LESSON 4: THE VASCULAR SYSTEM

LEVEL ONE

So we've done the non-vascular plants-- they turned out to be just mosses and liverworts. That means most plants must be vascular. Let's find out what a vascular system is.

If we cut the stem of a vascular plant and looked at it under magnification, we would see bundles of vessels-- little "pipes" running the length of the stem.



We would see bundles of little "tubes" running down through the stem. (If you've ever eaten celery, you've run into these little bundles-- they may have gotten stuck between your teeth or on the back of your throat!) The little tubes are actually made of long plant cells stacked end-to-end, as shown in the large circle on the left. Water travels from cell to cell, by osmosis. Sometimes the water goes up and sometimes it goes down, depending on the type of tube it is, the time of year, and the weather.

There are two kinds of tubes: *xylem* (*zi-lem*) and *phloem* (*flo-em*). The xylem tubes carry water (in which minerals are dissolved) from the roots up to the leaves. Phloem tubes carry sugary water up or down, depending on the plant's current needs.

Just as in mosses and liverworts, the force that keeps the water moving through the plant

is osmosis. In vascular plants, however, we add something called transpiration. Transpiration happens in the xylem tubes, and starts out in the leaves, where a plant does something akin to exhaling. When you exhale (breathe out), your breath contains some water vapor. You can see this water vapor in your breath if you exhale on a very cold day. Or if you breathe onto a mirror or glass window, you can see this water vapor as a foggy patch on the glass. Plants breath out, too, but you can't see their breath, even on a cold day. Plants are constantly releasing oxygen and water vapor through their leaves. As the water evaporates out from the leaves, the outer cells of the leaf become dry. Then osmosis causes water from wetter cells to go to these drier cells. As those wetter cells start losing their water and becoming drier, they start drawing water from cells deeper inside the plant. This process continues downward, from the leaves down to the stems, then down into the roots. Finally, the root cells start losing their water so they must take in water from the soil around them. So it's water evaporating from the leaves that causes the roots to take in water. This process can happen fairly quickly. The fastest transpiration speed ever recorded is 75 centimeters per minute-- about the speed of a minute hand on a clock.



An interesting side note is that transpiration only works because of the electrical attraction between water molecules. Each water molecule has a positive side and a negative side. The positives and negatives attract and hold the water molecules together. You might want to imagine the water molecules as elephants in a line, trunks holding tails. When the first elephant moves, the others have to follow along. In plants, the first water molecules in the line are the ones evaporating from the leaves. All the other water molecules then follow, one after another, like the elephants. It's amazing to think that this electrical attraction is strong enough to overcome gravity!



The xylem tubes are used to transport water and minerals up from the roots into all the stems and leaves. The phloem tubes also use osmosis but don't use transpiration. The plant is actually able to push the sugary water (sap) into the phloem tubes and force it to go other places in the plant. So in the xylem tubes, liquid is pulled, and in phloem tubes the liquid is pushed.

Scientists have had trouble studying the phloem because if you try to open up the tubes to study them they stop working. Then someone had a brilliant idea. Little insects called aphids feed on the sap in the phloem. They have specialized mouth parts designed to drill into a plant stem and tap into the phloem tubes. The aphids stick their mouth parts into the phloem tubes, then just hang

there letting the sap flow in and fill them up. The phloem tubes don't stop working for the aphids-- they keep right on flowing. The brilliant idea was to let an aphid stick its mouth into the phloem, then cut its body and head off, leaving just the mouth part stuck into the phloem. (Now this would be cruel to do to a higher animal, but remember an aphid is just a little bug and doesn't have a proper brain. It's just a bug.) By using this little "window" into the phloem, the scientists could then measure things like the flow pressure and the rate of flow.





Okay, we'll go back to boring. Go back to page 15 and take a look at the chart again. We need to discuss those two bottom categories: the *monocots* and *dicots*. One of the differences between these two groups of plants is the arrangement of xylem and phloem tubes in their stems. (There are other differences, too, but we'll come to those later.) But before we go on, let's talk about these weird names. You may already know that "mono" means "one" and "di" means "two." But what in the world is a "cot"? Sorry to make things more complicated, but "cot" is actually a shortened version of this word: *cotyledon* (*cot-ell-EE-don*). Their full names are monocotyledon and dicotyledon. You can see why they usually get shortened to monocot and dicot. Now you are wondering what a cotyledon is, right? The cotyledons are the first little leaves that come out of the

seed when it begins to grow. Sometimes cotyledons are called "seed leaves." So the plants in the monocot group have only one seed leaf and the plants in the dicot group have two. It's very easy to identify monocots and dicots when they sprout. You just look at how many leaves come out of the seed.

So who really cares how many seed leaves a plant has? One, two, three... what difference does it make? The number of seed leaves isn't the most important difference between these two groups-- it's just the most obvious one. The real importance for gardeners and botanists is that these two groups have chemical and structural differences that allow us to use chemicals that kill dicots while leaving monocots unharmed. Grasses are monocots and most weeds happen to be dicots. Presto-- spray your lawn and kill the weeds without harming the grass!

Back to the subject of xylem and phloem. In monocots, the xylem and phloem are arranged in bundles that are scattered fairly randomly throughout the stem. In dicots, the bundles are arranged in a very particular pattern, in a circle around the center.



Makes me

hungry for pizza!



A vascular bundle with all the xylem tubes on one side and the phloem tubes on the other side.



The center of a dicot stem is called the *pith*. (In some dicots, the center of the pith area can be hollow. Have you ever plucked a dandelion stem and looked inside it?) In the monocot, the pith is pretty much all the stuff around the vascular bundles. The very outer layer of both a monocot and dicot stem is called the *epidermis* ("epi" means "outside"

and "dermis" means "skin'). Right inside the epidermis is the *cortex*. Notice how in the dicot the bundles are arranged so that all the phloem tubes are on the outside and all the xylem tubes are facing the inside. (Just in case you are wondering, the area around the vascular bundles in the dicot does have a name, but we didn't bother you with it. Want to know it anyway? Okay-- it's the *parenchyma*. That's why we didn't bother you with it.) In trees, the phloem produces the bark and the xylem becomes wood. (You can remember which is which if you know that <u>xylophones are made of wood</u>.)

Since the roots are part of the vascular system, and we happen to be

discussing the vascular system right now, this would be a good time to mention another difference between monocots and dicots. Monocots have *fibrous roots* and dicots have *tap roots*. If you look at the picture on the left you'll immediately understand the difference between the two. Monocots have roots that stay near the surface and spread out. Dicots have a long central root with some much smaller roots branching off. Now, not all fibrous roots and tap roots look just like this. There are lots of variations, but the idea is the same-- the fibrous roots are shallow and the tap roots run deep.

Xylem: blue Phloem: red Pith: white Cortex: green Parenchyma: yellow

Coloring suggestion:



If the roots are part of the vascular system, then do they have xylem and phloem? Yes, they do, in fact. The xylem and phloem run down the center of every root, even the very tiny ones. (Very tiny roots are called **root hairs**.) The end of the root has a "cap" on it that protects the xylem and phloem as the root pushes through the soil. The space between the xylem and phloem and the root cap is called the area of elongation. This is the area where the most growth occurs. The cells here are doing some major mitosis!

The roots are the bottom end of the vascular system. At the top end of the vascular system are the veins running through the leaves. You've seen these veins and you've probably noticed how the veins getter smaller as they go out to the edges of the leaves. What you probably don't know is that you can tell whether a plant is a monocot or dicot by looking at the pattern of the veins. Monocots have parallel

veins that all run in the same direction. Dicots have "palmate" veins that branch off . (You can see the word "palm" inside the word "palmate." Palmate means that it looks sort of like the palm of your hand, with the fingers branching out from it.) The tiny veins that branch out from the main veins can be so small that you can't even see them. We'll be looking at some microscopic veins in the next lesson. Stay tuned...







ACTIVITY 1: SOME SHORT VIDEOS TO WATCH

Here is a very short video about transpiration: http://www.youtube.com/watch?v=At1BJJDcXhk&feature=related This is a "time lapse" video showing sprouting plants growing toward light: http://www.youtube.com/watch?v=khiCoog_98E&feature=related

ACTIVITY 2: AN ONLINE GAME ABOUT ROOTS

Here is an interactive game you can play online. You identify fibrous and tap roots, then guess if they are edible or not. There is extra information about the edible roots. (Another way to access this game is through SQOOL TUBE.)

http://www.harcourtschool.com/activity/root/rootfac.html

LEVEL TWO

Roots seem to know which way is down and stems know to grow upward. This used to mystify botanists. They knew it was true but hadn't a clue why. A botany text from 1858 says, "What makes the root grow downwards into the ground, and the stem turn upwards, we no more know than why newly-hatched ducklings take to the water at once." Botanists would still be wondering about this if it were not for advancements in the field of chemistry during the 1900s. It turns out that chemicals are the key to plant growth.

Plant cells make chemicals called *hormones*. You probably recognize the word "hormone" and have undoubtedly heard it used in sentences that also contain words like "teenager" and "puberty." But hormones occur in both plants and animals and they do lots of other jobs besides controlling puberty and reproduction. In animals, hormones regulate most bodily functions including blood pressure, appetite, body temperature and the sleep cycle. In plants, hormones control the formation of roots, stems, leaves and flowers, the ripening of fruit, the amount of light a plant needs, what it does in each season of the year, how long it lives, and many other things.

A hormone called **auxin** (*ox-in*) is responsible for the growth of roots and stems. Auxin stimulates cells to grow faster and longer. Botanists have done all kinds of experiments to determine just how much auxin it takes to influence growth. They discovered that it only takes a very tiny amount, and at high levels this growth hormone is actually poisonous to plants. Yes, their own hormone can be used to poison them! And dicots are much more susceptible to this hormone poisoning than monocots are. Since most plants that we consider to be weeds in our lawns are dicots, and grass is a monocot, this natural plant hormone can actually be used as a weed-killer for lawns. Weed killers are actually dicot killers.



Part of the DNA code inside a plant cell is instructions for how to make auxin. The amount of auxin the cells produce is related to the light they receive. The lower the level of light, the more auxin will be produced (and therefore the more stimulation to grow). This is because the plant needs light. If the plant is put in an area where the light is coming from only one side, it will eventually "lean" out into the light so that it can absorb as much as possible. The cells on the dark side of the stem receive less light so they produce more auxin, which makes the cells grow longer. The cells on the light side produce less auxin and there is less growth. This uneven cell growth results in the stem tipping to one side.





If we take a close-up view of this process and simplify it down to four cells long, it would look like this. Each row has the same number of cells, but they are longer on the left side. Since the cells are basically connected together and can't slide apart very much, this results in a bend in the stem.

Here's an interesting question-- what if there isn't very much light on either side? Do both sides produce more auxin and therefore more growth? Well, if

you've ever seen seedlings grown indoors where they don't get enough light, you know the answer. The little plants get very tall but very thin. The stems are so thin that they can hardly bear the weight of their own leaves. Too much auxin produces too much cell elongation. The cells grow too long, making the stem too tall and thin.

The same kind of thing goes on in the roots, only the cells don't react to light, but rather to gravity. Gravity causes the changes in the hormone levels, instead of light. (In reduced gravity situations, such as on a space station, roots grow in all directions.) These reactions of plants to their environment are called tropisms. The response to light is called **phototropism** ("photo" means "light" and "tropism" means "turning"), and the response to gravity is called either **gravitropism** or **geotropism** ("geo" means "earth").

I am exhibiting DONOTROPISM the tendency to go towards donuts!



ACTIVITY 1: A SHORT VIDEO THAT TALKS ABOUT TROPISMS AND AUXIN

Here is a brief video that talks about tropisms and auxin. You will hear the narrator talk about positive geotropism (growing toward gravity) and negative geotropism (growing away from gravity). You will also hear the term "apical dominance." This means that the tip of the central stalk determines how the plant will grow. http://www.youtube.com/watch?v=zctM_TWg5lk

ACTIVITY 1: AN ONLINE INTERACTIVE DEMONSTRATION OF AUXINS (FOR KIDS)

Here's more discussion about auxins and a demonstration of how they control plant growth. http://www.kscience.co.uk/animations/auxin.htm

ACTIVITY 2: A TRUE/FALSE QUIZ

Write T for true, or F for false.

- 1) ____ In the word "monocot" the word "cot" is short for "cotyledon."
- 2) ____ The word "cotyledon" is the correct name for the root cap on the tip of the root.
- 3) ____ In dicots, the vascular bundles are scattered randomly throughout the stem.
- 4) ____ The beginning of transpiration is when leaves give off water.
- 5) ____ Transpiration only works because water molecules are attracted to each other.
- 6) ____ Roots aren't really part of the vascular system because they are in the soil.
- 7) ____ Water goes up the stem through xylem cells.
- 8) ____ Auxin is a plant hormone.
- 9) ____ Hormones control growth in plants.
- 10) ____ Monocots have parallel veins.
- 11) ____ The outer layer of a stem is called the pith.
- 12) ____ The first little "seed leaves" a baby plant sprouts are called the cotyledons.
- 13) ____ In dicots, the phloem cells are closer to the outside than the xylem cells are.
- 14) ____ Monocots have deep tap roots that keep them anchored in the soil.
- 15) ____ Too much auxin can kill a plant.
- 16) _____ A low level of light stops the production of auxin.
- 17) ____ Plants release both carbon dioxide and water into the air.
- 18) ____ Both monocot and dicot stems have a cortex.
- 19) ____ A dicot leaf has palmate veins.
- 20) ____ Grass would be a good example of a dicot.



LESSON 4

1) Dissect xylem tubes out of a piece of celery

You will need:

- stalk of celery
- tall glass of water
- food coloring (red or blue would be best)
- knife

• a pin, or knife tip, or scissor tip, to help remove xylem tubes (use your own discretion when giving sharp tools to your students-- many kids are very responsible with sharp tools)

• optional: magnifier

Put a fair amount of food coloring (at least 20 drops) in about two inches of water in the glass and let the celery soak in it for at least an hour (longer is better, and overnight is okay). Make a clean cut at the bottom of the celery and observe. You should see little colored dots toward the outside edge of the celery. These dots are the xylem tubes. You will notice that they are spaced exactly the same distance apart and look very orderly. This is because celery is a dicot. Cut a section of stem that is a couple inches long and then see if you can dissect out the xylem tubes from this section, using a pin or the point of a knife or scissor. (This should not be too difficult to do.)

Follow-up idea: Take a fresh stalk of celery, cut a section, and dissect out the xylem tubes. Then put just these xylem tubes into the food coloring and see what happens. Can you trace the progress of the colored water as it goes up the xylem tubes? How fast does it go?

2) Measure a growing root

You will need:

- a corn or bean seed (corn is ideal)
- a moist paper towel
- a waterproof ink pen

Sprout a corn seed by placing it in a moist paper towel and leaving it there for a few days. When the root is about half an inch long, make some pen marks on the root at very regular intervals (every 1/16 inch or so). Put the sprout back into the moist towel and leave it there overnight. The next day, look at the pen marks. Where are the marks now? Which part of the root grew the fastest? Check the root again after two days. Do you see the same result?

3) Play a trick on some roots!

You will need:

• some small dicot seeds (Radishes are ideal. Next best might be spinach, beet, carrot or lettuce, but you could use cucumber or squash seeds since they are fairly flat. Don't use grass seed.)

- some moist paper towels
- a piece of fairly stiff clear plastic (or a piece of glass with the edges taped) at least 6 inches square (15 cm), but the exact size is not important-- it could also be slightly rectangular
- some rubber bands (thinner ones are fine, thick ones might bend the plastic and cardboard)
- a piece of heavy cardboard (or thin plywood) the same size as the piece of plastic

You will make a "sandwich" of these materials, laying down the cardboard or wood backing board first, then some moist paper towels, then the radish seeds, then the clear plastic. Rubber-band this "sandwich" together tightly enough that the seeds don't fall out when you set it upright.



Put this finished panel in a window with the clear side facing the light. Make sure the paper towels stay moist. All you need to do is apply water to the edges. Osmosis should spread the moisture to the center of the towel. After the seeds have sprouted and grown about an inch (or even half an inch), turn the panel 90 degrees. When the roots have grown another inch (or half an inch), turn it 90 degrees again. Keep repeating this every day, or every other day. You will end up with a root system with a pattern of 90 degree turns. (Your pattern probably won't look exactly like this one.)

4) Make "cross section cookies"

You will need:

- cookie dough (standard sugar cookie recipe)
- food coloring
- · baking sheets

Divide the dough in half. Leave one half uncolored and then split the remaining half in half; make one half red and the other half blue. (If you don't have red and blue you could substitute other colors.)

Divide up the red and blue dough into smaller chunks and roll these chunks into long, thin cylinders about 1/4 inch thick (about 1/2 cm). These will represent the phloem (red) and the xylem (blue). Roll out the plain dough into a rectangle. Place a red and blue strip together, put them on the rectangle and then roll a short ways. Do this again, placing a red and blue cylinder next to each other (as xylem and phloem tubes are found next to each other, in a vascular bundle), then roll another short distance. Keep repeating this until the cookie is all rolled up. Then slice into thin slices and bake at 350 degrees F for 8-10 minutes. They will cook quickly. (If they start to brown, the colors won't look as bright.)

If your bundles are scattered randomly, call them monocot cookies. If your bundles are very neatly spaced in a symmetric way (like a dicot cross section) call them dicot cookies. Either way, the students should have a better understanding of what they are looking at when they see a microscopic cross section picture. Some kids have trouble visualizing what a cross section is, and they have a hard time interpreting the visual data given by a cross section picture. Perhaps this activity will help their understanding.

