Lessons 1-15: The Revolution Begins

Lesson 1: Nicolaus Copernicus (1473 – 1543)

Many science historians think that the 16th century (the era of the 1500s) marks the beginning of the **Scientific Revolution**. That's because a lot of great scientific discoveries were made and publicized during that time, and more importantly, those scientific discoveries would seriously change the way natural philosophers thought about the world around them. Some say they can even pinpoint the very year when the Scientific Revolution began: 1543. That's because two very important books were published that year.

This statue of Nicolaus Copernicus is in Toruń, the Polish city where he was born. Note the sun is at the center of the model he is holding.

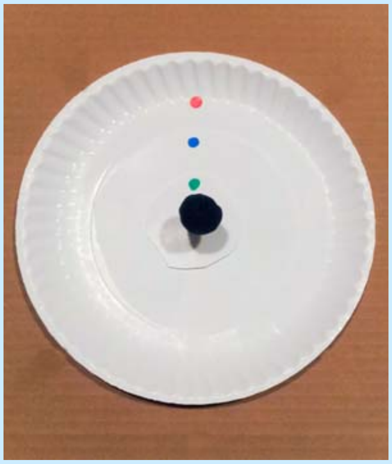
The first book I want to discuss was written by **Nicolaus** (nik uh lay' us) **Copernicus** (koh pur' nih kus), a Polish astronomer. His book was titled *On the Revolutions of the Celestial Spheres*. If you studied Aristotle, you should understand the title. Aristotle thought that the planets were embedded in spheres that revolved around the earth. While Copernicus agreed with Aristotle about the spheres, he made a significant change to Aristotle's view: he put the sun at the center of the universe, while Aristotle had put the earth at the center.

The sun-centered system, called the **heliocentric system**, was not new. If you studied a natural philosopher named Aristarchus, you might remember that he suggested a sun-centered system around 230 B.C. However, the earth-centered system, also called the **geocentric system**, was considered the correct view by almost all natural philosophers in the 16th century. As a result, what Copernicus suggested was very controversial. In fact, it was so controversial that Copernicus was hesitant to publish it. However, most of his close friends and even one of the most important men in the Roman Catholic church at that time (former Cardinal Nikolaus von Schönberg) urged him to publish it. Because of the delay, however, he died either shortly after or just as the book was published. Historians are not sure which. There is no historical evidence to back this up, but legend has it that the first printed copy of the book was placed in his arms while he lay dying. According to the legend, he awoke from his coma, looked at the book, and then died peacefully.

Why did Copernicus suggest that the sun is at the center of the universe, instead of the earth? One key reason was that he believed God created the universe, and therefore, he thought that the universe should be very orderly. In his book he wrote that the machinery of the world "has been built for us by the Best and Most Orderly Workman of all." However, the geocentric view of the universe was very messy. If you studied the work of the ancient natural philosopher known as Ptolemy (c. AD 90 – c. AD 168), you know that the geocentric view of the universe had to have several epicycles added to it in order to make it consistent with most of the observations astronomers had made. That made it very complicated, which didn't fit well with Copernicus's view of God as an "Orderly Workman." Copernicus's arrangement of the universe was more orderly and pleasing to the eye.

Also, Copernicus's arrangement could explain some observations that had always puzzled astronomers who believed in the geocentric system. For example, the planets that astronomers knew about during the 16th century were Mercury, Venus, Mars, Jupiter, and Saturn. They noticed that Mars, Jupiter, and Saturn could appear in the eastern sky right after the sun set in the west. However, Mercury and Venus never appeared in the eastern sky after sunset. When they appeared in sky after sunset, it was always in the west. That was hard to explain in the geocentric system. Do the following activity to understand why.

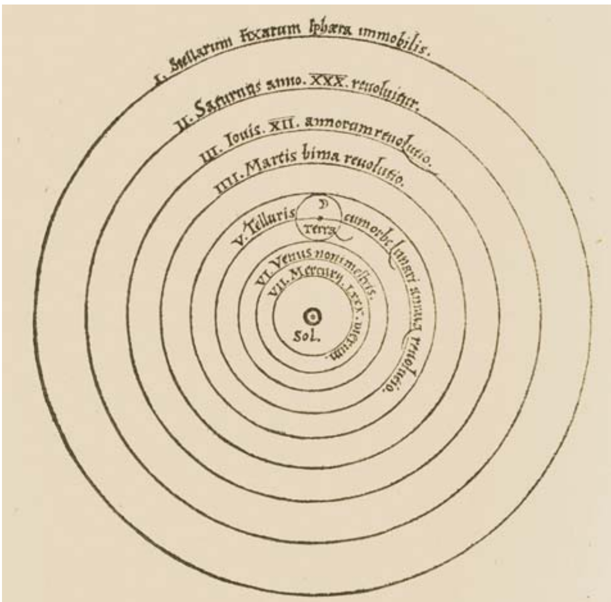
Where are Mercury and Venus?



What you will need:
- A square or rectangle of cardboard that is larger than a paper plate
- Three paper plates
- A nail
- Scissors
- Crayons, colored pencils, or markers
- A small amount of modeling clay, like Play-Doh
- An adult to help you

What you should do:
1. Draw a large red dot near the edge of one of the paper plates.
2. Cut a circle out of the other paper plate that is about half as big around as the plate.
3. Draw a large blue dot near the edge of the circle you just cut out of the paper plate.
4. Cut a circle out of the third paper plate that is about half as big around as the one you cut in step 2.
5. Draw a large green dot near the edge of that circle.
6. Have an adult help you stick a nail through the center of the square of cardboard.
7. Have an adult help you stick the paper plate with the red dot on it into the point of the nail so that the nail goes through the center of the plate.
8. Repeat step 7 for the circle with the blue dot and then the circle with the green dot.
9. Make a small ball of clay and stick it on the pointed end of the nail. Your model should now look like the picture above.
10. Let's start by thinking about a geocentric system. In that case, the ball of clay is the earth, the green dot is a planet, the blue dot is the sun, and the red dot is another planet.
11. Spin the circles so that all three dots line up above the ball of clay, as shown in the picture above.
12. Imagine the sun is setting in the west. If you are on the ball of clay (the earth) and face towards the sun (the blue dot) and wait for it to get dark, where will the planets appear when they are arranged like this? You will be facing them, so they will appear in the western sky, where the sun just set.
13. Keeping the blue dot where it is, move the red and green dots so they are below the ball of clay.
14. Once again, imagine that the sun is setting in the west. When the planets are arranged like this, where will they appear in the night sky? Think about standing on the earth (the ball of clay) and facing the sun (the blue dot). The planets will be behind you, so they will appear behind you in the eastern sky.
15. Now let's assume this is a heliocentric system. In that case, the ball is the sun, the green dot is a planet, the blue dot is earth, and the red dot is another planet.
16. Arrange the circles so all the dots are lined up like they are in the picture above.
17. Now where will the two planets appear in the sky when the sun sets? Remember, you are on the blue dot (earth). Imagine standing on that blue dot and facing the sun (the ball of clay). You are facing the green dot, so it will appear in the western sky. However, the red dot is behind you, so it will appear in the eastern sky.

18. Keeping the blue dot (the earth) where it is, move the red and green dots so they are below the ball of clay.
19. Now where will the two planets appear in the night sky right after sunset? If you think of yourself standing on the blue dot and facing the ball of clay, both dots will be in front of you, so they will appear in front of you, or in the west.
20. Play with the model a bit and notice that while the red dot can appear in the eastern sky at sunset, because you can arrange it to be behind the blue dot, the green dot cannot. There is just no way to arrange things so the green dot is behind the blue dot.
21. Keep your model, because you will use it again in the next lesson.



This drawing comes from Copernicus's book. It shows his view of the universe, with the sun (Sol) at the center, and the planets orbiting the sun in circles in the following order: Mercury (closest to the sun), Venus, earth, Mars, Jupiter, and Saturn. In his view, the stars were farthest from the sun and did not move.

Why did I have you do all that? Well, as you saw, if the earth is at the center, when the planets are arranged correctly, they can be seen in the eastern sky at sunset. Ancient astronomers could find Mars, Jupiter, and Saturn in the eastern sky at sunset during certain times of the year. However, Venus and Mercury *never* appear in the eastern sky at sunset. Mercury appears low in the western sky at sunset when it does appear, and Venus appears a bit higher in the western sky at sunset. Neither of them ever appears in the eastern sky at sunset, however.

This was a real puzzle for the geocentric system, but it made perfect sense in the heliocentric system. Venus and Mercury never appear in the eastern sky at sunset because they are between the sun and the earth. As a result, there is never a time when the sun is on one side of the earth and Mercury or Venus is on the other side. Because of this, Mercury and Venus can never be in the opposite sky as the sun. Since Mercury usually appeared lower than Venus in the western sky at sunset (closer to the sun), Copernicus decided that it was the planet closest to the sun. This provided an arrangement of planets that allowed astronomers to finally understand why finding Mercury and Venus at sunset was so different from finding the other planets that were known at the time.

LESSON REVIEW

Youngest students: Answer these questions:

1. What was controversial about Copernicus's book?

2. Fill in the blank: Copernicus put the planet _______ closest to the sun.

Older students: Make a drawing of Copernicus's view of how the sun, planets, and stars are arranged. Explain how it was different from the view of most natural philosophers of that time.

Oldest students: Do what the older students are doing. In addition, use the heliocentric system to explain why Mercury and Venus never appear in the eastern sky just after sunset.

Lesson 6: Cartilage and Bones

In the previous lesson, you learned about two mistakes that were made by Galen and corrected by Vesalius. Vesalius corrected many other mistakes made by Galen, and you'll learn about another one in this lesson. Before you learn about that, however, you probably noticed that so far, I have been talking about the skeleton. That's because the first part of Vesalius's book was all about the skeleton. Vesalius was fascinated by bone. In fact, here's how he described it at the beginning of his discussion of the skeleton:

> Bone is the hardest and driest of all parts of the human body, the most earthy and cold, and, with the sole exception of the teeth, most lacking in sensation. God, the supreme maker of things, rightly made its substance of this temperament so as to supply the entire body with a kind of foundation. For what walls and beams provide in houses, poles in tents, and keels and ribs in ships, the substance of bones provides in the fabric of man. [*On the Fabric of the Human Body*, translated by Daniel Garrison and Malcolm Hast, Book 1, Chapter 1]

So Vesalius correctly understood that bone was made by God in order to provide support for the body, much like walls and beams provide support for a house.

At the same time, however, Vesalius understood that there was more to the skeleton than just bone. In fact, the second chapter in his section on the skeleton is all about **cartilage** (kar' tih lej). To give you a good idea of what cartilage is, perform the following experiment.

Hyaline Cartilage

top (part of the knee joint)

bottom (part of the ankle joint)

What you will need:
- A fresh chicken drumstick (uncooked)
- A knife
- A cutting board
- A pushpin
- An adult to help you

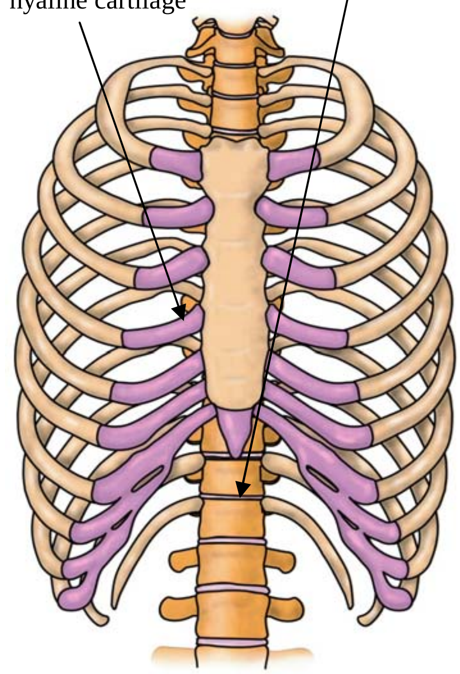
What you should do:
1. Have an adult help you remove the skin and meat from the drumstick. In the end, the only thing you want left is the large bone that is found at the very center of the drumstick. It should look something like the picture on the left.
2. This is the tibia of the chicken. If you noticed a thin bone that broke off as you were pulling the meat away from the bone, that was the fibula.
3. Look at the top end of the bone and the bottom end of the bone. Do you see that the bone is "capped" on both ends by white tissue?
4. Slide your finger along the white tissue and then along the rest of the bone. Do you feel any difference?
5. Push the pushpin into the white tissue on one end of the bone. **Be careful!** If the pushpin slips, it could stick one of your fingers! Repeat this on the white tissue at the other end of the bone.
6. Try to push the pushpin into the bone at several places where there is no white tissue. Do you notice a difference between this and what happened in step 5?
7. Clean up your mess and dispose of the chicken meat and bone as instructed by your parent/teacher.

What did you notice about the ends of the bone compared to the rest of it? If your fingers were sensitive enough, you should have noticed that the white tissue at the ends of the bone was smoother than the bone itself. In addition, you should have noticed a big difference between how the pushpin went into the white tissue and the rest of the bone. While you probably couldn't get it to sink into the bone (at least not without a lot of effort), it sank more easily into the white tissue, didn't it?

As you've probably already guessed, the white tissue on the ends of the bone is cartilage. Vesalius noted that cartilage is hard, but not nearly as hard as bone. Because it is soft, it is more flexible than bone. What does cartilage do in the skeleton? Well, there are three different kinds of cartilage, and they perform different functions in the body.

The cartilage you saw in your experiment is called **hyaline (**hi' uh lun) **cartilage**. It is found in joints. As you've probably already learned, the joints in your skeleton allow you to move and bend your body. They are the places where two bones come together and move relative to one another. Because the bones move in the joints, they rub against each other. If the joint had bone rubbing on bone, it would not move well and would quickly become painful, because bone is hard. To keep this from happening, God capped the ends of the bones in joints with hyaline cartilage. Because it is smoother and softer than bone, it moves more easily and painlessly in a joint.

Hyaline cartilage is also used to make certain structures in your body. For example, look at the ribcage illustrated on the right. The purple tissue that connects the ribs to the sternum is made of hyaline cartilage. Since the cartilage is flexible, it allows the ribcage to expand when you breathe in and contract when you breathe out.



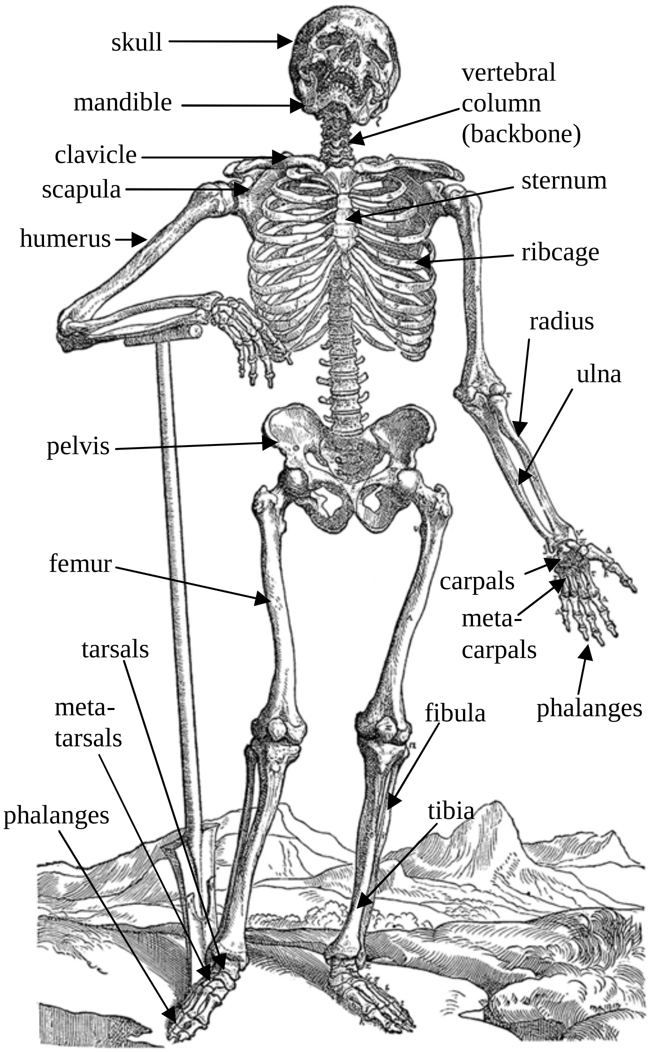
This illustration of the ribcage shows two types of cartilage.

A second type of cartilage is **fibrocartilage** (fye' broh kar' tih lej). It is found in joints that require the bones to be held together but cushioned. The individual bones in your spine (which you probably know are called vertebrae) are cushioned with fibrocartilage, as shown by the pale purple tissue in the illustration on the right.

Finally, there is **elastic cartilage**. It is the most flexible form of cartilage, and it is found on parts of the body that need to be really flexible. Grab the top of your ear. Pull down so the top of your ear bends. Now release it. What happens? Your ear pops right back into its normal shape, right? That's because your external ear (the part of the ear that is on the outside of your head) is made of elastic cartilage.

You can feel the difference between bone, hyaline cartilage, and elastic cartilage by pinching your nose right between your eyes, where it attaches to your face. That's bone between your fingers. Now pull your fingers down but keep pinching. You should eventually feel a ridge. That's the end of your nasal bone. Directly below that ridge, your nose is made of hyaline cartilage. Pull your fingers down farther and you will come to the part of your nose that wiggles. That's elastic cartilage.

There is one other thing that is interesting about cartilage. Your body can make it into bone! In fact, when you are developing inside your mother, your skeleton starts out as cartilage. However,



over time, much of it turns into bone through a process called **ossification** (os' uh fih kay' shun). This process continues most of your life, because your bones have to grow with you and change as you change. Any new bone that is formed starts out as cartilage and is then ossified into bone.

Now, of course, Vesalius's main focus in the first part of his book was bones. He had several very detailed illustrations of a complete human skeleton made, such as the one shown on the left. We aren't really sure who made most of the illustrations, and many historians think that they are the work of several different artists. Many of the illustrations are so detailed and accurate that it is thought the artists were actually present for many of the human dissections upon which the book is based.

You have probably learned about most of the bones pointed out in the illustration already, but you might want to review them again to help you remember them better. In addition, notice the bone labeled **mandible**. This is commonly called the jawbone, and it is the bone that moves up and down when you talk and chew. This drawing corrected another mistake that had been made by Galen. Based on animal dissection, Galen thought that the human mandible was made of two separate bones that were fused together. Vesalius showed it as being made from a single bone, which is correct.

LESSON REVIEW

Youngest students: Answer these questions:

1. What is the soft "cap" at the end of a bone that moves in a joint made of?

2. What does the term "ossification" mean?

Older students: List the three types of cartilage found in the human skeleton, and give examples of where each is found. In addition, explain that cartilage can be turned into bone, using the word "ossification" in your explanation.

Oldest students: Do what the older students are doing. In addition, write about how Vesalius corrected Galen when it came to the mandible. Explain what the mandible is.

NOTE: The activity in the next lesson (a challenge lesson) requires a long time for clay to dry. You should do the first five steps of the activity now so the clay can dry for a couple of days.

Lesson 9: Arteries and Veins

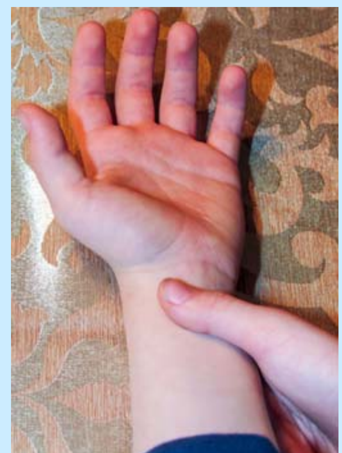
In the third part of his book, Vesalius turned his attention to the blood vessels known as **arteries** and **veins** in the body. You may have learned a bit about them already. For example, you might have learned that other natural philosophers, like Galen, noticed that there is a difference between arteries and veins. The blood they both carry looks slightly different, and the vessels themselves are different. Arteries, for example, have thicker walls than veins.

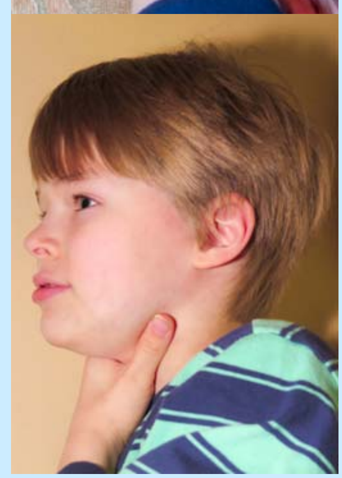
Vesalius detailed these differences, as well as some others. Do the following activity to notice two more differences between arteries and veins.

Arteries and Veins

What you will need:
- A magnifying glass
- A mirror

What you should do:

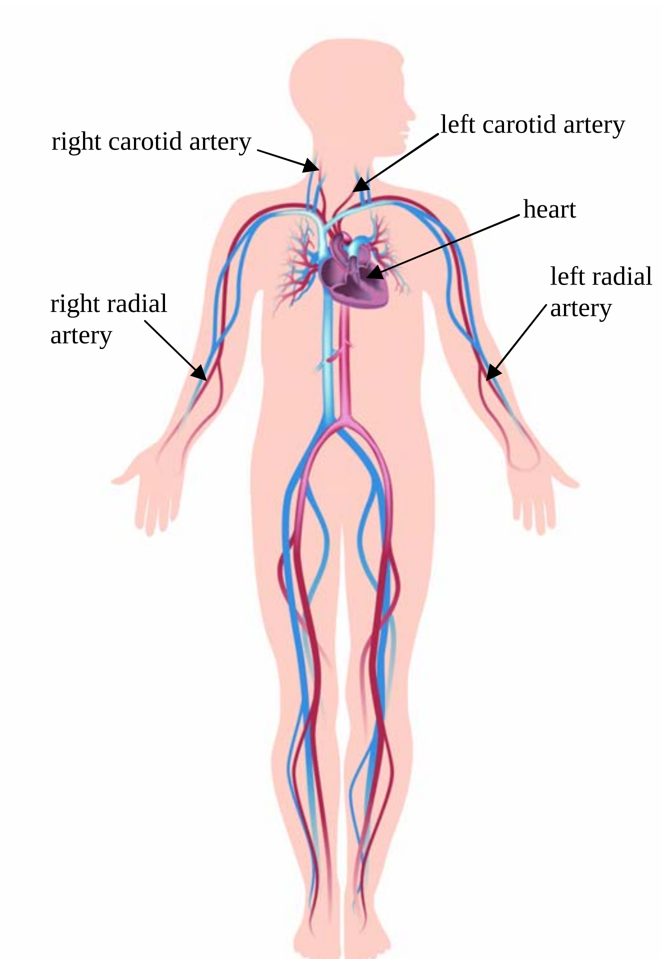




1. Put the thumb of your right hand on the left side of your left wrist, as shown in the picture on the right.
2. Push your thumb gently into your wrist and move it around until you feel the throbbing of your pulse.
3. Note where your thumb is.
4. Lift up your thumb and look at your wrist where your thumb was. Do you see anything but skin and perhaps some hair?
5. Use the magnifying glass to look more closely. Do you see anything throbbing? Probably not.
6. Note the blood vessels you see near the place your thumb felt your pulse. Are they throbbing? No.
7. Put the thumb of your left hand on the left side of your neck, as shown in the picture on the right.
8. Press down gently with your thumb and move it around until you feel the throbbing of your pulse again. This time, it should feel much stronger.
9. Use the mirror to look at that part of your neck. Do you see it throbbing? Probably not.
10. Repeat steps 7 & 8 to once again find your pulse with your left thumb.
11. Keeping your left thumb on the pulse in your neck, find the pulse in your left wrist with your right thumb, as you did in steps 1 & 2.
12. You should now be feeling a pulse on each thumb. What do you notice about them?
13. Put the magnifying glass and mirror away.

In the activity, you should have noticed that even though you could clearly feel your pulse throbbing in your wrist and neck, you couldn't see anything throbbing. In addition, even though you could see blood vessels in your wrist, they were clearly not throbbing. So what did you feel throbbing, and why couldn't you see it happening, despite the fact that you saw blood vessels in your wrist?

The answers to these questions lie in a distinction between arteries and veins. Arteries pulse, but veins do not. When you felt the pulse in your wrist, then, you were feeling an artery in your wrist. When you felt the pulse in your neck, you were feeling an artery in your neck. But why didn't you see anything pulsing in your wrist or neck? That's because of another distinction between veins and arteries: arteries are usually found deeper in the body than are the veins.



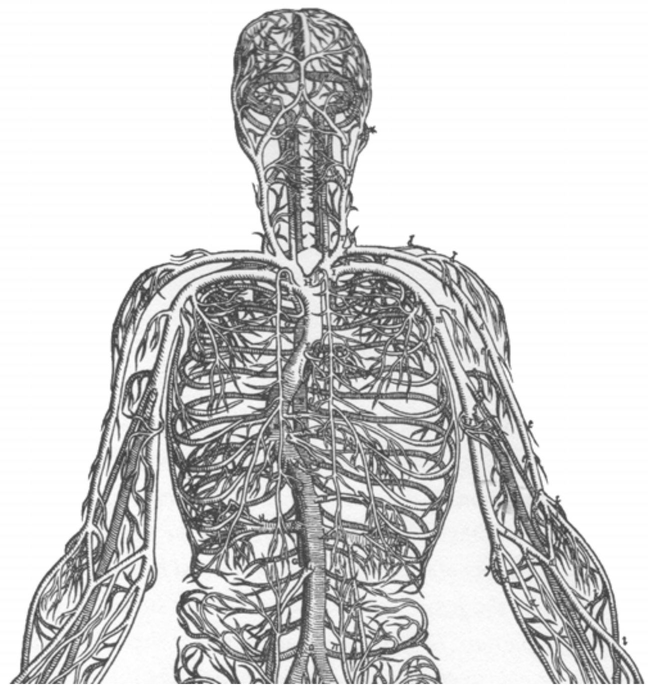
In this drawing, the veins are colored blue, and the arteries are colored red. Please note that veins are not really blue; they are dark red. They only appear to be blue because your skin distorts their color.

Do you remember learning about the difference between superficial muscles and deep muscles? The superficial muscles are closer to the skin, while the deep muscles are underneath the superficial muscles. Well, the words "superficial" and "deep" are used a lot when studying anatomy. In general, "superficial" means "closer to the surface," while "deep" means "deeper in the body." Using that terminology, then, anatomists say that arteries are deep, while veins are superficial.

What does that tell you about the blood vessels you can see through your skin? They are veins, because veins are close to the skin, while arteries are much deeper. As a result, if you push on certain parts of your skin, you can *feel* the arteries, but because they are deeper inside the body, you can't *see* them through the skin. You can see only your veins, which don't pulse. That's why you don't see your pulse.

With that knowledge under your belt, look at the drawing on the left. It shows the largest arteries (colored red) and veins (colored blue) in the human body. There are a *whole lot* more arteries and veins in the body, but the drawing shows you the major ones. When you felt the pulse in your wrist, you were feeling your **radial artery**. Specifically, you were feeling your left radial artery. Can you tell me why it is called the radial artery? Look back at the skeleton drawn on page 18. Can you tell me now? It's because this artery travels along the bone known as the radius. When you felt the pulse in your neck, you were feeling your **carotid** (kuh rot' id) **artery**. Specifically, you were feeling your left carotid artery.

When you felt both your radial and carotid arteries together, what did you notice? They were pulsing at exactly the same time, weren't they? It turns out that's true of all your arteries. They pulse together. Think about that for a moment. All your arteries are pulsing together, but your veins don't pulse at all. Also, most of your arteries are deeper in your body, and most of your veins are superficial. Finally, the blood your veins carry is dark red, while the blood your arteries carry is bright red. As a result, the system of veins in your body is very different from the system of arteries in your body. It's not surprising, then, that Vesalius (as well as other natural philosophers before and after him) thought the arteries and veins were two different systems, carrying two different kinds of blood.



This is the upper portion of Vesalius's diagram of the veins in the human body. Notice that the heart is missing.

Because of this, Vesalius discussed veins and arteries as if they were two completely different systems. Look, for example, at the drawing on the right. It is taken directly from Vesalius's book, and it represents the veins in the upper part of a person's body. Do you notice anything missing? There is no heart! Why would Vesalius have the veins in the human body drawn but leave out the heart? Think about it. The heart beats in time with the pulse. As a result, it was thought that the system of arteries in a person's body originated in the heart. However, since the veins do not pulse, and since the blood they carry is a slightly different color from the blood in arteries, it was thought that the system of veins started somewhere else.

Galen taught that the system of veins in a person's body started in the liver. Vesalius offered several arguments against this idea, but he didn't come right out and say that it was wrong. Instead, after giving his arguments against Galen's idea, he then said that he would discuss the veins in the human body as if they did start in the liver. This was because despite all the great things Vesalius had discovered about the human body, he couldn't figure out exactly how blood flowed through the body. As a result, he thought that he should teach blood flow in the traditional way and simply mention his observations that led him to question that teaching.

Of course, the arguments he listed inspired someone else to study the veins, arteries, and heart even more carefully, and eventually, blood flow in the body was figured out. So even though Vesalius didn't get it exactly right, his observations led natural philosophers down the path of eventually figuring it all out.

LESSON REVIEW

Youngest students: Answer these questions:

1. Which type of blood vessel pulses?

2. Which is usually found more superficial in the body: arteries or veins?

Older students: Make a drawing of where you found your pulse on your wrist and neck. Name the arteries that you were feeling, and explain why you don't see them pulsing through your skin. Also, explain why you can see some of your veins, but you can't see them pulsing.

Oldest students: Do what the older students are doing. In addition, try to think of a reason why arteries have thicker walls than veins. Check your answer, and correct it if it is wrong.

Lesson 12: A Trip Through the Digestive Tract

Note: All Vesalius quotes in this lesson come from *On the Fabric of the Human Body*, Volume 4, translated by William Frank Richardson and John Burd Carman, Norman Publishing, 2007. The page numbers are listed with each quote.

In the previous lesson, you learned about the organs of digestion and the distinction between the digestive tract and the rest of the digestive system. In this lesson, I want you to get a real "hands-on" view of digestion. Do the following activity, which makes up the majority of the lesson. A word of warning: the last part of this activity gets very messy!

The Digestive Tract

What you will need:
- Three slices of bread
- An old sock that you aren't going to use anymore (the longer, the better)
- A gallon-sized Ziploc bag
- White vinegar
- A ½-cup measuring cup
- Scissors
- Some nylon stockings that you can cut up
- A sink
- Someone to help you
- A camera (optional and only for those who do the "older" and "oldest" student assignments)

What you should do:
1. If you can, have someone take pictures of you as you do this activity. It will make your notebook assignment more interesting.
2. Hold the three slices of bread in your hands. In this activity, they represent the food that you eat.
3. Use your hands to smash the slices of bread until they are just one big lump of bread. This is similar to what your teeth and tongue do – they form the food into a lump, or bolus.
4. What happens to the bolus? It goes down your throat and into your esophagus. I want you to make something to represent the esophagus. Use the scissors to cut the end off the sock so that it is now a "tube" that is open on both ends.

5. Open the Ziploc bag and have your helper hold it over the sink.
6. Hold the sock vertically so that it hangs directly over the opening of the Ziploc bag, as shown in the picture on the left. At this point, the sock represents your esophagus, while the Ziploc bag represents your stomach.
7. Put the wad of bread in the top opening of the sock. It should be big enough that the bread won't just fall down the sock and into the Ziploc bag. Instead, it should get "stuck" in the sock.
8. Once the ball of bread is completely inside the sock, use your hands on the outside of the sock to work it down the sock towards the Ziploc bag. Do not put your hand inside the sock and push it.

9. Did you figure out how to do it? You need to squeeze the sock right above the ball of bread. That pushes it down, and the lower part of the sock expands to allow it to do so. Believe it or not, this is exactly how your esophagus pushes food into your stomach. Here is how Vesalius described it: "[The esophagus] takes up the food that is pushed along and as it were packed down by the vigorous movements of the tongue and sends it on downwards by expanding its parts below what is being swallowed and contracting those above." (p. 60) In other words, the esophagus gets wider below the bolus and gets smaller above the bolus. That pushes it down, just like you saw happening with the sock and the lump of bread.
10. Once the lump of bread (which has probably had some scraps broken off it as it traveled down the sock) is in the Ziploc bag, put the sock down and take the Ziploc bag from your helper.
11. The Ziploc bag represents your stomach. Before you actually use it, I want to point out that the stomach is something else on which Vesalius had to correct Galen. Galen said that the stomach was at the center of the body, but as you can see from the drawing on page 32, it is offset to the left side.
12. Add ½ a cup of white vinegar to the bag. That will represent what Vesalius calls the "juices" of the stomach.
13. Notice that space inside the Ziploc bag expands to allow the addition of things like the bread and the vinegar. Your stomach does something similar. As Vesalius put it: "In size the stomach varies greatly…This means that it adjusts its size in proportion to what is put into it; it can make room for a great deal (so that the person does not have to be perpetually eating) and yet, if offered only a little, can embrace and concoct that too." (p. 67) In other words, the stomach changes size to allow for a lot of food or a little food, depending on what you eat. When you eat just a little, you don't feel "full," because your stomach can still get bigger to allow for more food. As you eat more, you eventually feel "full," because your stomach is reaching the limits of what it can hold.
14. Zip the Ziploc bag closed.
15. Use your hands to repeatedly squeeze the bread and vinegar. This will allow the bread to mix with the vinegar, making a gross-looking concoction. Do this for several minutes so that the bread and vinegar are thoroughly mixed together. This represents something your stomach does – it churns the food to mix it with digestive juices. This turns the bolus into a liquid slurry that is usually called **chyme** (kyme).
16. Cut one of the legs off the nylon stockings, and then cut the foot end off as well so that, like the sock you used before, it is now a "tube" with openings at both ends.
17. If the sink isn't dry, dry it.
18. Hold the Ziploc bag so that the slurry of bread and vinegar collects in one of the bottom corners.
19. Have your helper hold the "tube" made from the nylon stocking so that it is in the sink and one end is open.
20. Hold the Ziploc bag so that the corner where the "chyme" has collected is right over the opening, as shown in the picture on the right.
21. Use the scissors to cut the corner of the Ziploc bag where your "chyme" has collected.
22. Allow the "chyme" to leak out of the bag and into the nylon tube. Squeeze the bag gently to make this happen more quickly. This is like what happens when the stomach pushes the chyme into the small intestine.
23. Once all the "chyme" is in the small intestine, use your hands on the outside of the nylon tube to push the "chyme" down

the nylon tube, similar to how you pushed the bolus of bread down the sock tube. This time, however, the results should be different. As you start pushing the "chyme" through the nylon tube, what happens? Some of it leaks out from the nylon tube doesn't it? That's because the nylon tube represents your small and large intestines. As the chyme passes through them, the materials that the body can use are pulled out of the chyme and sent to the liver.

24. Of course, once the chyme travels all the way through the small and large intestines, there is nothing useful left. Did you get anything to come out the other side of the nylon tube? I suspect that there was a lot of stuff that came out the other side. Whatever is left at the end of the nylon tube represents waste, which is stored in the rectum and then eliminated as feces.
25. The last part of this activity was probably pretty messy, so be sure to do a good job cleaning up after yourself and putting everything away.

Hopefully, you now have a better idea of what happens as food travels through the digestive tract. Now, before I end this lesson, I have to tell you that while the activity was a reasonable representation of what happens as you digest food, it is a bit too simplistic. For example, the juices in your stomach are acidic. Since vinegar is also acidic, it can be used to represent them. However, the juices in your stomach are a very complicated mixture of chemicals designed to help break down your food, and they are also much more strongly acidic than vinegar.

In addition, the nylon tube was *much* shorter than your intestines. The small intestine, for example, is so long that it must be twisted and curved to fit in the body. Why is it so long? Vesalius says, "[The intestine]…is coiled up in innumerable circles, spirals, and convolutions (so that the human nutriment shall not pass through too quickly and so fail to be sucked completely dry)…" (p. 96) In other words, the small intestine needs to be long because it takes time to draw all the necessary material out of the chyme. If it were short and not coiled like it is, the chyme would travel through it too quickly, and lots of useful material would never get to the body. One more thing: your intestines don't "leak" like the nylon tube did. Instead, there are intricately designed systems that interact with the chyme as it passes through the intestine and then pull out anything the body can use.

LESSON REVIEW

Youngest students: Answer these questions:

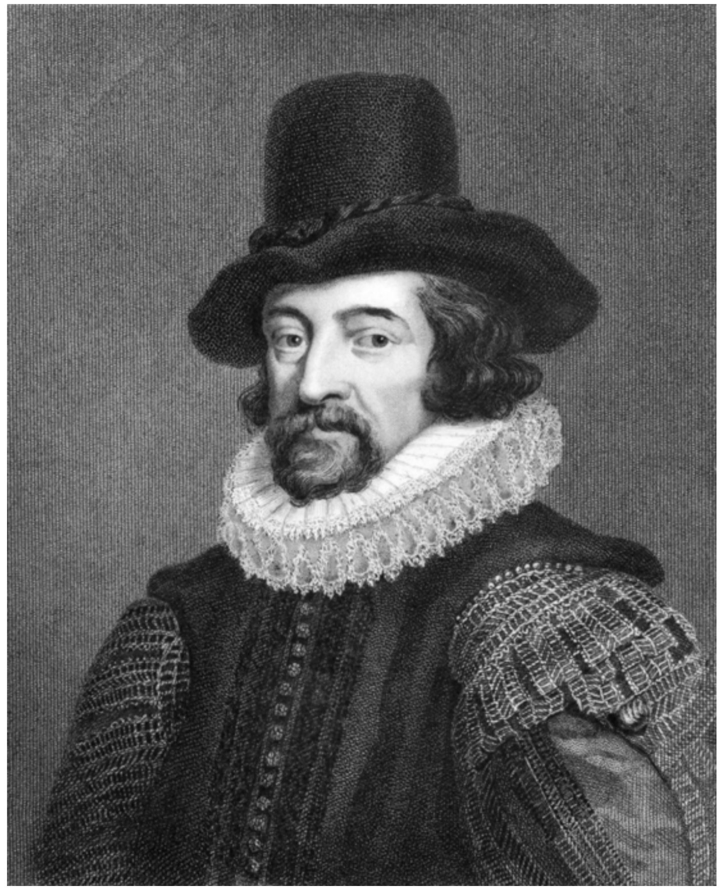
1. What is the slurry of food and juices called when it comes out of the stomach and goes to the small intestine?

2. Why are the intestines so long?

Older students: If you took pictures of the experiment, glue or tape them into your notebook, and caption the photos to explain what you are doing in each of them and why it represents a part of the digestive process. If you didn't take pictures, make drawings of what you did and caption those drawings.

Oldest students: Do what the older students are doing. In addition, write down the parts of the digestive system that weren't covered in the activity.

Lesson 35: Francis Bacon (1561 – 1626)


This is a portrait of Sir Francis Bacon.

During this time in human history, there were several natural philosophers who realized that the way to understand the world around them was to observe it. They understood that collecting evidence was more important than relying on the authorities of the past. However, there were still many who thought that all natural philosophy needed to be done with reverence to the great thinkers of the past, such as Aristotle. This is why even though Galileo and Kepler collected all sorts of evidence to support heliocentrism, there were many natural philosophers who simply would not accept it. They were unwilling to consider the idea that the great thinkers of the past could be so wrong when it came to how the universe was ordered.

Fortunately, there were men willing to fight against that mentality, and one of those men was **Sir Francis Bacon**, an English gentleman who spent most of his life in law and politics. His father was an important political figure, and Bacon decided to follow in his father's footsteps. He spent years studying and practicing law, and then he had a very successful career in politics. In fact, towards the end of his life, he was named Lord Chancellor, which was one of the highest political offices in England. Unfortunately, he eventually had to resign that position because he was convicted of accepting bribes.

Why am I talking about a lawyer and politician in this science course? Because while those professions occupied most of his time, Sir Francis Bacon also wrote about natural philosophy. In his main work, *Novum Organum Scientiarum* (*New Instrument of Science*), he argued that reverence for the great thinkers of the past was holding back our understanding of the world. In order to better understand the world, natural philosophers had to stop trying to understand things in terms of old ideas. They had to generate new ideas, and those ideas had to *start* with observations. After making observations, a natural philosopher could then begin trying to understand why the thing being observed behaved in the way that it did.

One reason Bacon argued so strongly for this method was that he knew that the world often behaved in a **counterintuitive** way. If you haven't heard that word before, it means going against what you expect. A natural philosopher might expect one result, but when he actually makes the observation, he might get a result that is quite different from what he expects. That's a counterintuitive result, and experiments often produce such results. Bacon believed that since the world can behave in a counterintuitive way, a natural philosopher shouldn't start with some ancient person's view of how the world should be. Instead, he should start with observations of how the world actually is. To give you an idea of what Bacon meant, perform the following experiment.

Oil, Water, and Salt

What you will need:
- Vegetable oil
- Water
- Salt in a saltshaker
- A glass that you can see through
- Your notebook or, for younger students, a piece of paper

What you should do:
1. Fill the glass halfway with water.
2. Add some vegetable oil to the water so that it forms a layer about 2 centimeters (1 inch) thick on top of the water.
3. In the next step, you are going to shake salt on top of the oil. Before you do that, however, I want you to predict what will happen as a result. If you are keeping a notebook, write a short description of what you have done and your prediction about what will happen when you shake the salt on the oil. If you are not keeping a notebook, tell someone what you think will happen.
4. Shake a lot of salt onto the top of the oil layer.
5. Observe what happens. You will want to observe for at least a few minutes. If you want to see the effect again, just shake more salt on the oil.
6. If you are keeping a notebook, write down what *actually* happened, and note whether or not your prediction was anywhere close to what you observed.
7. Clean up your mess and put everything away.

What happened in the experiment? You should have seen that once you added salt, small globs of oil sank to the bottom of the water, but then after a while, those same blobs rose back to the oil layer. Why did this happen? Remember that in order for something to float, it must weigh less than an equal volume of water. Oil floats because a given volume of oil weighs less than that same volume of water. A given volume of salt, however, weighs more than an equal volume of water. When you added salt to the oil, then, it added to the weight of the oil, causing it to sink.

Salt cannot dissolve in oil, but it does dissolve in water. When the glob of oil reached the bottom of the glass, the salt continued to sink until it completely passed through the glob of oil. At that point, the salt dissolved in the water. Once it had left the glob of oil, however, the oil became lighter than an equal volume of water, so it ended up floating back up to the top!

How did your prediction turn out? Don't worry. When someone told me about this experiment, I didn't make the correct prediction either. That's Sir Francis Bacon's point. I have been doing chemistry most of my adult life, and I have a PhD in the subject. Nevertheless, I couldn't predict what would happen in this situation, because the result is counterintuitive. This is why Bacon thought it was so important to start with observations. Since the world often behaves in a counterintuitive way, it doesn't make sense to attempt an understanding of it without first starting with experiments!

Because he promoted the idea that all knowledge of the world around us starts with experiments or observations, Sir Francis Bacon is often called a champion of **empiricism** (em pir' ih siz' uhm), the idea that the only way we can learn anything is through experiment or observation. However, that's not completely correct. Bacon thought that empiricism was the proper way to learn about the world around you, but he was also a Christian. As a result, he thought that the Bible was the best source of knowledge when it came to other issues, such as the meaning and purpose of life, how to be good, and what happens after you die.

Interestingly enough, while Bacon promoted the idea that the only way to properly learn about the world around you was by making observations and doing experiments, he is not actually remembered for any of the experiments he did or observations he made! This might be due, in part, to the fact that he spent a lot of time practicing law and dealing with politics. As a result, he didn't have a lot of time for experiments. Nevertheless, Bacon was in the interesting position of strongly arguing that experiments had to be an important part of natural philosophy, even though he didn't do any memorable experiments himself!

This illustration comes from Bacon's book. It shows a ship sailing through the "Pillars of Hercules," which mythology said marked the end of the well-charted ocean and the beginning of unknown waters. It symbolized the fact that he wanted natural philosophers to explore things that the ancient thinkers never dreamed of.

Despite the fact that Bacon produced no memorable experiments, he had a lasting impact on science. Remember, one reason many natural philosophers didn't want to believe in heliocentrism was because they held the great thinkers of the past in such high regard. Bacon's book was able to reduce the importance of the ancient thinkers and increase the importance of observations and experiments. As time went on, this allowed more natural philosophers to accept the heliocentric view of the universe, since there was so much evidence in its favor.

This brings me to another interesting point. While Bacon ended up making it easier for many natural philosophers to believe in heliocentrism, Bacon himself was a strong geocentrist! He believed that there was simply no way to make enough observations about the universe to understand its arrangement by observation. As a result, he believed what the Church of England taught at the time, which was geocentrism.

LESSON REVIEW

Youngest students: Answer these questions:

1. What is empiricism?

2. (Is this statement True or False?) Sir Francis Bacon believed in heliocentrism.

Older students: Explain why Bacon thought that natural philosophy should start with experiments. Also, define empiricism and explain where Bacon thought it should and should not be used.

Oldest students: Do what the older students are doing. In addition, explain why Bacon is so important to natural philosophy, despite the fact that he did no memorable experiments. Also, explain why he believed in geocentrism.