozoans, cnidarians and planaria) are in constant contact with the external environment, allowing them to use their cell surface to obtain and transport nutrients and also expel wastes. Pseudocoelomate invertebrates (e.g.
Ascaris), in contrast, utilize the fluids present inside their body cavities not only as a hydrostatic skeleton (for movement) but also as a means of circulation. However, transport of nutrients, gases, and waste products presents a major challenge for large, multicellular organisms (Why?). As a result, these animals developed specialized organs and organ systems, i.e. circulatory and respiratory systems, for this purpose.

In an open circulatory system (Fig. 2A), as found in mollusks and arthropods, a muscular heart pumps hemolymph (blood and fluid of the body tissues) through a network of channels and cavities in the body which eventually drain back into a central cavity. On the other hand, in a closed circulatory system (Fig. 2B), as found in annelids and vertebrates, the heart pumps blood through a series of blood vessels (arteries, veins, and capillaries) that transport oxygen and nutrients to the rest of the body while simultaneously removing wastes from the tissues.

Organisms respire (breathe) to obtain the oxygen necessary for cellular respiration and to eliminate carbon dioxide. Depending on their body size, oxygen demands and environment, organisms have developed a variety of respiratory structures (Fig. 3). Arthropods, for example, do not possess a single respiratory organ. Instead, air enters the body through spiracles (specialized openings in the exoskeleton) and into small, branched, cuticle-lined trachea (air-ducts) which transmit gases to the entire body. Aquatic vertebrates, in contrast, use gills to extract oxygen from their surrounding environment. Within the gills, lamellae (membranous plates within the gill arches) are arranged to create countercurrent flow, where blood flows in the opposite direction of water movement, thus maximizing blood oxygenation. Meanwhile, amphibians respire via the lungs and the skin. Their highly vascularized epidermis allows exchange of oxygen and carbon dioxide in a process referred to as cutaneous respiration. Finally, in terrestrial organisms, lungs minimize water evaporation by moving air through tubules where gas exchange takes place. Respiratory systems of most terrestrial organisms are most efficient because they need to maintain the high metabolic demands of endothermy and increased cellular respiration.
Figure 3. Respiratory structures of different organisms

Task 1: Measuring heart rate, blood pressure and tidal volume

The human circulatory (cardiovascular) system is composed of (1) a heart, (2) blood and (3) blood vessels. The heart pumps blood through the blood vessels to various organs, supplying the tissues with oxygen and nutrients while concomitantly removing carbon dioxide and other wastes produced by them. In this system, oxygenated blood flows away from the heart to the rest of the organs (with the exception of the lungs) and tissues through arteries. Deoxygenated blood, on the other hand, leaves the tissues and organs through veins and returns to the heart.

The cardiovascular system is divided into two parts, the systemic circuit and the pulmonary circuit. The pulmonary circuit is composed of the lungs and all the vessels that connect the lungs with the heart while the systemic circuit consists of the entire body (excluding the lungs) and the remaining vessels. The heart is also separated into right and left halves, where the right half (right atrium and ventricle) supplies blood to the pulmonary circuit and the left half (left atrium and ventricle) supplies blood to the systemic circuit. In mammals, birds and crocodiles, the septa between the atria (interatrial septum) and the ventricles (interventricular septum) prevent oxygenated and deoxygenated blood from mixing. Furthermore, multiple valves within the heart ensure that blood flows in the right direction (Fig. 4) and also prevent backflow. The atrioventricular valves (AV valves), namely the bicuspid/mitral (left) and tricuspid (right) valves, allow blood in the atria to empty into the ventricles. The semilunar valves (aortic and pulmonary), on the other hand, are located between ventricles and arteries. When the left ventricle contracts, the aortic valve opens pushing blood from the ventricle into the aorta, the main artery supplying oxygen-rich blood to the entire body (systemic circulation). The pulmonary valve, in contrast, forces blood from the right ventricle into the pulmonary artery, which transports deoxygenated blood from the heart back to the lungs (pulmonary circulation).
In summary, blood flow alternates between the pulmonary and systemic circuits. The left ventricle pump oxygenated blood into the aorta and to the rest of the body. As blood flows through tissues and organs, it becomes deoxygenated and is eventually returned to the right atrium of the heart via the venae cavae. As the right atrium contracts, deoxygenated blood flows into the right ventricle and then into the pulmonary arteries. The pulmonary arteries carry blood to the lungs, where it supplied with oxygen. This oxygenated blood is then returned to the left atrium of the heart by the pulmonary veins. Thus, with every heartbeat, a highly coordinated series of contractions push blood from the atria into the ventricles and then either to the lungs or to the rest of the body.

To accommodate the increased metabolic demands of endothermy, mammals evolved lungs that are composed of millions of alveoli that function in gas exchange. During inhalation, the diaphragm contracts, pushing down against the abdomen, which results in an increased volume of the thorax. Opening of the thorax allows air that has been inhaled through the mouth and nose to pass through the pharynx into the larynx (voice box) and then into the trachea. The trachea then bifurcates to form left and right bronchi in the left and right lung, respectively (Fig. 5).
In this task you will examine the structure and function of your circulatory and respiratory systems. You will also measure the effects of exercise on these systems. For this task, you will need to choose two people from your group whose pulse rate, blood pressure and tidal volume will be measured both before and after exercise. The other two group members will administer the tests and record the data.

Procedure 1: Measuring pulse rate

1. Find your pulse by placing your second and third fingers on the side of your inner wrist that is closest to the thumb (the radial artery passes into the hand there).
2. Press down slightly and count your pulse (the number of beats you feel) for 15 seconds. Record your results in Table 1.
3. Multiply this value by 4 to get your pulse rate in beats/minute. Record your results in the “Pulse Rate” column of Table 1.
4. Repeat steps 1-3 three times.
5. Average your results for the three trails and record this value in Table 1.

Table 1:

<table>
<thead>
<tr>
<th>Sampling time</th>
<th>Beats in 15 seconds</th>
<th>Pulse Rate (beats/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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<td>3</td>
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</tr>
<tr>
<td>AVERAGE</td>
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</tbody>
</table>
6. Measure your pulse at the common carotid artery (on either side of your neck):

\[ \text{Pulse Rate} = \underline{\text{beats/min}} \]

Procedure 2: Measuring the effect of exercise on blood pressure

For this procedure, you will work in pairs, serving as subject and experimenter.

1. Attach the inflatable cuff around his/her arm above the elbow (Fig. 6). Tuck the flap of the bag under the fold.

2. Inflate the cuff to about 200 mm Hg. This pressure will collapse the brachial artery, causing the blood flow to stop. At this point, you should not feel a pulse in your partner’s wrist.

3. Place the stethoscope over the brachial artery (underneath the cuff as shown in Figure 6). You should not hear anything with the stethoscope.

4. If the pressure has gone below 200 mm Hg, inflate the cuff again.

5. Slowly begin releasing the pressure in the cuff. As the pressure falls, the blood will begin to spurt through the artery, producing vibrations and turbulence that are audible through the stethoscope. You should hear loud, tapping sounds as the heart contracts. The pressure at which you begin hearing these sounds is termed \textbf{systolic pressure}.

\[ \text{Systolic pressure} = \underline{\text{mm Hg}} \]

6. Continue releasing the pressure from the cuff until you stop hearing any sound. As you release the pressure, more blood is going to flow through the artery and the tapping sound is going to increase. However, as the cuff pressure reaches

\[ \underline{\text{mm Hg}} \]
**Diastolic pressure** (pressure present when the heart is relaxed), the blood flow is going to stabilize and become continuous. At this point, all sounds will disappear.

**Diastolic pressure** = ______ mm Hg

7. Measure the pressure of your partner three times and record the results in Table 2.

**Note:** Do not keep the cuff inflated around your partner’s arm for more than a minute or so at a time.

Table 2:

<table>
<thead>
<tr>
<th>Sampling time</th>
<th>Student 1 Systolic</th>
<th>Student 1 Diastolic</th>
<th>Student 2 Systolic</th>
<th>Student 2 Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>AVERAGE</td>
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</tr>
</tbody>
</table>

8. Now have your partner stand up and measure his/her blood pressure three times. Record your results in Table 3.

Table 3:

<table>
<thead>
<tr>
<th>Sampling time</th>
<th>Student 1 Systolic</th>
<th>Student 1 Diastolic</th>
<th>Student 2 Systolic</th>
<th>Student 2 Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>AVERAGE</td>
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**Procedure 3. Measuring the effect of exercise on respiratory and circulatory systems**

In this exercise you will measure the effect of exercise on pulse rate, blood pressure and tidal volume. As in previous procedures, you will work in pairs. You will need to measure every parameter three times and log your results in Tables 4 and 5. Review the instructions for measuring tidal volume below.

**Procedure:**

1. Measure the resting pulse rate, blood pressure and tidal volume of your partner. Record these values in the appropriate columns of Table 4 – Student 1.
2. As your lab mate is breathing normally, before exercise, observe how many times his/her chest rises in 15 seconds.
   a. Multiply this number by 4 to get respiratory rate/minute.
   b. Record this number below
i. Student 1:
ii. Student 2:

3. Exercise for exactly 5 minutes. You can do jumping jacks, run in place or do push-ups.

4. Immediately after the 5 minutes, measure pulse rate, blood pressure and tidal volume again (3 times). Take an average of each parameter and log the results in the appropriate Table.

5. After 5 minutes of exercise, count how many times his/her chest rises in 15 minutes.
   a. Multiply this number by 4 to get respiratory rate/minute.
   b. Record this number below
      i. Student 1:
      ii. Student 2:

Measuring tidal volume

Tidal volume is defined as the amount of air a person at rest normally takes in during a single normal breath. A spirometer (Fig. 7) is an apparatus that measures the volume of air inspired and expired by the lungs. It can also measure vital capacity, which is the maximum amount of air that can be expired after a maximum inspiration. A person’s vital capacity is a good measure of his/her overall respiratory efficiency and health. Diseases such as asthma, emphysema, tuberculosis and cancer can severely decrease a person’s vital capacity.

1. Insert the sterilized mouthpiece into the spirometer and seal your mouth around the mouthpiece.

2. Inhale and exhale three times through your mouth only.
   - You will need to do this before and after exercise

3. Read the reading off of the dial and record the tidal volume (volume is measured as cubic centimeter, cc) in the appropriate Table.

Figure 7. Spirometer
Table 4: Student 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Initial pulse rate (beats/min)</th>
<th>Pulse rate after exercise (beats/min)</th>
<th>Initial blood pressure (mm Hg)</th>
<th>Blood pressure after exercise (mmHg)</th>
<th>Initial tidal volume (cc)</th>
<th>Tidal volume after exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td></td>
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<td>3</td>
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<tr>
<td>Average</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

While reclined

Blood pressure (mm Hg)_________________________________________________

While Standing

Blood pressure (mm Hg)_________________________________________________

Pulse rate (beats/min)__________________________________________________

Table 5: Student 2

<table>
<thead>
<tr>
<th>Name</th>
<th>Initial pulse rate (beats/min)</th>
<th>Pulse rate after exercise (beats/min)</th>
<th>Initial blood pressure (mm Hg)</th>
<th>Blood pressure after exercise (mmHg)</th>
<th>Initial tidal volume (cc)</th>
<th>Tidal volume after exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>Average</td>
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</tr>
</tbody>
</table>

While reclined

Blood pressure (mm Hg)_________________________________________________

While Standing

Blood pressure (mm Hg)_________________________________________________

Pulse rate (beats/min)__________________________________________________

Questions:
1. How does exercise affect pulse rate, blood pressure and tidal volume?

2. Explain what happens to the circulatory system during exercise. Include the major organs involved in your explanation.
   
i. Why does increased physical activity increase heart rate?

   ii. Why is heart rate lower in an individual who does aerobic exercise regularly?

   iii. From your study of the circulatory system, how would you describe a “fit” individual?

3. Explain what happens to the respiratory system during exercise. Include the major organs involved.

4. Plot the relationship between pulse rate and tidal volume both before and after exercise.
5. Explain the relationship between the circulatory and respiratory systems.

6. How and why does heart rate change with body position?

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**Circulatory systems and Hearts of Vertebrates:**
In the next two tasks (Tasks 2 and 3) you will examine the circulatory and respiratory systems of vertebrates from different phyla. As you observe these systems, consider the habitats that each organism is found in and the challenges that these environments present for obtaining oxygen, delivering oxygen and other nutrients to vital organs, and removing wastes. The basic differences between circulatory and respiratory systems of aquatic and terrestrial organisms are shown in Figure 8.

![Figure 8. Comparison of respiratory and circulatory systems of vertebrates](image)
NOTES:

- You will examine the same organisms for Tasks 2 and 3. Many of these organisms you have observed previously to understand the digestive and nervous systems.
- Pay special attention to the dogfish shark, fetal pig, frog and pigeon. These organisms are double injected with red and blue dyes marking the arteries and veins, respectively.

General Procedures:

1. Examine the positions of the organs listed in Tables 6 and 7 within the animal. Make sure that you understand how these organs connect to the rest of the body.
2. Once you feel comfortable, carefully cut out the hearts, gills, lungs and a piece of leopard frog skin.
   a. Examine all of these structures under a dissecting microscope.
   b. Examine the external morphology of each organ paying attention to the structures noted in Tables 6 and 7.
Cut open the heart and lungs to identify the structures noted in the Tables.

Task 2: Respiratory systems

In this task, you will examine the different respiratory structures (Table 6) in organisms belonging to various animal phyla. Sketch your observations in the space provided. Refer to the figures indicated below each organism in your Dissection Atlas.

Table 6:

<table>
<thead>
<tr>
<th>Organism</th>
<th>Main respiratory organ</th>
<th>Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perch</td>
<td><strong>Locate:</strong> Gills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operculum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gill arches and Gill rakers</td>
<td></td>
</tr>
<tr>
<td>Shark (by TA)</td>
<td><strong>Locate:</strong> Gills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gill Slits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gill arches and Gill rakers</td>
<td></td>
</tr>
</tbody>
</table>
| **Leopard frog** | **Locate:**  
| Skin  
| Lungs |  |
| **Pig (by TA)** | **Locate:**  
| Trachea  
| Lungs |  |
| **Rat** | **Locate:**  
| Lungs  
| Cut a piece of the lung and observe it under a dissecting microscope. |  |
| **Pigeon** | **Locate:**  
| Trachea  
| Lungs  
| Air sacs (if visible) |  |

**Questions:**

1. Examine the lungs of the pigeon. How do they compare to the lungs of other mammals? (Use the Figures listed in Table 6 to help you)

   a. The avian respiratory system is considered to be the most efficient. Based on this organism’s lung anatomy and what you know about gas exchange in birds (from lecture) can you explain why it is so efficient?
2. Compare and contrast the respiratory systems of the rat and pig with that of the shark and perch?

3. What is the benefit of respiring cutaneously?

   a. Are there possible disadvantages for this type of respiration? Consider the role of temperature regulation in your answer.

   b. Why are terrestrial animals unable to respire cutaneously?

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**Task 3: Circulatory systems**

In this task, you will examine the heart anatomy in animals from different phyla. Sketch your observations in the space provided. Use Figures 9a and 9b to guide you.

As you examine the various hearts, locate the following structures:

1. Ventricles (note quantity)
2. Atria (note quantity)
3. Aorta (if present)
4. Pulmonary arteries and veins (if present)
<table>
<thead>
<tr>
<th>Organism</th>
<th># of chambers in heart</th>
<th>Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep heart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rat</td>
<td></td>
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<tr>
<td>Pig (by TA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leopard frog</td>
<td></td>
<td></td>
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<tr>
<td>Perch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shark (by TA)</td>
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</tbody>
</table>

Table 7:
Questions:

1. Consider the size of the hearts you examined. How does heart size relate to the size of the animal?

   a. What does this relationship tell you about the animals’ ability to sustain normal function? (Hint: consider the main function of the heart)

2) Label the structures of the heart on the figure below.

3) Place a number on each line which represents the path of blood as it moves from the body, through the heart to the lungs, back to the heart and then to the rest of the body.
4) Consider Task 1 performed at the beginning of the lab period. How did your circulation and blood pressure change during exercise?

a. What happened to your heart as you exercised?

**Figure 10.9**
Perch (Perca flavescens): (a) External anatomy. (b) Internal viscera.
1. Anterior dorsal fin
2. Fin spine
3. Gill cleft
4. Eye
5. Mouth
6. Pectoral fin
7. Trunk
8. Caudal fin
9. Pelvic fin
10. Posterior dorsal fin

1. Spiracle (first visceral slit)
2. Eye
3. Nostril
4. Mouth
5. Gill slits
6. Gill clefs
7. Pectoral fin
8. Trunk
9. Palpebral fissure
Figure 10.11
Fetal pig: (a) Major anterior and posterior arteries. (b) Respiratory system and the heart, ventral view.
Figure 10.13
Dissection of a pigeon (Columba sp.) showing blood vessels and major viscera.