Introduction

Like many good things in life, the inspiration for Bottle Biology arose unexpectedly — in this case from a pile of autumn leaves. While raking his garden, Paul Williams, a professor of Plant Pathology at the University of Wisconsin-Madison, asked himself what might be going on in the middle of the large compost pile he was creating. Why not put some of the leaves in an empty soda bottle and watch them to find out, he wondered. The result: The Decomposition Column and the beginning of Bottle Biology.

Hands-on, eyes-on, noses-on, mouths-on, minds-on: If you combine science with a soda bottle, what do you get? Two liter soda pop bottles orbiting Earth with NASA, might be one result. But did you know you can use bottles to create an ecosystem, explore the concept of niche, and model a lakeshore? You may have made a tornado in a bottle but have you used bottles to pickle your own cabbage? Have you made a bottle microscope, a bottle timer or bottle tweezers?

This website is full of ways you can use recyclable containers to learn and teach about science and the environment. The projects on this website promote science as a tool everyone can use to explore the world. These explorations can be integrated with history, art, music and other creative endeavors.

Out of the trash, into the classroom: You'll find the inexpensive materials you need for Bottle Biology in your trash can, backyard, supermarket, neighborhood park and recycling center.

Bottle Biology Tips

Make your own bottle constructions before introducing them to others: Cutting and hanging bottles is easy but a little practice can vastly improve your technique. By making constructions before you introduce them to a classroom or a workshop, you can work out the details and any unexpected hitches. You will also provide your audience with a model to aspire to, or even surpass.

Do Bottle Biology in cooperative groups: The mechanics of cutting bottles, the planning and filling of columns, and the observation and exploration of each project are ideal jobs for two or three students working together. Group projects can foster student discussion and also cut down on the number of columns taking up precious space.

Allow plenty of time for group discussion: These Bottle Biology projects have been developed to provoke discussion on a wide range of topics. Before diving into a construction, lead a class discussion about issues raised by the project, and what in particular you and your students would like to explore.

Reserve your right not to answer a good question: You can use Bottle Biology to promote the idea that science is not a lengthy list of facts, but a tool for exploration. When students ask questions, encourage them to think about the information they have, to predict possible answers, and to form their own methods of inquiry.

Improvise: Bottle Biology should be adapted to fit specific needs and interests. Some techniques will need to be modified as the world of plastic containers continues to evolve. Also, don't worry about repeating Bottle Biology activities. Every time you do an activity, you'll discover something new.

Bottle Biology is for teachers, parents and all students. Anyone can use soda bottles and other items from unexpected places to nurture new ideas and explore exciting science, in and out of the classroom.

Adapt Bottle Biology for any skill level: Bottle Biology is currently used in classrooms from kindergarten to college. Most of the activities can be adapted to teach a wide variety of subjects at different levels. Slightly more involved constructions and emphasize forming hypotheses and experimental design. Decomposition Column and Kimchee focus on observation and exploration and are easy to construct.

Bottle Basics

With a pair of scissors and your imagination, you can turn plastic soda bottles into tools for exploring the world.

- Anatomy
- Species
- Bottle Care
- Collecting Bottles
- Removing Labels

- Cutting Bottles
- Building Blocks
- Making Holes
- Joining Bottles
- Hanging Bottles

Anatomy: The first step in any construction project is to understand your materials. Almost all soda bottles taper at the shoulder and hip. Because of this shape, you can "nest" the tapered ends inside the straight sides of another bottle.

Species: Not all bottles are exactly the same. Some have thinner, gently tapering bodies, while others are wider with rounder shoulders. Bottles that appear the same may vary by a millimeter or two in diameter and this can make a difference. These differences will affect how your bottle constructions fit together. When you are collecting bottles to construct the columns, look for bottles with similar shapes and sizes. One way to guarantee this is to use bottles of the same brand of beverage. Most bottles work equally well in bottle biology constructions. Constructions can also utilize additional common plastic containers such as deli containers, cottage cheese dishes or other similar shaped plastic containers.

Bottle care: Creased and bent bottles have weak spots. Use bottles without dents so your columns are strong and durable. Also, remember that air expands and contracts with temperature changes. If you carry sealed bottles from a warm room to a cold car, your bottles will crumple. When transporting bottles, keep the caps off or loosely attached to allow air exchange.

Collecting bottles: For better or for worse, plastic soda bottles are not difficult to come by. If your plans involve many bottles, however, you may need to organize some type of bottle collection activity. Ask students to bring in bottles. Some teachers use extra credit points or other incentives to encourage students to contribute bottles. Your community recycling center is also an excellent source.

Removing labels: Once you have collected bottles, you will need to remove the labels. Most labels are attached by a heat-sensitive glue. Resist ripping off the labels, or you may end up with many small pieces of label stuck to the bottle.

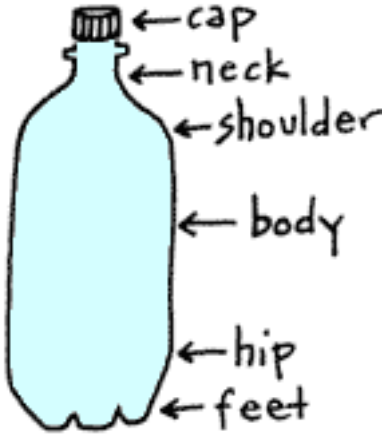
An inexpensive hair dryer will remove the label and base from your bottle in a jiffy. Set the hair dryer on low. Hold your bottle about 10 cm away from a blowing nozzle, and move it rapidly up and down so that the air warms the seam of the label. Gently pull on an edge of the label until you feel the glue begin to give. This takes about 4 seconds.

Bottles are made from PETE (polyethylene teraphthalate). This is a generally inert plastic, but it will warp easily if overheated, so keep the bottle moving. Leave the bottle cap on or fill the bottle with water first to prevent warping.

A quieter way to remove the label and base from your bottle is to fill it about 1/4 full with very warm water (49 - 65 degrees C or 120 - 150 degrees F; hotter than this may warp your bottle). Cap the bottle in order to retain pressure inside so the bottle doesn't crumple, and tip it on its side to warm the glued seam. After a few seconds tug on a label corner.

Glue is often left on the bottle after the label is removed. If this offends your aesthetic sensibilities, rub a small amount of peanut butter onto the glue. As you rub, the oil in the peanut butter causes the glue to ball up so it can be pulled off (no kidding, crunchy works best). If you are really into the clean bottle look, wash your bottles with soap and warm water and dry them – they'll shine!

Cutting bottles: There are only so many ways you can cut a bottle; above the shoulder, below the shoulder, above the hip and below the hip, and only so many things you can do with each piece you create.



The easiest way to cut a bottle is to cut along a marked line with scissors. Once you have decided where to cut a bottle, place it on its side in the corner of an empty drawer, tray, or box — shallow cardboard flats and computer printer paper box tops work well. Brace the bottom of the bottle against a corner of the box. Rest a pen or wax pencil against the edge of the box, so the tip rests against the bottle where you want your cutting line. Slowly turn the bottle. Two people make this job easy.

We use erasable felt tip pens or wax pencils to make cutting lines because they don't smear and can be easily removed. Make sure your bottle is dry before marking. If you want lines that last, use a permanent marker.

Draw all of your cutting lines first (it's hard to do once the bottles have been cut), and then use a cutting blade to begin the bottle cuts. You only need a cut big enough to insert the top arm of a scissors. You will make a smoother cut with the top arm of the scissors inside the bottle, so insert the top arm into your initial cut and snip around, following your cutting line. Don't worry about ragged edges; they are easy to snip away with scissors once the bottle is in pieces.

Building Blocks*: Step-by-step bottle constructions specific to each Column Investigation. Bottle Biology investigations can and should go beyond this book. Just like Legos™ or Tinker Toys™ , Bottle Biology Building Blocks can be combined in an infinite variety of ways. Each possible combination is helpful for exploring different concepts.

*Building Blocks concept has been adapted from the Families Understanding Nature Project (F.U.N.) by Heather Putnam, 2002

Making holes: The size, shape and number of air holes you put in a bottle column is part of your experiment – there's no wrong way to do it. Keep in mind, however, that with the Decomposition Columns, you will most likely want holes small enough to keep fruit flies and other insects inside the bottle and out of your classroom. You will want adequate ventilation for plants, insects and other life, so make four or five "stars" of holes (see picture) – but keep them small.

A poke is a needle, pin, or nail, with the blunt end stuck into a wooden handle. Diaper pins, safety pins, upholstery needles and compass points all work as well.

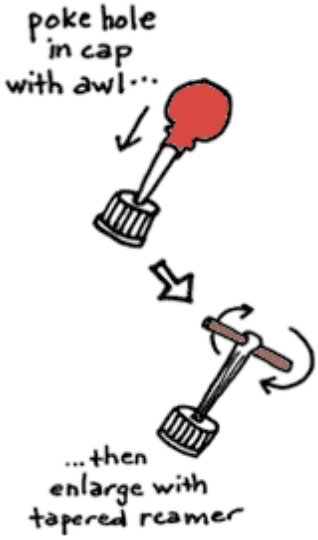
For needle pokes, you needn't cut off the eye of the needle. For large nail poke handles, you may want to use a small dowel, and will need to drill a hole just a bit smaller than the nail into one end of the dowel in which to insert the cut end of the nail.

Hot pokes or soldering irons are useful for creating larger holes or making holes near the neck or base of the bottle where the plastic is thicker. Very large holes can be made by heating the open end of a pyrex test tube in a gas torch or Bunsen burner and pushing the tube through the bottle. Obviously, burns are a hazard of this technique. Also, plastic smokes a bit as it melts, so an entire class using hot pokes can create a real stink. Be sure you let the pokes cool off in a safe place.

A woodworking awl is quite effective at making small holes in bottles and bottle caps. If an awl is pushed all the way through a surface, it will create a hole several millimeters wide, enough for fruit flies to pass through. Awls are particularly sharp, so place a piece of wood underneath whatever you are poking and watch your fingers.

A tapered reamer, available at the hardware store, is excellent for enlarging holes. Normally used for creating holes in sheet metal, it will easily make a hole in plastic up to 1 cm in diameter. Since the reamer has a blunt tip, begin your hole with an awl or poke.

A paper punch will easily penetrate a soda bottle or film can. Different punches create different sized and shaped holes. Since the holes are quite large, punches are not recommended for investigations that you want to keep moisture or small insects from either entering or existing the investigation.



If you are preparing materials for many students, a drill press is the most efficient tool if you have access to one. Regular spiral fluted drill bits work well, and sharp "brad" pointed bits will wander less on the surface of the plastic as you start your hole. For holes larger than 1 cm, flat wood bits with spurs on the blade tips work best.

Pieces of old hosiery or no-see-um tent netting, plastic window screening or nylon bridal veil material will keep out even the smallest flies and can be used to cover window bottles. Use double-sided sticky tape to attach netting by surrounding the hole with tape and pressing on an appropriately sized piece of netting. Alternately, 5-minute epoxy glues work well.

Joining bottles: Tape is the best material for joining bottles and will help columns survive handling in the classroom. However, not all tape is created equal.

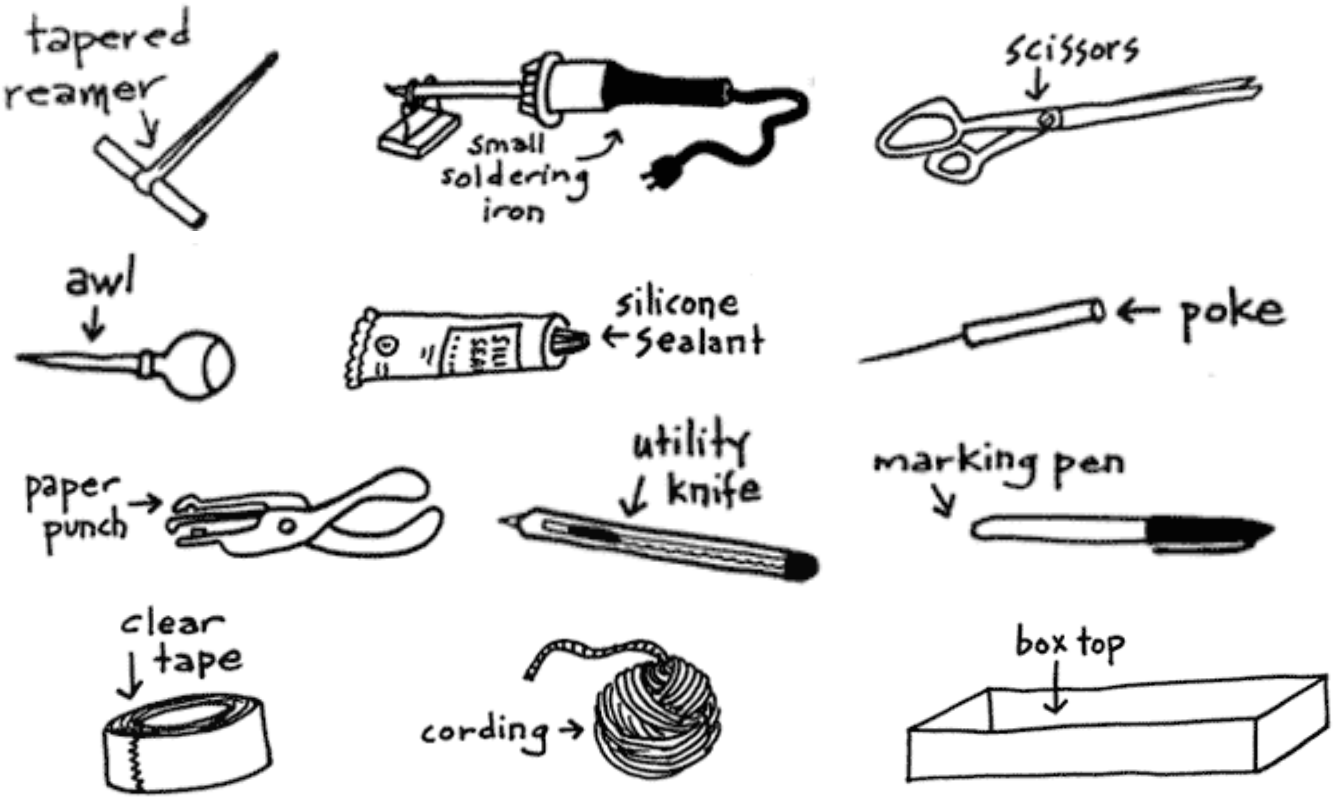
Tapes that are clear, waterproof, and wide (about 5 cm) work well. For a large number of constructions, you may want to buy a dispenser. The best tape we have used (and the most expensive) is bookbinding tape. We use it for making demonstration constructions.

Silicone sealant such as bathtub or aquarium sealant is required for the Terraqua Column to produce waterproof joints, since even a waterproof tape will eventually leak. Silicone sets over a 24-hour period and is slippery when fresh. Fix the joint to be sealed with several small pieces of tape, which you can remove after the seal has solidified. Buy your sealant in a tube with a nozzle that you can fit as far into the joint as possible. This will give you a strong and watertight seal. Be sure to keep the silicone bead thin, 2-3 mm in diameter, so it sets in 24 hours. Also note that the chemicals used in silicone sealant are a health hazard. Use the stuff in a ventilated area.

Hanging Bottles: Hanging bottles will have gravity working for you rather than against you. By hanging your bottle investigations with nylon cording or macrame string, each component is individually accessible, securely threaded together and stabilized with cording. Once the bottles are hanging they will not fall over and they will take up less table space.

Tool Box

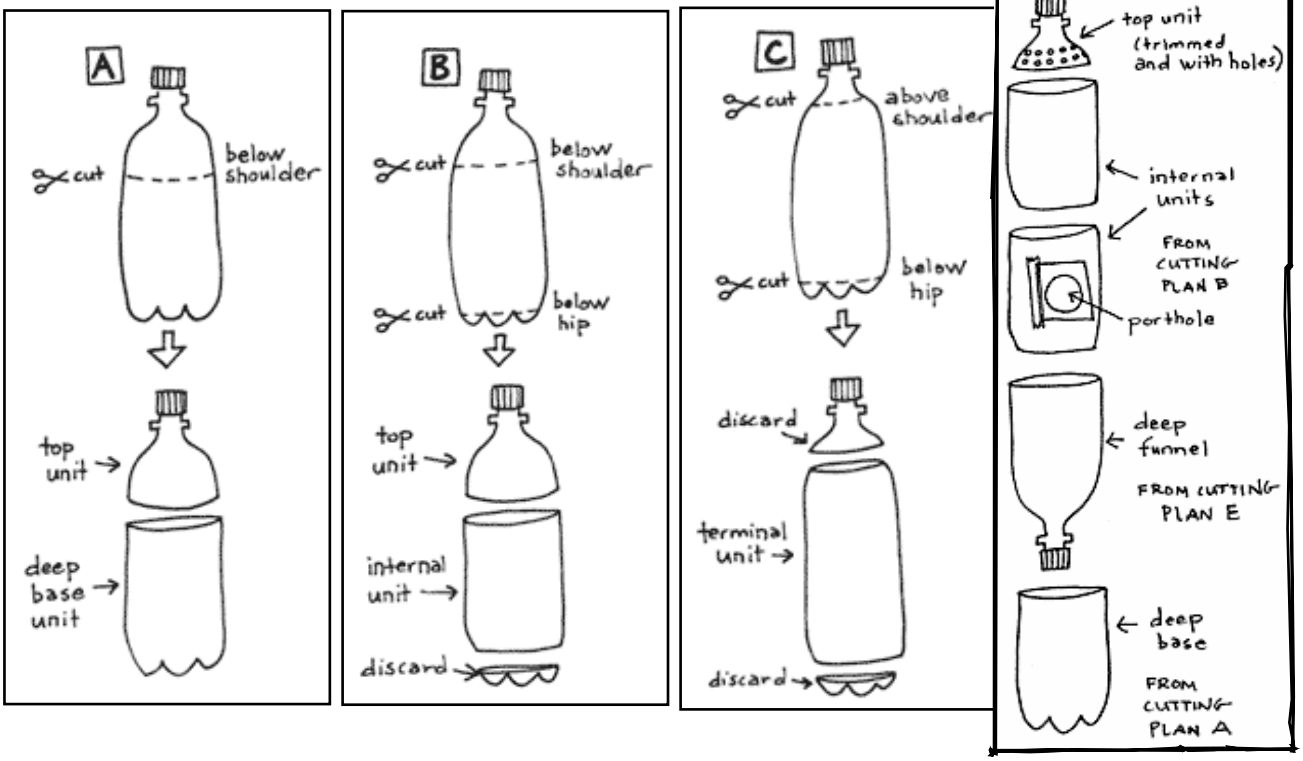
These tools will enable you to construct any of the investigation columns on this site. Some of these items are not critical – you do not need to use a razor to start bottle cuts, for example, or a tapered reamer to enlarge holes – but they can make construction easier.

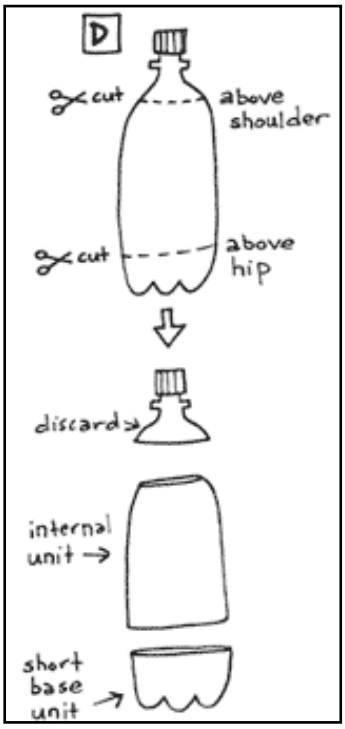


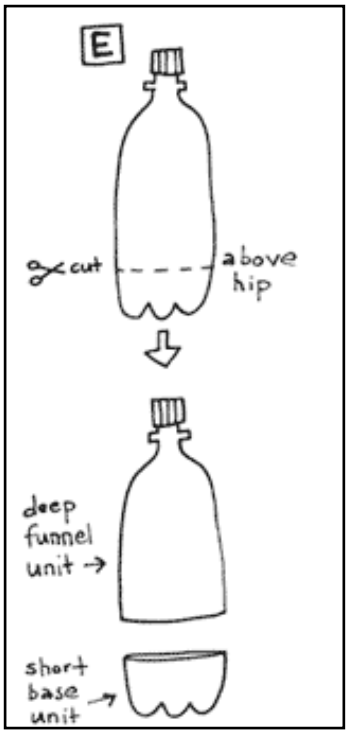
- Box top or drawer to stabilize bottle while making cutting lines
- Marker, wax pencil or crayon for drawing cutting lines
- Cutting blade or utility knife to start cut
- Scissors to cut bottle
- "Poke," darning needle or diaper pin to make air holes
- Awl to make holes in bottle caps and film cans
- Tapered reamer for enlarging holes
- Paper punch for making large holes in thin plastic
- Clear waterproof postal or bookbinding tape to join columns
- Silicone sealant to waterproof joints
- Clothes line, polyester or nylon craft cording
- Small inexpensive electric soldering iron
- Hair dryer
- Plant Light House

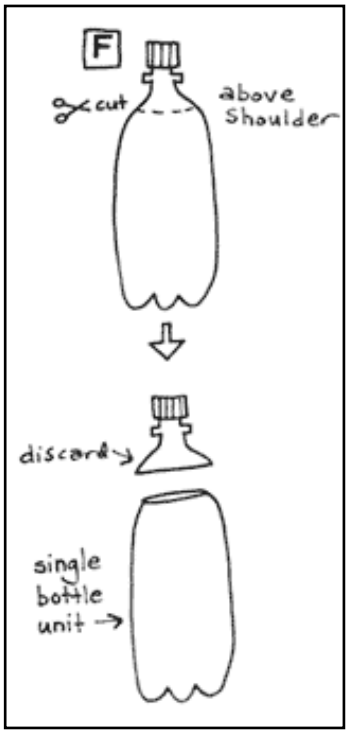
Building Blocks

Bottles A-F illustrate six different cutting plans using the four basic bottle cuts. The construction on the right is a model for creating your own bottle constructions using these simple methods.





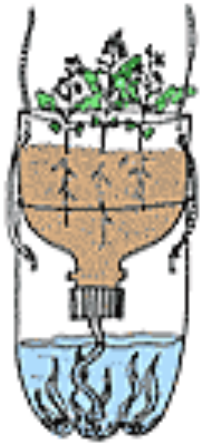




Bottle Column Investigations

Decomposition Investigation Column

Kimchee Fermentation Chamber



TerrAqua Investigation Column

Decomposition Column

The U.S. generates 190 million tons of solid waste a year — enough to fill a bumper-to-bumper convoy of garbage trucks halfway to the moon. So why aren't we up to our necks in garbage?

Nature recycles garbage all the time, and this recycling is essential to the availability of nutrients for living things. Nature's recyclers are tiny bacteria and fungi, which break down plant and animal waste, making nutrients available for other living things in the process. This is known as decomposition.

Decomposition involves a whole community of large and small organisms that serve as food for each other, clean up each other's debris, control each other's populations and convert materials to forms that others can use. The bacteria and fungi that initiate the recycling process, for example, become food for other microbes, earthworms, snails, slugs, flies, beetles and mites, all of which in turn feed larger insects and birds. You can think of the Decomposition Column as a miniature compost pile or landfill, or as leaf litter on a forest floor. Through the sides of the bottle you can observe different substances decompose and explore how moisture, air, temperature and light affect the process.Many landfills seal garbage in the earth, excluding air and moisture. How might this affect decomposition? Will a foam cup ever rot? What happens to a fruit pie, or tea bag? Which do you think decomposes faster, banana peels or leaves? If you add layers of soil to the column, how might they affect the decomposition process? What would you like to watch decompose?

Build a Decomposition Investigation Column

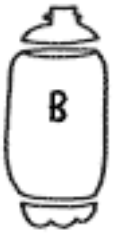
Decide whether you want a table top construction or a hanging construction before you begin.

Materials

- Three 2-liter soda bottles
- one bottle cap
- tool box

Step 1 – Remove labels from all three 2-liter bottles.

Step 2 – Cut the top off bottle #1 2-3 cm below shoulder so that cylinder has straight sides.

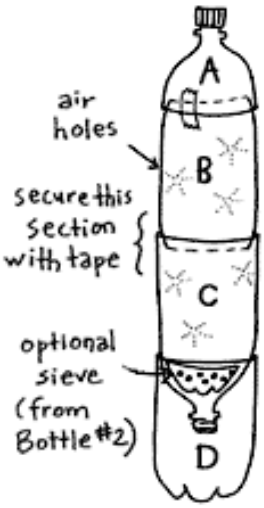


Step 3 – Cut top off of Bottle #2 2-3cm above shoulder. Cut bottom off 2-3 cm below hip so the resulting cylinder has two tapered ends.

Step 4 – Cut bottom off Bottle #3 1-2 cm above hip, so cylinder has a straight end.

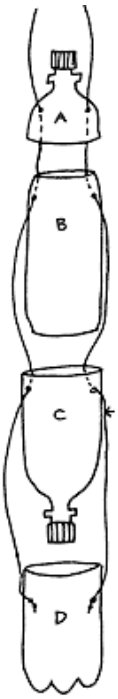
Step 5 – Invert "C" and stack into base "D." Stack "B" and tape middle seam securely. Poke air holes. Add top "A" with a piece of tape for a hinge to the bottle column.

Step 6 – Poke air holes in column. Optional: Poke holes in the cap.



If you want to modify this construction go to BB Building Blocks.

Hang Your Decomposition Column



Step 1 - Cut two, 3-foot lengths of cording and fuse the fiber ends with heat from a flame or hot nail.

Step 2 - Using a soldering iron or hot nail, melt pairs of 4 mm diameter holes opposite each other on the seams of bottle components "A," "B," "C" and "D" as in the drawing.

Step 3 - Tie a simple knot in one end of each cord, then thread each cord through the hole in the rim of "D," from the inside to the outside the knot will be on the inside of the reservoir unit "D." Continue threading the cords from the outside of unit "C" to the inside to the outside of the base of "B," then work inside through the holes just below the hip (top) of "B,"

Step 4 - Thread the cords from the inside of column top unit "A," then tie the ends of cords together with a square knot.

Hang your bottle on a hook and it is ready for loading.

Fill Your Decomposition Column

Choosing ingredients: Decomposition Column ingredients can include leaves, grass and plant clippings, kitchen scraps, newspapers, animal manure and soil. If you are interested in how fast things decay, try building two identical columns, but fill them with leaves from two different species of trees. Try adding fertilizer to your column, or water from a pond or river. How do you suppose differences in temperature, light or moisture will affect the decomposition process?

The time it takes: You'll begin to see mold and other evidence of decomposition within the first few days after filling your column.

Two or three months is plenty of time to see soft organic material such as leaves, fruits, vegetables and grain products decompose dramatically. (The term organic applies to something that is derived directly from a living organism.) Bark, newspapers and wood chips all take longer to decompose, though they still undergo interesting changes in two to three months.

How wet?: Keep your column moist in order to observe more rapid decomposition. Avoid flooding your column or it will become waterlogged. This can create an anaerobic environment, or one completely lacking oxygen, in which certain microbes create particularly vigorous odors.

Using your nose: Odor is a by-product of decomposition, and can tell you a lot about the materials in your columns. Odors may be strong at first, but can mellow and become musty with time. Classrooms full of odorous Decomposition Columns, however, have been known to try the patience of colleagues and building supervisors. The strongest odors arise from animal products such as meat and dairy products. Grapefruit rinds and grass cuttings can also produce strong odors. Why is this

so? If you use food scraps, mix in plant matter such as leaves, twigs and dried grass to temper odors. Layering soil on top of contents also lessens the odor.

Increasing the number and size of air holes in your column will increase air exchange. How do you think this will affect decomposition? Keep holes small so fruit flies stay inside.

If your classroom fruit fly population booms anyway, make a Fruit Fly Trap!

Observe Your Decomposition Column

Recording data: Once you've decided how to fill your column, carefully observe what you put inside. In a notebook, describe the color, texture, smell and shape of everything you put in the bottle. Weigh everything before it goes into the column.

Schedule column checks for at least once a week to record changes. Note changes in the column contents' height, color, shape, texture and odor. Hold a ruler next to the column to record changes in the height of the contents. Insert a thermometer from the top of the column to determine temperature changes. Can you figure out the rate of change? You can also test the pH of the leachate (the solution that drips through the column) or use it in a bioassay for more on pH.

Is anything moving?: Look for the appearance of any "critters," such as flies, beetles, slugs, millipedes, or snails. Decomposition Columns offer good opportunities for observation and description. Try using photographs or drawings to record changes. Write a story about what is going on in your column. What do you predict will happen during decomposition?

Explore with your Decomposition Column

What peaks your curiosity about decomposition? Consider questions that interest you, and design an experiment to look for evidence that could lead to a scientific explanation.

Jim Leidel's 6th-grade students in Madison, WI build Decomposition Columns and try to model natural systems. Some students, for example, pour vinegar solutions through their columns in order to model acid rainfall. Vinegar solutions are also poured through limestone and granitic gravel buffers in order to imitate what might be occurring in eastern U.S. lakes. Levels of pH are measured and compared. In the past, Jim's students tested solutions of their own choosing, among which were tomato juice and sugar water.

For more ideas about investigating decomposition and other scientific experiments using Bottle Biology, check out the Bottle Biology book.

Microbiology of Decomposition

Decomposition can be thought of as a parade of many very tiny creatures. How decomposition proceeds in your column depends on which bacteria and fungi inhabit it, what ingredients you have put inside, and environmental factors such as light, temperature and moisture.

The first decomposing organisms that go to work attack the most available food molecules, such as sugars, carbohydrates and proteins. As they grow, these first bacteria and fungi also change the environment. For example, they produce heat, change the pH and consume oxygen. You will see these changes in your column as plant parts become dark and slimy.

As they change their own environment, these organisms can create conditions that favor competing microbes. The biological definition of succession is the replacement of one type of organism by another, often caused by environmental changes wrought by the first organism.

In your Decomposition Column, for example, one type of bacteria might flourish, changing the pH and raising the temperature of the column in the process. These new conditions may be favorable for a more heat tolerant type of bacteria, which will take over the original bacteria.

A Decomposition Column will show you the dynamic process of decay: strange white fuzz may appear and cover your column for a few days before suddenly disappearing to be replaced by a dark fuzz that climbs up one side. You might see something orange and slimy moving slowly along a rotting twig. You may also observe nonmicrobial life such as fruit flies, mites and millipedes.

Bacteria, fungi, algae, protozoa and other organisms that live on dead or decaying matter are collectively known as saprophytes.

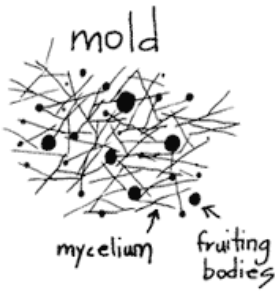
Saprophytes often secrete enzymes onto material they want to eat. Enzymes are biochemicals, responsible for all kinds of chemical reactions including the breakdown of matter into digestible parts for the decomposers. A crumbling log lying on the forest floor, for example, shows the work of enzymes made by saprophytes.

Bacteria are the most numerous of the decomposers. Good soil may have 100 to 1,000 million bacteria per gram. You may see bacterial colonies as round spots, ranging from white, to cream, to brown in color.

There are many types of bacteria. You might identify one type by its odor. These bacteria, called actinomycetes, live in the soil and are responsible for that fresh, earthy smell that accompanies newly plowed soil, or a long awaited summer rain.

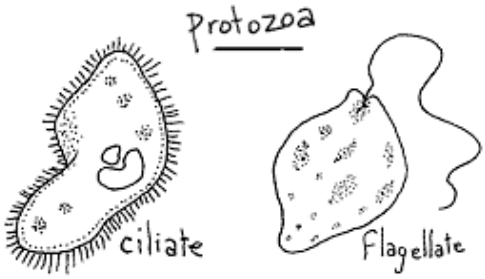
Fungi might appear in your column as a fuzzy blanket of mold covering some delectable rotting thing. Mold fungi form mazes of tiny threads called mycelium. If you look closely, you may see tiny dots along the threads. These dots are fruiting bodies, which release fungal spores. A particularly common mold, Rhizopus, has a cottony appearance with black dots, and often shows up on bread, fruits and other food.

Slime molds are organisms that move, feeding on microorganisms such as bacteria. They are often brightly colored and have the appearance and consistency of pudding. Slime molds often move toward light, leaving snail-like tracks behind, and producing numerous tiny fruiting bodies, some resembling tiny mushrooms.



Algae might show up in your column as a green tinge on the soil surface or on a moist twig. You have probably seen algae, like Spirogyra, growing on the banks of a river, a lake, or perhaps the sides of a fish tank, or as seaweed in the ocean.

Protozoans are another organism with a role in the decomposition drama. These single-celled organisms, such as amoebas, vary widely in size, shape and the manner in which they move. You might see protozoa swimming if you mix a little water with some decomposing material and examine it under a microscope. Although much of the action takes place on a microscopic scale, decomposition is an exciting process even to the naked eye. By studying your Decomposition Column you can get a sense of the great diversity and activity of microbial life. Bacteria, fungi, algae and protozoa may be small but they are responsible for a great deal of change.



Kimchee

What pickles a cuke? Is yogurt alive? Where does Swiss cheese get its holes? How is pizza dough made?

These questions all relate to fermentation, a process people use to create and preserve many types of food.

The term "fermentation" refers to the activity of bacteria and fungi, such as yeast (which is a single-celled fungus). These microbes break complex compounds, like sugars, into simpler substances, such as carbon dioxide and alcohol. Because these simpler substances are toxic to food-spoiling microbes, they act as natural preservatives for food.

Before refrigeration, fermentation was a primary method of food preservation. Builders working on China's 1,500-mile-long Great Wall in the early part of this millennium ate cabbage fermented in wine.

Genghis Khan's forces carried pickled food with them on their invasions of eastern Europe in the 12th century. In the early 18th century, the British Navy carried pickled cabbage to provide sailors with vitamin C in order to prevent scurvy.

Kimchee is a traditional fermented cabbage dish from Korea. Koreans eat kimchee year round for the spicy taste and because it contains lots of vitamins C and B.

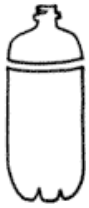
You may be more familiar with the traditional German pickled cabbage dish, sauerkraut, a less spicy version of kimchee.

In a bottle fermentation chamber you can pickle your own cabbage. You'll learn a lot about fermentation, and enjoy great-tasting results.

Build a Kimchee Investigation Column Fermentation Chamber

Materials

- One 2-liter soda bottle
- One plastic lid about 9 cm across
- One 2-3 lb. Head of Chinese cabbage (Brassica rapa), also called napa or petsai, cut into 4 cm Chunks. (For sauerkraut use European round-headed green cabbage.)
- Chopped hot chili pepper, or chili powder
- Two cloves garlic, thinly sliced
- 20 grams (3 tsp) non-iodized (pickling or kosher) salt
- pH paper or red cabbage juice
- tool box



Step 1 – Remove label from the 2-liter bottle.

Step 2 – Cut the top off bottle 1 cm below shoulder.

Step 3 – Layer cabbage, garlic, chili, pepper or chili powder, and a sprinkling of salt into the bottle. (If you are making sauerkraut, use round green cabbage and omit garlic, chili powder and chili peppers.) Repeat layers until the bottle is packed full, placing the plastic lid on each layer and pressing down vigorously to break up the cabbage and distribute the salt.

Step 4 – Press down occasionally over the next hour or two. You can also use a quart Mason jar or freezer bag filled with water, or a peanut butter jar.

Step 5 – After a few hours, the cabbage should fill 1/2 to 2/3 of bottle. Slide the bottle top inside, forming a sliding seal. Push down so no air remains under the lid. The cabbage must be submerged at all times. You can also leave the jar or bag on top of the plastic lid.

When pH indicator drops to about 3.5 (3 days to 2 weeks), your kimchee or sauerkraut is ready.

Kimchee Observe

How pickling proceeds: Fermentation is the work of millions of microbes. You can't see them without a microscope, but you can see, smell and taste evidence of their activity.

Each day, press down on the jar or bottle top so that cabbage juice always covers the cabbage, and the cabbage is kept from contact with the air. You are cultivating anaerobes, organisms that grow best where there is no oxygen. As you press down on the cabbage, you will see bubbles of carbon dioxide (CO_2) rising to the surface. Where do they come from?

How long does it take?: Cabbage can take 3 days to 2 weeks to complete fermentation, depending on the surrounding temperature. The warmer it is, the faster it ferments. If your classroom is a steady 25 degrees C (75 degrees F) or more, you can have kimchee within 4 days; sauerkraut requires more like 2 weeks.

Measure the acidity of the cabbage juice with pH paper daily. Link toKimchee Explore (pH indicator text) You can record the date and pH directly on the paper strips, and then tape them on the bottle to keep track of changes.

Your kimchee or sauerkraut is ready to eat when the pH of the cabbage juice has dropped from about pH 6.5 to pH 3.5. You'll have to open the sliding seal in order to taste the cabbage. When you remove the top, however, the bottle's contents are exposed to air, which may allow different kinds of microbes to grow. To be safe, refrigerate after opening. Do not eat the kimchee or sauerkraut if mold is present.

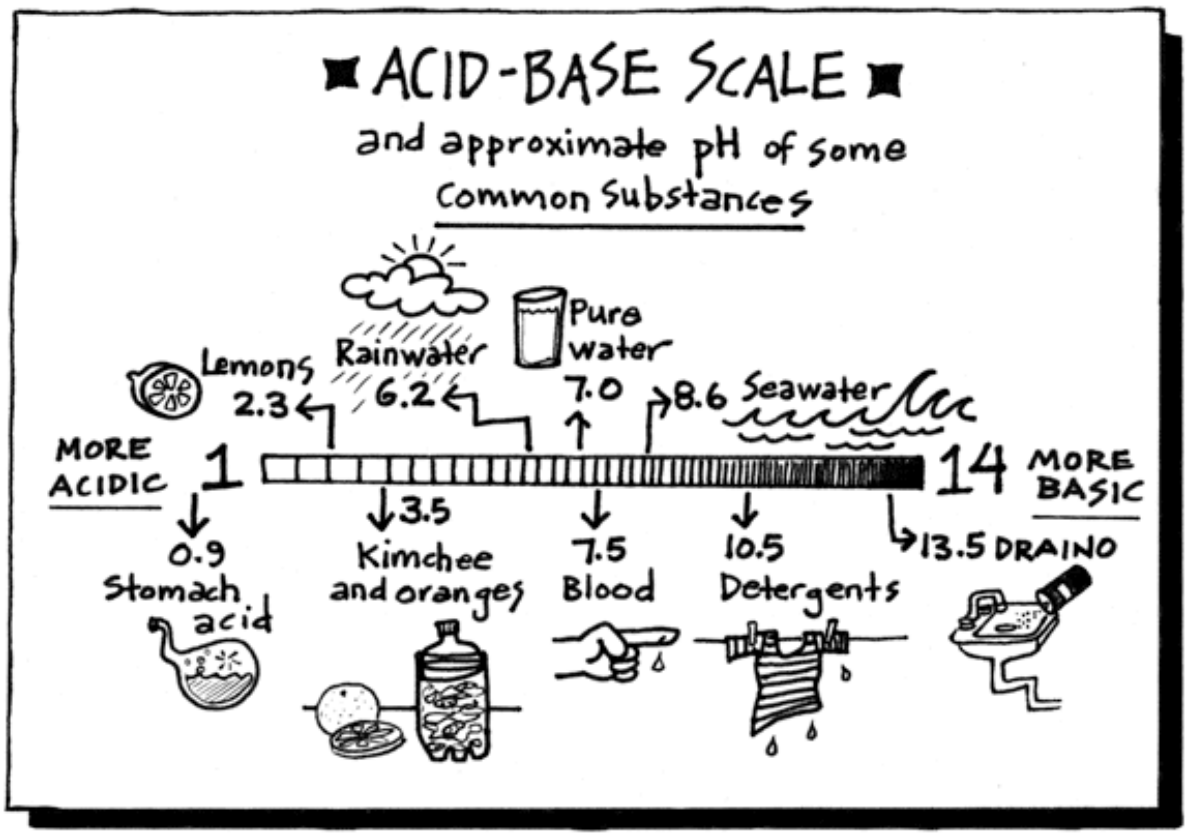
Smell and taste your kimchee: Do you notice the aroma of garlic and pepper? How do the odors change with time? Can you taste the garlic and the pepper? You can explore flavors by adding other ingredients such as ginger, radishes, or different amounts of pepper and garlic.

Make your own pH Indicator

What is pH?: The terms acid and base describe chemical characteristics of many substances that we use daily. We use bases to make soaps and detergents, for example. Almost all the foods we eat, from bread to coffee, are slightly acidic.

The pH scale is a measure of acidity. You can buy pH indicator paper from any biological or lab supply company, which can be used to give you an accurate measurement of the acidic or basic quality of substances you want to test. You can also make your own pH indicator using red cabbage juice, for example, to track the changing pH in your fermentation chamber.

Make your own acid/base indicator: Blend 2 cups chopped red cabbage leaves and 1 cup water in a food processor or electric blender until pieces are tiny and uniform. Strain the liquid. You can also chop the cabbage coarsely and boil it in the water for about 5 minutes until the liquid is dark purple. This purple liquid will change color according to the acidity or alkalinity (basic quality) of substances you want to test.

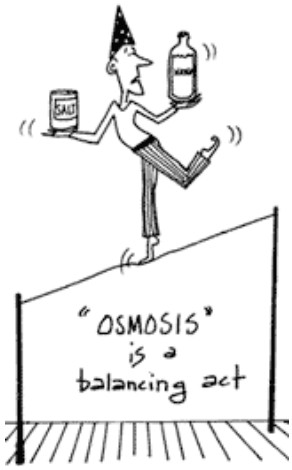


Add about 10 drops of cabbage juice to approximately 1 tablespoon of a test substance. What color does cabbage juice turn in an acid like white vinegar? What about in a base such as a baking soda solution?

Test the pH of various substances and develop a corresponding color-pH scale.Compare your results with the chart here.

You can also make indicator paper by dipping strips of white paper towel, coffee filters, or construction paper into the cabbage juice until they are purple. When the purple strips are dry, use a toothpick, soda straw or eye dropper to place a drop of a test solution on the strips. How do the results compare to your pH chart?

What does salt do?
Osmosis and density changes in kimchee



Osmosis: When you sprinkle salt on cabbage leaves and then exert pressure on them, you'll notice that the leaves become limp and the bottle begins to fill with liquid. Just what is going on here?

Liquid inside the cells of the cabbage leaves is flowing out of the cells in response to the salt, a phenomenon called osmosis.

Osmosis is the movement of fluid through a membrane in order to create an equal concentration of dissolved solids (salt, in this case) in the fluid on either side of the membrane. When you salt a cabbage leaf, you create a difference in salt concentration — higher outside the cabbage leaf and lower inside the cells. In order to equalize the salt concentration, water from inside the cabbage leaf cells will exit through the cell membranes. The water will continue to flow out of the cells until there is an equal concentration of salt in the fluids on either side of the cell wall, or until the cell is completely dehydrated.

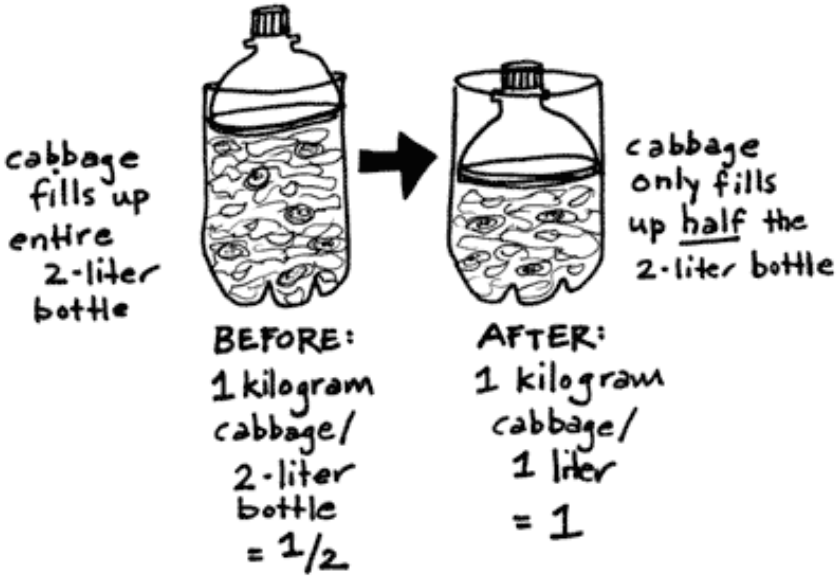
The 2% solution: People who pickle often use a 2% salt concentration. How much salt must you add to your 2-liter bottle of cabbage to produce a 2% salt concentration?

It just so happens that a 2-liter soda bottle packed full of cabbage leaves weighs approximately 1 kilogram. Chinese cabbage is about 95% water, so you need only to figure out how much salt you need to add to 1 kilogram (1,000 grams) of water in order to create a 2% solution. Two percent of 1,000 (.02 x 1,000) is 20 — you need 20 grams of salt. Since one 35 mm film can holds 40 grams of salt, a film can half full of salt is a good measure of what you will need.

Density changes: During the first few hours after you fill your kimchee bottle, you will observe that the height of cabbage leaves falls by half. The weight of the bottle remains the same, but the density changes. How can you quantify the density changes in your 2-liter bottle?

A 2-liter bottle newly packed full of leaves weighs about a kilogram. Since density is grams per volume (d=g/v), your kimchee or sauerkraut has an initial density of 1 kilogram of cabbage per 2-liter soda bottle, or 1/2.

Due to osmosis, however, the cabbage level drops to about half the bottle. In other words, the volume drops to 1 liter. Now the density equals 1 kilogram per 1 liter, or 1. The mass of the bottle hasn't changed, but the density has doubled.



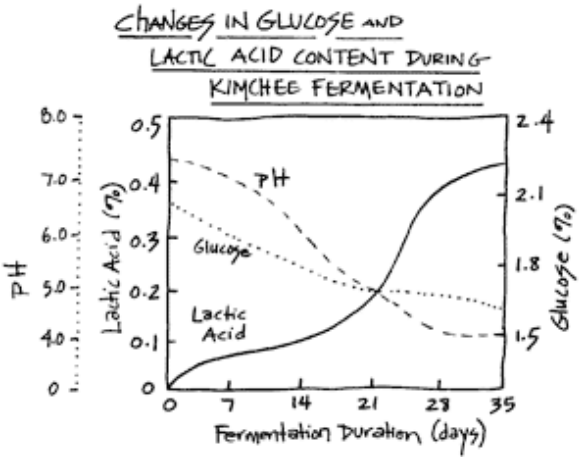
Good Bug-Bad Rap | Kimchee - Fermentation

Microbes get a pretty bad rap. We give them long, complicated names like Streptococcus thermophilus, or else we call them something negative like "germs." But we depend on microorganisms in every realm of life, from producing the food we eat to cycling energy in our ecosystems.

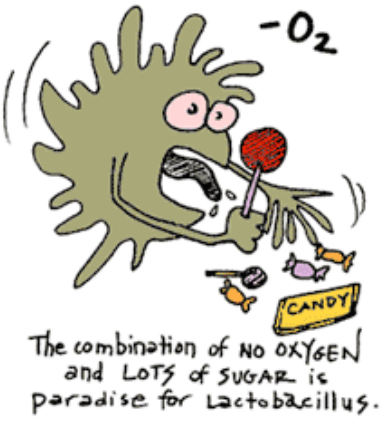
Meet Lactobacillus. This friendly microbe lives just about everywhere, including in dairy products and on fruits and vegetables. Most types of Lactobacillus wouldn't hurt a flea (though they might change your milk into yogurt). We use Lactobacillus to make yogurt, as well as cheese, buttermilk, soy sauce and kimchee.

Lactobacillus is an anaerobe, which means it grows best in environments lacking oxygen (though it has no trouble living with oxygen; it just slows down).

When you make kimchee, you set up a very friendly environment for Lactobacillus by filling a bottle with cabbage and adding salt, which helps to release water and sugars from the cabbage cells. By keeping the cabbage submerged in cabbage juice, you create an anaerobic environment.



This combination of no oxygen and lots of sugar is a paradise for Lactobacillus, which happens to be quite fond of sugar. It will happily eat up the sugars and churn out lactic acid, a habit that gives the microbe its name.



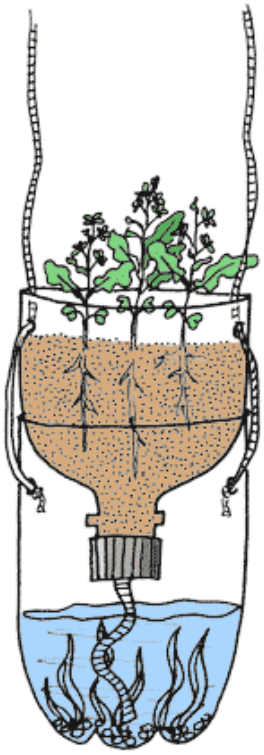
This activity is at the heart of kimchee fermentation. The more sugar Lactobacillus eats, the more lactic acid it produces, and this is why the pH of your kimchee drops over time. Lactobacillus grows best at a pH of about 5. The accompanying chart shows how pH, glucose (or sugar), and lactic acid all change over time in kimchee fermentation.

There are several species of Lactobacillus, which fall into two major groups depending on what they produce after eating sugars. The homofermentative bacteria produce one thing: lactic acid.

TerrAqua Column - What is the Land-Water Connection?

What common substance falls from the atmosphere, flows through our bodies, runs through the soil beneath our feet, collects in puddles and lakes, then vaporizes back into the atmosphere in a never-ending cycle?

Water, as it cycles between land, ocean and atmosphere, forms the major link between the terrestrial world (involving anything living on the earth) and the aquatic world (involving anything living on or in the water).



Water drips off rooftops, flows over roads, off your toothbrush, and down the drain, percolates through the soils of fields and forests and eventually finds its way into rivers, lakes and oceans.

During its journey, water will pick up leaf litter, soil, nutrients, agricultural chemicals, road salts and gasoline from cars, all of which have profound impacts on life in aquatic systems. Water can also be filtered or purified as it percolates through soil.

The TerrAqua Column provides you with a model to explore the link between land and water. The model has three basic components: soil, water and plants.

By varying the treatment of just one of these components you can explore how one variable can affect the whole system. How does salt affect the growth of plants? How does adding fertilizer to the soil affect algal growth in the water chamber? What type of soil best purifies water?

Experimentation with the TerrAqua Column is practically unlimited. You can define a question, and then design your experiment to explore it.

Build a TerrAqua Investigation Column

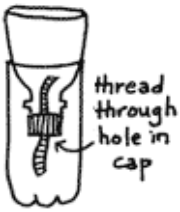
Option 1

Materials

- One 2-liter soda bottle
- One bottle cap
- Tool Box
- Wicking material-fabric interfacing or cotton string
- Water, soil and plants

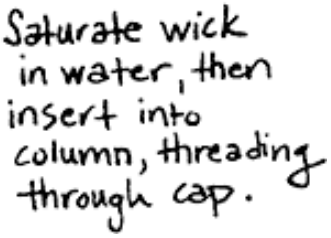
Step 1 – Remove label from the 2-liter bottle. Cut bottle 1 cm below shoulder.

Step 2 – Poke or drill a 1 cm hole in bottle cap.



Step 3 – Thread a thoroughly wet wick strip through bottle top, invert top, and set into base. Wick should reach bottom of reservoir and thread loosely through cap.

Step 4 – Fill reservoir with water. Add soil and plants to top chamber. To be effective, the wick should run up into soil, not be plastered along a side of the bottle. For better drainage, place a layer of gravel, sand or vermiculite in the bottom of the soil unit.



Option 2

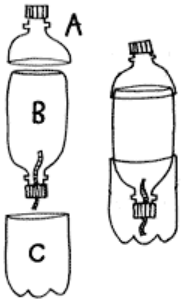
Materials

- One 2-liter soda bottle
- One bottle cap
- Tool Box
- Wicking material-fabric interfacing or cotton string
- Water, soil and plants

Step 1 – Remove label from the 2-liter bottle. On bottle #1, cut 2 cm below shoulder to produce component "A," a shallow funnel top and "C" a deep reservoir.

Step 2 – Poke or drill a 1 cm hole in bottle cap.

Step 3 – Cut Bottle #2, 1 cm below hip to produce component "B" a deep funnel unit with hip taper.



Step 4 – Fill reservoir with water. Add soil and plants to top chamber. To be effective, the wick should run up into soil, not be plastered along a side of the bottle. For better drainage, place a layer of gravel, sand or vermiculite in the bottom of the soil unit.

Hang your TerrAqua Column

Step 1 - Cut two, 3-foot lengths of cording and fuse the fiber ends with heat from a flame or hot nail.

Step 2 - Using a soldering iron or hot nail, melt pairs of 4 mm diameter holes opposite each other on the seams of bottle components "A," "B" and "C" as indicated in the drawing.

Step 3 - Tie a simple knot in one end of each 3-ft cord. Thread each cord from inside of section "C" so knot is inside reservoir.

Step 4 - Thread each cord from outside of "B" to the inside of the deep funnel "C."

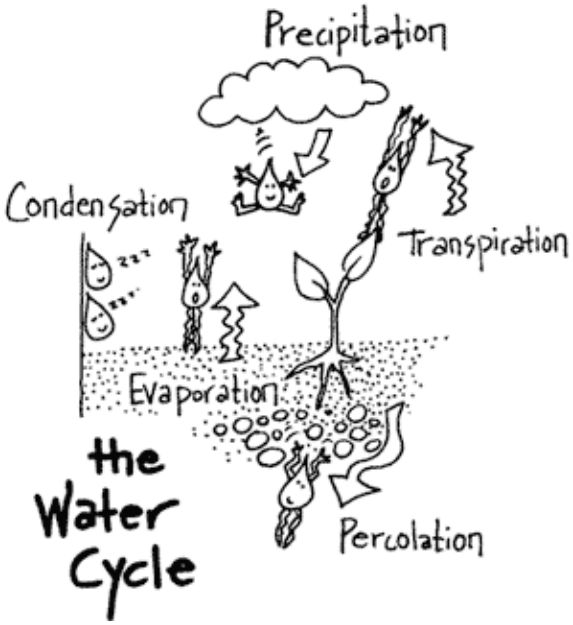
Step 5 - Thread each cord end from the inside of component "A" to the outside of the top funnel unit. Tie the two ends in a square knot and hang.

Your TerrAqua Column is ready to be filled.

Fill for TerrAqua

The basic components of the TerrAqua Column are soil, water and plants.

How do these components interact in a Terr-Aqua system? (The word system indicates you are dealing with a diversity of organisms and the interactions between them.)



Plants growing in the upper part of the TerrAqua Column take nutrients from the surrounding soil and, with the aid of the wick, take water and other substances from the aquatic portion below. Substances you add to the terrestrial section will move down, or percolate, through the soil and drain into the aquatic section.

How do land and water interact in your area? Does runoff from fertilized lawns or agriculture threaten the quality of your streams or groundwater? Is salt pollution a problem, from either road salt, irrigation, or saltwater intrusion? Are landfills affecting local groundwater?

Soil, water, and plants: Fill the top unit of your TerrAqua Column with soil you collect, or with potting soil from a gardening store. Fill the lower aquatic unit with tap water, or water from a pond, lake, puddle or fish tank.

Collected soil and water will likely contain algae, phytoplankton, plant seeds and insect larvae. Store-bought soil and tap water will include far fewer organisms. (To observe this, fill one TerrAqua Column with soil and water from nearby woods or park and another with potting soil from a garden store and tap water. Set them side by side and observe for several weeks.

Terrestrial and aquatic plants are excellent indicators of change in your system. Fast-germinating and fast-growing plants will most effectively register change in a short period of time.

Grasses, particularly lawn seed mixes, work well. Prairie grasses grow more slowly but have deep roots that are interesting to observe. Radishes and beans also work well, though you will need to soak dried beans overnight before planting. Fast Plants, which have been developed to complete their life cycle in 35-40 days, are ideal candidates for experimentation in TerrAqua Columns.

Observe you TerrAqua Column

A simple model, a complex world: The TerrAqua Column, a relatively simple model, allows you to focus on specific aspects of a complex world. Imagine, for example, a lake near your house that is suddenly overtaken with algae.

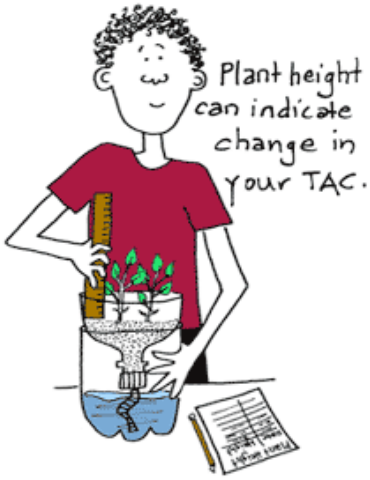
Given all the environmental factors that influence the lake, you would be hard pressed to determine exactly which factors encouraged the slimy green stuff to get out of control.

You could build several TerrAqua Columns in order to explore specific factors that might encourage algae. Try taking samples of lake water and local soil, for example, and then testing them under different conditions to see in what sorts of environments algae grows best.

Your observations and experiments can go in many directions, so the clearer you are in defining your question and designing your experiment, the more successful your experiment will be.

Variables: Variables to consider in your experiments include:

- The type and amounts of soil, water, and plants – remember, depending on their source, the soil and water will likely contain such life as algae, fungus, mites, Daphnia, etc.
- Substances that might affect terrestrial and aquatic systems – nutrients (fertilizers), or pollutants (salts, pesticides, acids).
- A treatment plan – once you have decided on a substance to test you can apply different amounts of that substance; treat only the terrestrial chamber; treat only the water reservoir; apply it directly to plant leaves; test it on plants of various ages; or vary the treatment schedule.



- Physical factors – temperature, light, sound, etc. (Try singing or screaming at your plants. One student grew Fast Plants to the tunes of Bach, Barry Manilow and Heavy Metal - Barry Manilow encouraged the most growth!!)

Indicators: Indicators in a TAC are plants and animals and other system characteristics that change in response to your experiments, giving you information regarding your hypothesis. Indicators include terrestrial and aquatic plants and the pH of soil and water.

Some observations you can make of a plant indicator, for example, include percentage of seeds that germinate, plant height and weight, leaf size and shape, root structure, number of flowers, length of life cycle and seed production. In the aquatic system, indicators include increases or decreases in populations of algae and duckweed. These changes can show up as cloudiness in the water. You can also use the bioassay to determine the effects of a substance on plants.

Controls: With every experiment you run, set up one control TAC in which you do not vary any of the components. This acts as a standard against which you can compare the effects of variables you do change.

Keep it simple: The TAC is a simple model, but all of its parts are dynamic. Keep your investigations very simple by changing only one variable of the system at a time.

Some of the more often investigated substances include fertilizer, pesticides, acid "rain" and oil. A detailed example of a salt pollution experiment follows; you can also use the procedure to investigate other substances.

Salt Pollution: Does salt affect plant growth?

Roads in Massachusetts* are salted in the winter to de-ice them, frequently with NaCl (sodium chloride), sometimes with CaCl2 (calcium chloride). The question arises whether the salt, carried by melt-water runoff from the road, affects plants growing in the vicinity, or aquatic systems where the runoff goes.

The following list of questions and answers provides you with a model for how you might set up an experiment with TACs.

What question are you exploring?

Are plants affected by runoff from roads de-iced with salt in the winter?

What specific idea (hypothesis) are you testing?

Higher concentrations of salt (NaCl) negatively affect plant growth.

What variable will you change in your experiment?

The concentration of NaCl in water fed to plants.

What variables will remain constant in your experiment?

Type of soil, water, and plants, age of plants, and salt treatment schedule. Physical conditions such as temperature and light.

List all the items you will need:

- four TACs filled with 50 ml of water below and equal amounts of a potting soil above
- seeds of grass, Fast Plants, radishes, or other fast-growing plants
- four labels
- salt – Use road salt, lab grade NaCl, pickling or kosher salt. Table salt often contains iodine and "flowing agents" that may affect results
- eye dropper
- soil testing kit to monitor soil pH (optional)

What is your experimental procedure?

1. Plant seeds in four TACs.
2. After plants have sprouted, label one column CONTROL, label a second 0.1% NaCl, a third 1.0% NaCl and the last TAC 5.0% NaCl.
3. Prepare salt solutions of 0.1%, 1.0% and 5.0% salt by weight. (For example, 0.1% is one tenth of a gram of salt per 100 ml of water, or 1 gram of salt per liter of water.)
4. Treat each TAC with 10 ml of the appropriate salt solution. Use an eye dropper to place 5 ml on the soil and 5 ml in the reservoir. Treat the CONTROL with plain water.
5. Treat plants every fourth day for a month.
6. Observe and record plant development, including height, leaf number, size and color. You might also take pictures of the plants to monitor changes in color and other aspects of physical appearance.
7. Test the soil pH
8. Repeat this experiment, or run several at once. Can you reproduce your results?

Do the results of your experiment support your hypothesis?

The Medfield High School students found that the higher salt concentrations had more negative effects on plant growth and development.

Discuss your experience with others. Write a report and create a graph to illustrate your investigation.