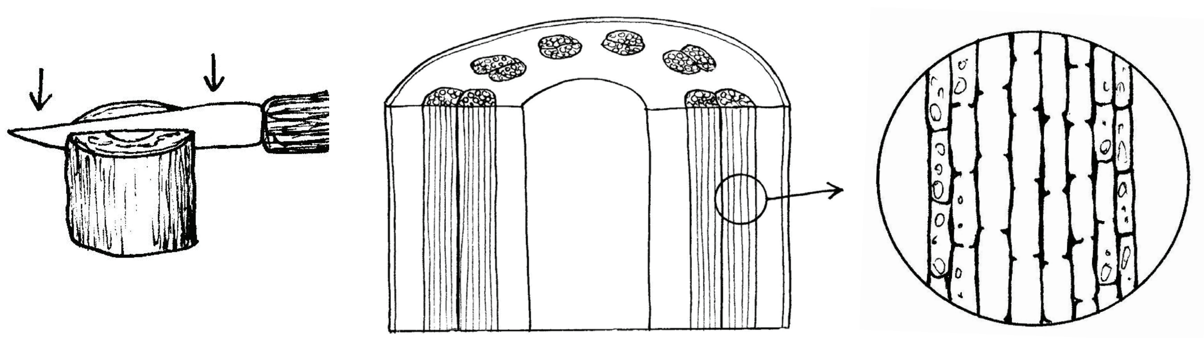
LESSON 4: THE VASCULAR SYSTEM

LEVEL ONE

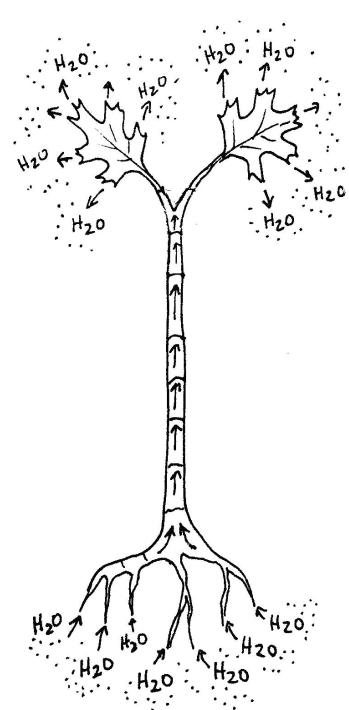
Without water, plants die very quickly. A plant must have a way to absorb water and distribute it to all its cells. Osmosis works very well for mosses and liverworts because they are small and live in areas with plenty of moisture. The cells in the center of a moss plant are still close enough to water to be able to absorb it by osmosis. Water flows right in and among all the cells.

This system doesn't work so well for vascular plants. Most vascular plants are much larger than mosses. Osmosis may work well enough for tiny plants, but not for larger ones. Also, the outside layer of cells in most vascular plants is covered with a waxy substance that protects the cells from drying out. This protection is necessary, but it does rule out relying on osmosis as the primary way to get water to the cells. (Compare regular paper to waxed paper. If you put a drop of water on regular paper, it soaks in. If you put a drop of water on waxed paper, the droplet will sit there, unable to penetrate the paper. Non-vascular plants are like the regular paper and vascular plants are like the waxed paper.) So vascular plants need a way to deliver water to all their cells.



If we cut the stem of a vascular plant and look at it under magnification, we will see bundles of vessels—little "pipes" running the length of the stem. (If you've ever eaten celery, you've met these little bundles—they may have gotten stuck between your teeth or on the back of your throat.)

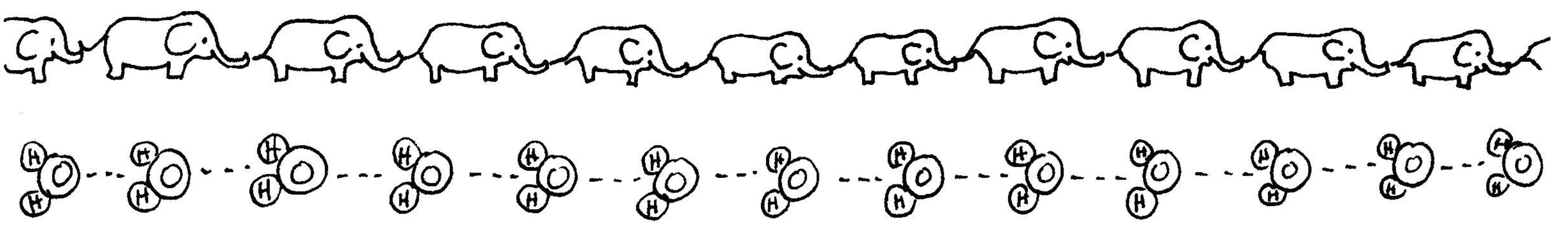
There are two kinds of bundles: ***xylem*** (*zi-lem*) and ***phloem*** (*flo-em*). The xylem tubes carry water (in which minerals are dissolved) from the roots up to the leaves. Phloem tubes carry sugary water up or down, depending on the plant's current needs.



In animals, fluids are circulated around the body by the heart, or by other muscles. Plants don't have muscles. How, then, can an oak tree move water from its roots all the way up to the highest leaves? It uses a process 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. Plants breath out, too, but you can't see their breath, even on a cold day. Plants are constantly releasing water vapor through microscopic holes in their leaves. As the water evaporates out from the leaves, the cells inside the leaves start to dry out. Water from tiny xylem tubes flows out to replenish the cells. As the water in the tiny tubes begins flowing out into the leaf, the tiny tubes begin drawing water out of the larger tubes they are attached to. When these larger tubes start to get dry, water from even larger tubes begin flowing into them. This process keeps going, with water being drawn from deeper inside the plant. Eventually this process reaches all the way down to the roots. When the root cells begin to get dry, they start taking in water from the dirt around them. The roots can't suck in water like you can from a straw. Their ability to take in water is the result of what is happening in the plant above them.

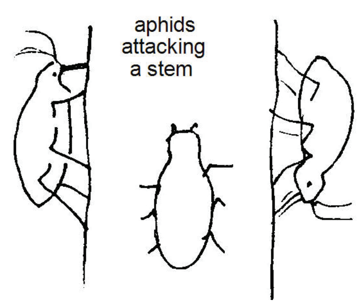
Transpiration depends on the electrical attraction between water molecules. Each water molecule has a positive side and a negative side. The positives and negatives attract and hold the water molecules together. You might want to imagine the water molecules as elephants in a line, trunks holding tails. 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!

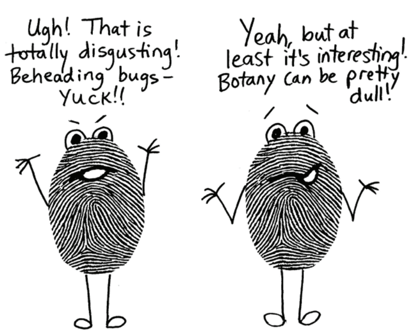


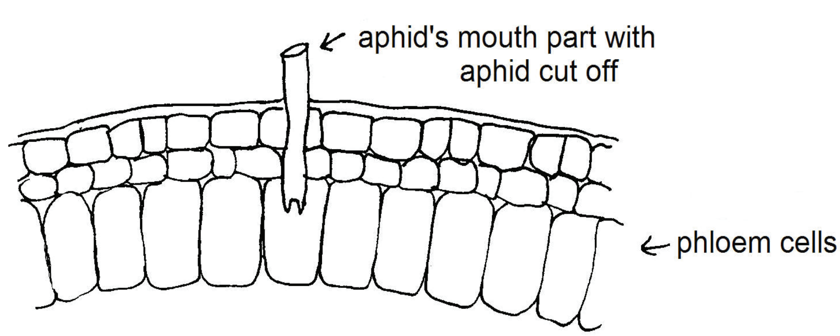
The water molecules can travel fairly quickly. The fastest transpiration speed ever recorded was about 75 centimeters per minute. That's about as fast as the minute hand on a clock sweeps around the dial.

The xylem tubes are used to transport water and minerals up from the roots into all the stems and leaves. The phloem tubes don't use transpiration. The use a form of osmosis where a lot of something goes to places where there is less of it. In this case, the "something" is sugary sap produced by the plant. The sap flows to places where there is less of it — places where it is needed.

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 sap. 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 that 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, scientists could then perform experiments.



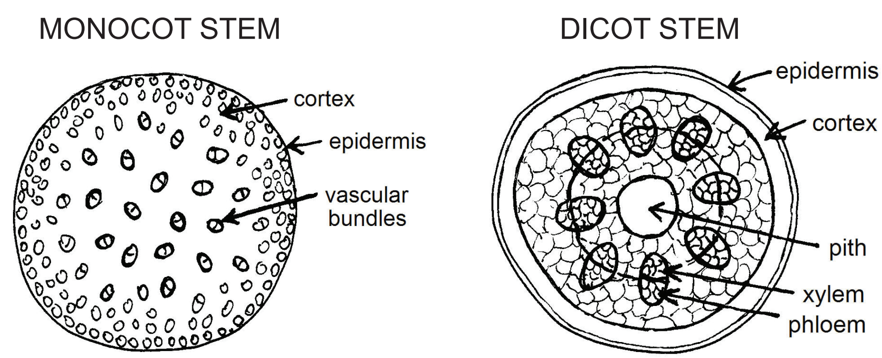




Okay, we'll go back to boring. Go back to page 15 and take a look at the chart again. We need to discuss those two bottom categories: the ***monocots*** and ***dicots***. One of the differences between these two groups of plants is the arrangement of xylem and phloem tubes in their stems. (There are other differences, too, but we'll come to those later.) 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 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. So what is a cotyledon? The cotyledons are the first little “leaves” that come out of the seed when it begins to grow. Sometimes cotyledons are called “seed leaves” because they aren’t proper green leaves. They don’t do photosynthesis. (We’ll take a closer look at cotyledons in a later chapter.) It’s very easy to identify monocots and dicots when they sprout. You just count the seed leaves. Monocots have one, dicots have two. That’s one of the easiest parts of botany.

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 differences. These differences allow us to make chemicals that kill dicots while leaving monocots unharmed. Grasses are monocots and most weeds happen to be dicots. Presto--you can spray your lawn with dicot killer and kill the weeds without harming the grass! (This is not an official endorsement of lawn chemicals, just a piece of scientific information.)

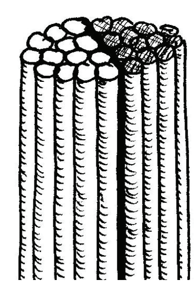
Now back to the subject of xylem and phloem. In monocots, the xylem and phloem are arranged in bundles that are scattered fairly randomly throughout the stem. In dicots, the bundles are arranged in a very particular pattern, in a circle around the center.



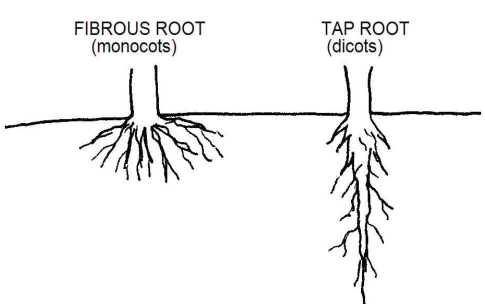
Coloring suggestion: xylem: blue, phloem: red, pith: white, cortex: green

The center of a dicot stem is called the ***pith***. (In some dicots, the center of the pith area can be hollow—a dandelion stem, for example.) In a monocot, the pith is pretty much all the stuff around the vascular bundles. The very outer layer of both a monocot and a dicot stem is called the ***epidermis*** (“epi” means “outside” and “dermis” means “skin’). Right inside the epidermis is the ***cortex***.

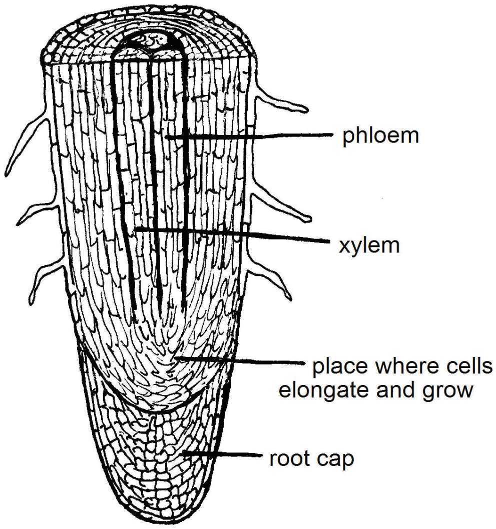
Notice how in the dicot the bundles are arranged so that all the phloem tubes are on the outside and all the xylem tubes are facing the inside. (Just in case you are wondering, the area around the vascular bundles in the dicot does have a name, but we didn’t bother you with it. Want to know it anyway? Okay--it’s called 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 xylophones are made of wood.)



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

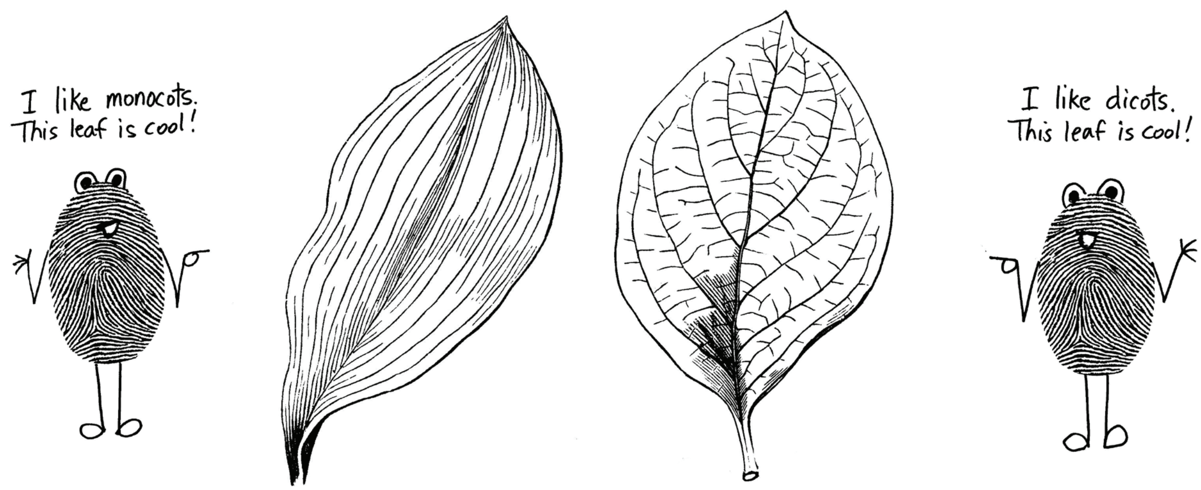


Since the roots are part of the vascular system, and we happen to be discussing the vascular system right now, this would be a good time to mention another difference between monocots and dicots. Monocots have ***fibrous roots*** and dicots have ***tap roots***. If you look at the picture on the left 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. Not all fibrous roots and tap roots look just like these. There are lots of variations, but the idea is the same. The fibrous roots are shallow and the tap roots run deep.



Since roots are part of the vascular system, they have xylem and phloem, just like stems and leaves do. Xylem and phloem tubes run down the center of every root, even the very tiny ones (***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 in this area 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 get 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 the center. 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...



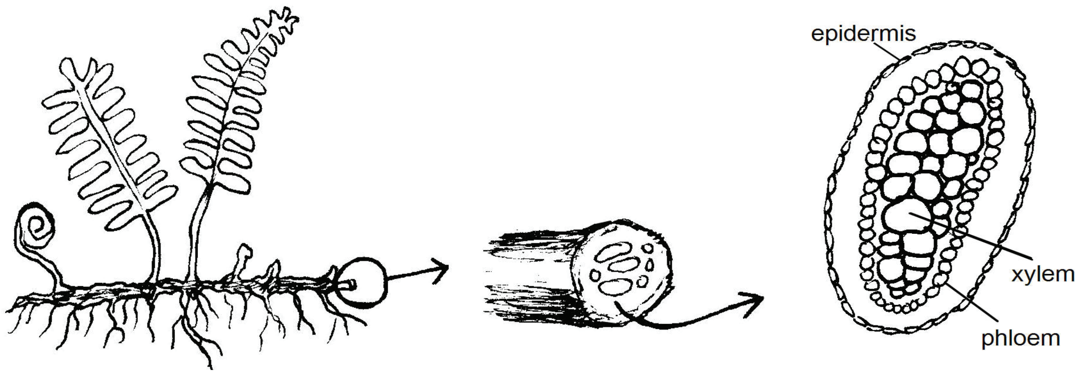
MONOCOT DICOT

If you took a careful look at the chart on page 15, you might be wondering if we are going to talk about the other branch of vascular plants: the seedless plants (which are mainly ferns). We seemed to have skipped right over them and moved to the bottom of the chart very quickly. (If you didn't notice this, you might want to take a quick look at page 15 right now.)

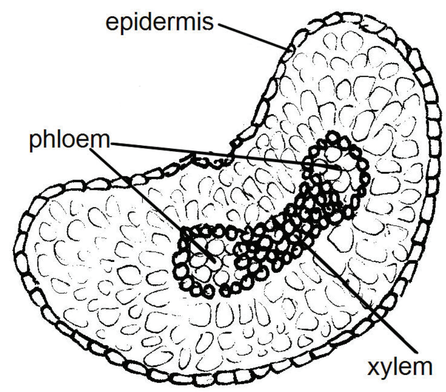
Most of what we'll learn about ferns is at the beginning of chapter 6. But let's take a quick look at the vascular system of ferns since they are indeed part of the "vascular plants" category. It would be unfair to skip over them completely.

Ferns have actual roots, stems and leaves, like all vascular plants do. However, ferns are in their own category because they do not produce seeds. They are neither monocots not dicots. They have neither fibrous roots not tap roots. Let's look at a cross section of a fern stem and compare it to the monocot and dicot cross sections we looked at on page 29.

On the left is a section from a fern plant. Fern roots are usually called rhizomes. They run along under the ground and have many fronds (leaves) sprouting up from them. If we make a cut and then look at that cut end (center picture), we'll see some tiny ovals. If we put one of those ovals under a microscope, you'll see that the oval is a vascular bundle and has xylem and phloem cells. The xylem and phloem are not arranged like the monocot or the dicot. The fern has its own arrangement.



If we cut a fern stem and look at the sliced end, it will look something like this:



It has the same parts as the monocots and dicots, but they are arranged in a different pattern. The vascular bundle looks more like a xylem banana with phloem pockets at either end. (To see an astounding color photograph of what this looks like, go to: **http://www.sciencephoto.com/media/17206/enlarge**. You'll see a micrograph—a photograph taken with a microscope.)

Not all fern stems are this shape. If you search for images of cross sections of fern stems, you'll see that they don't all look just like this one. The basic shape and pattern will be similar, though—much more like this picture than like the monocot and dicot pictures on page 29.

ACTIVITY 1: A SHORT VIDEO ABOUT TRANSPIRATION

There is a very short video about transpiration posted on the Botany playlist.

ACTIVITY 2: AN ONLINE GAME ABOUT ROOTS

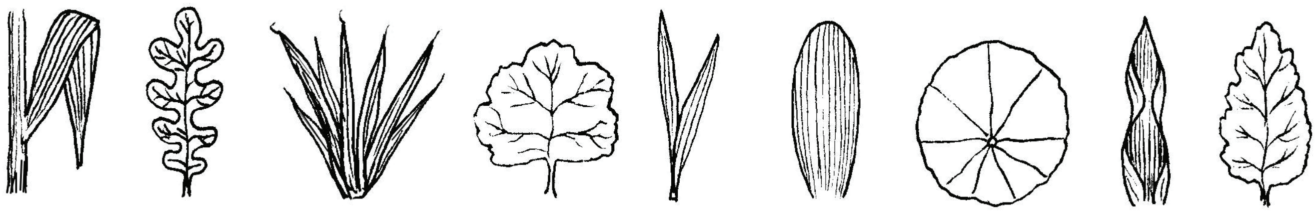
Here is an interactive game you can play online. It's just a quick game that won't take any more than 10 minutes or so. You identify fibrous and tap roots, then guess if they are edible or not. There is extra information about the edible roots. (You will need Adobe Flash Player, but it will install automatically if you don't have it. Just make sure you uncheck the boxes about installing the ad-ons.)

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

Another way to access this game is through SQOOL TUBE.

ACTIVITY 3: USE LEAF PATTERNS TO IDENTIFY MONOCOTS AND DICOTS

Look at the patterns on these leaves and guess which are monocots and which are dicots. Write "M" for monocot or "D" for dicot. (Remember, monocots have parallel veins.)



corn	oak	yucca plant	geranium	grass	orchid	nasturtium	tulip	mint
___	___	___	___	___	___	___	___	___

ACTIVITY 4: FILL IN THE GAPS

Catastrophe Cathy was asked to write some paragraphs about vascular plants. Unfortunately, she used edible writing paper and then left the page outside. Some hungry caterpillars came along and decided to have a snack. Can you fill in the words that the caterpillars ate?

VASCULAR PLANTS
by Catastrophe Cathy

Vascular plants have a system of ___ that deliver water to their cells. They are made of two types of cells: ___ and ___. The ___ tubes take water up from the roots and into the ___. This process is called ___ (The reason this process works is because of the electrical attraction between ___ molecules.) The ___ tubes carry water that has sugars in it. This sugary water can go either up or ___ depending on where it is needed. In northern climates, sap in maple trees rises from ___ up into the leaves. If you put a tube into the tree you can catch some of this sap and make ___ from it.

Most vascular plants make ___ but a few do not, such as the fern. Most vascular plants are either monocots or ___. The monocots have one ___ when they first sprout, whereas the ___ have two. The monocots have ___ veins in their leaves. The ___ have veins that resemble a palm shape.

The central part of a stem is called the ___. The outer cells are the epidermis. Just inside the epidermis is a layer of cells called the ___ In trees, the old, dead phloem cells become the bark.

Another way you can tell monocots from ___ is to look at their roots. Monocots have ___ roots and dicots have a long ___

Roots are part of the vascular system. A ___ on the end of the root tip protects it while it grows.

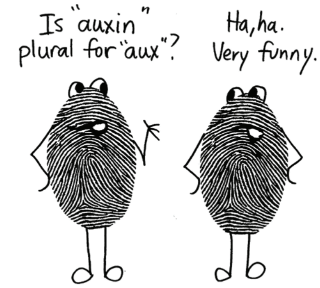
You can remember that in trees the ___ is the part we called "wood" because you know that a musical instrument called ___ is made of wood.

LEVEL TWO

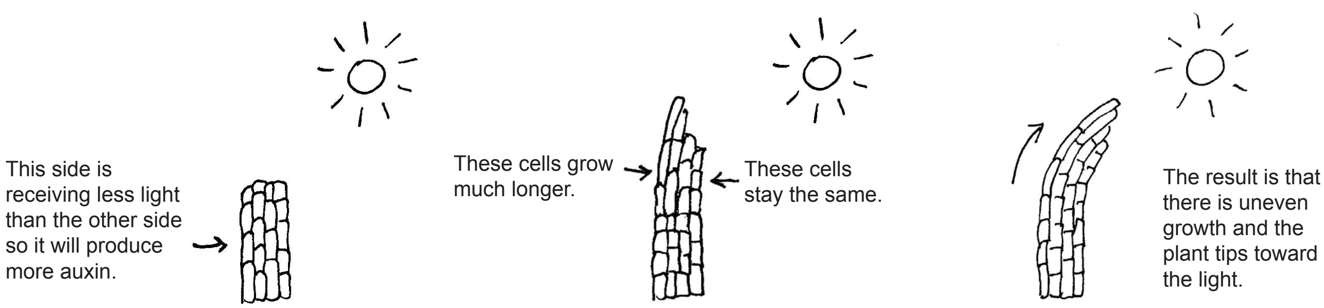
Roots seem to know which way is down and stems know to grow upward. This used to mystify botanists. They knew it was true but hadn't a clue why. A botany text from 1858 says, "What makes the root grow downwards into the ground, and the stem turn upwards, we no more know than why newly-hatched ducklings 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.

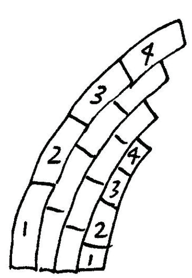
Plant cells make chemicals called ***hormones***. You probably recognize the word "hormone" and have undoubtedly heard it used in sentences that also contain words like "teenager" and "puberty." But hormones occur in both plants and animals and they do lots of other jobs besides controlling reproduction. In animals, hormones regulate most bodily functions, including blood pressure, appetite, body temperature and the sleep cycle. In plants, hormones control the formation of all the parts, 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.



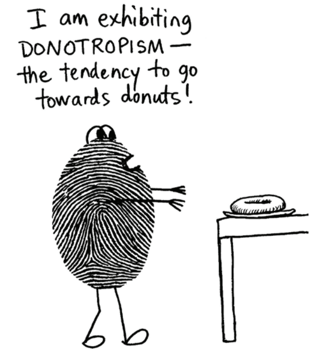
Part of the DNA code inside a plant cell is instructions for how to make auxin. The amount of auxin a cell produces is related to the amount of light it receives. The lower the level of light, the more auxin will be produced, stimulating growth. This is because the plant needs light. If the plant is 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 light 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 only four cells, it would look something like this drawing. Each row has the same number of cells, but they are longer on the left side. Since the cells are basically connected 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. (Plants like this usually don't survive.)



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. When a plant reacts to its environment, it's called ***tropism***. The word "tropo" means "to turn or change." The response to light is called ***phototropism*** ("photo" means "light"), and the response to gravity is called either ***gravitropism*** or ***geotropism*** ("geo" means "earth").

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

Watch 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. The video is posted on the Botany playlist.

ACTIVITY 2: 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 3: 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 "exhale" 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) ___ Geotropism is a plant's reaction to the pH of the soil.
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 1

Level 1

Activity 5: (Crossword puzzle)

ACROSS: 1) chloroplasts 2) membrane 3) daughters 4) photosynthesis 5) elongation
6) energy 7) water 8) nucleus 9) chlorophyll 10) carbon dioxide

DOWN: 1) light 2) mitosis 3) eat 4) sugar 5) oxygen 6) DNA 7) vacuole 8) respiration 9) wall

Activity 6: Compare your drawing to the one in the chapter

Activity 7: 1)D 2)A 3)B 4)F 5)H 6)C 7)E 8)G

Level 2

Activity 1: 1)J 2)I 3)B 4)F 5)G 6)D 7)A 8)H 9)C 10)E

Activity 2: 1)B 2)F 3)C 4)G 5)A 6)D 7)H 8)E

Activity 3: 1) Answers will vary. 2) ATP 3) no 4) respiration 5) no 6) split water molecules
7) light 8) carbon dioxide and water 9) the P 10) light phase 11) RuDP
12) there would be no photosynthesis 13) no 14) magnesium

LESSON 2

Level 1

Activity 1: 1) Muehlenberg 2) Engelmann 3) Michaux 4) Kellogg

Activity 3: 1)C 2)G 3)B 4)H 5)I 6)F 7)J 8)E 9)A 10)D

Activity 4: Answers will vary.

Level 2

Activity 1: 1) H 2) A 3) I 4) D 5) C 6) F 7) J 8) B 9) G 10) E

Activity 3: 1) China, 2) Italy, 3) Virginia, 4) India, 5) Tasmania, 6) Brazil, 7) Australia

Activity 4: The prunus fruits all have one large seed that we sometimes call a "pit."
1) acorn squash (same species), 2) tomato (yam is monocot), 3) chestnut (both are Fagales)

LESSON 3

Level 2

Activity 2: 1) zygote 2) osmosis 3) sporophyte 4) bryophyte 5) thallus 6) gametophyte
7) gemma 8) wort 9) vascular 10) alternation of generations

Stupid plant joke missing words: moss, liverwort, argument, a, bryo-phyte (sounds like "fight")

LESSON 4

Level 1

Activity 3: The monocots are: corn, yucca, grass, orchid, tulip. The dicots are: oak, geranium, nasturtium, mint.

Activity 4: Vascular plants have a system of [pipes/tubes] that deliver water to their cells. They are made of two types of cells: [xylem] and [phloem]. The [xylem] tubes take water up from the roots and into the [leaves]. This process is called [transpiration]. (The reason this process works is because of the electrical attraction between [water] molecules.) The [phloem] tubes carry water that has sugars in it. This sugary water can go either up or [down] depending on where it is needed. In northern climates, sap in maple trees rises from [the roots] up into the leaves. If you put a tube into the tree you can catch some of this sap and make [maple syrup] from it.

Most vascular plants make [seeds] but a few do not, such as the fern. Most vascular plants are either monocots or [dicots]. The monocots have one [seed leaf] when they first sprout, whereas the [dicots] have two. The monocots have [parallel] veins in their leaves. The [dicots] have veins that resemble a palm shape.

The central part of a stem is called the [pith]. The outer cells are the epidermis. Just inside the epidermis is a layer of cells called the [cortex], In trees, the old, dead phloem cells become the bark.

LESSON 4, Level 1, Activity 4 continued:

Another way you can tell monocots from [dicots] is to look at their roots. Monocots have [fibrous] roots and dicots have a long [tap roots]. Roots are part of the vascular system. A [cap] on the end of the root tip protects it while it grows. You can remember that in trees the [xylem] is the part we called "wood" because you know that a musical instrument called [the xylophone] is made of wood.

Level 2

Activity 3: 1)T 2)F 3)F 4)T 5)T 6)F 7)T 8)T 9)T 10)T 11)F 12)T 13)T 14)F 15)T 16)F 17)F 18)T 19)T 20)F

LESSON 5

Level 1

Activity 2: We counted 45 rings (including the central "dot" which would have been the first year). The tree was 34 years old when a very wet summer occurred.

Level 2

Activity 1: (Crossword puzzle)

ACROSS: 2) carotene 6) stomata 7) lobed 11) abscission 12) whorl 14) pinnate 17) xanthophyll 21) apex 22) phloem 24) guard 25) petiole 26) xylem

DOWN: 1) deciduous 3) anthocyanin 4) cuticle 5) cambium 6) serrated 8) dendrochronology 9) margin 10) cordate 13) deltoid 14) palmate 15) woody 16) palisade

LESSON 6

Level 1

Activity 2: FRUIT: tomato, peas, beans, pumpkin, corn, zucchini, cucumber, pepper, eggplant, olive, avocado
VEGETABLE: spinach, lettuce, carrots, kale, cabbage, broccoli, beets, asparagus, celery, parsley, rhubarb

Activity 5: 1) zygote 2) stamen 3) anther 4) pistil 5) angio 6) style 7) fruit 8) embryo 9) harden 10) fern 11) filament 12) share 13) rhizome 14) receptacle 15) the wind 16) prothallus 17) double Stupid joke: "Why did the botany student fail the test? He forgot the anthers!"

Activity 6: 1) photosynthesis 2) respiration 3) CO2, H2), 1, O2, H2O 4) mitosis 5) nucleus 6) vascular 7) angiosperms, gymnosperms 8) monocot 9) moss/liverwort/bryophyte 10) osmosis 11) spores 12) male, female 13) xylem, phloem 14) pith 15) woody, herbaceous 16) fibrous 17) parallel 18) xylem cells 19) phloem cells 20) phloem 21) cambium 22) rhizome 23) petiole 24) apex 25) stomata 26) palisade 27) c 28) b 29) guard cells 30) dendrochronology

Level 2

Activity 1: 1) stigma (is female part, others are male parts) 2) almond (is dry fruit, others are succulents)
3) tomato (is a fruit, others are vegetables) 4) peanut (is a legume, others are nuts)
5) filament (is male part, others are female parts) 6) cabbage (is a leaf, others are stems)
7) apple (has multiple seeds, others have just one) 8) pineapple (is a multiple fruit, others simple)
9) dandelion (is not a legume like the others) 10) potato (is a tuber, not a true root like the others)
11) strawberry (not a true berry like the others) 12) sago (is a gymnosperm, others are angiosperms)
13) bark (is dead, the other tissues are living) 14) geranium (is a dicot, others are monocots)
15) serrated (describes edge of leaf, others describe placement of leaves on stem)
16) gemma (part of a moss, not a fern) 17) lamina (name for leaf, other words describe shapes)
18) moss (not vascular, others are vascular) 19) chlorophyll (is a molecule, others are organelles)
20) sodium (is not an element found in chlorophyll molecule)

LESSON 4

1) DISSECT XYLEM TUBES OUT OF A PIECE OF CELERY

You will need:
- Celery
- A 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 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 small section of stem see if you can dissect out the xylem tubes using a pin or the point of a knife or scissor. (This should not be too difficult to do.)

Follow-up ideas:

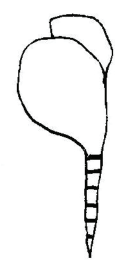
1) Take a fresh stalk of celery, cut a section, and dissect out the xylem tubes. Then put just these xylem tubes into the food coloring and see what happens. Can you trace the progress of the colored water as it goes up the xylem tubes? How fast does it go?

2) Set up a celery transpiration race. Find two stalks of celery that are as idential as possible—same number and size of leaves, same width and length. (You might have to pull a few leaves off one of them to make them the same.) Put each in a glass of water that contains food coloring. Let one celery be the control and put it in a quite area, undisturbed. Set the other celery in front of a fan or a hair dryer set on low. Predict ahead of time what should happen and why.

3) Use other types of stems. Does the dye highlight the xylem tissue? How are the bundles arranged?

2) MEASURE A GROWING ROOT

You will need:
- A corn or bean seed (corn is ideal)
- A moist paper towel
- A waterproof ink pen



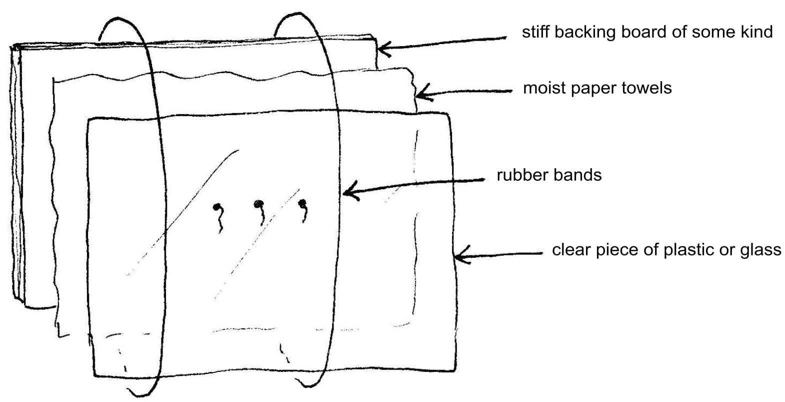
Sprout a corn seed by placing it in a moist paper towel and leaving it there for a few days. When the root is about half an inch long, make some pen marks on the root at very regular intervals (every 1/16 inch or so). Put the sprout back into the moist towel and leave it there overnight. The next day, 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? (Results should suggest that most of the growth occurs at the tip.)

3) PLAY A TRICK ON SOME ROOTS!

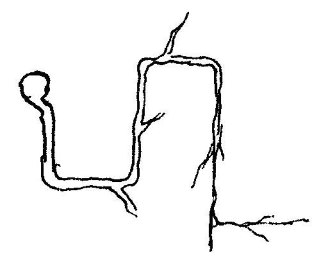
You will need:
- Some small dicot seeds (Radishes are ideal. Next best might be spinach, beet, carrot or lettuce, but you could use cucumber or squash seeds since they are fairly flat. Don't use grass seed.)
- Some moist paper towels
- A piece of fairly stiff clear plastic (or a piece of glass with the edges taped) at least 6 inches square (15 cm), but the exact size is not important—it could also be slightly rectangular

• Rubber bands
• 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 (2 cm), turn the panel 90 degrees. When the roots have grown another inch (2 cm), 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. The root always knows which direction is down!



What would happen if seeds were grown in a gravity-free environment? (This experiment was performed inside the space shuttle. The roots grew in random directions.)

4) MAKE VASCULAR STEM COOKIES

You will need:

• Cookie dough (standard sugar cookie recipe, or your own adaptation if you have students with special nutritional requirements)
• Food coloring

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 it just a bit. 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 it a bit more. Keep repeating this until the cookie is all rolled up. Then cut the roll 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 cross section picture. Some kids have trouble visualizing what a cross section is. This activity should help their understanding.