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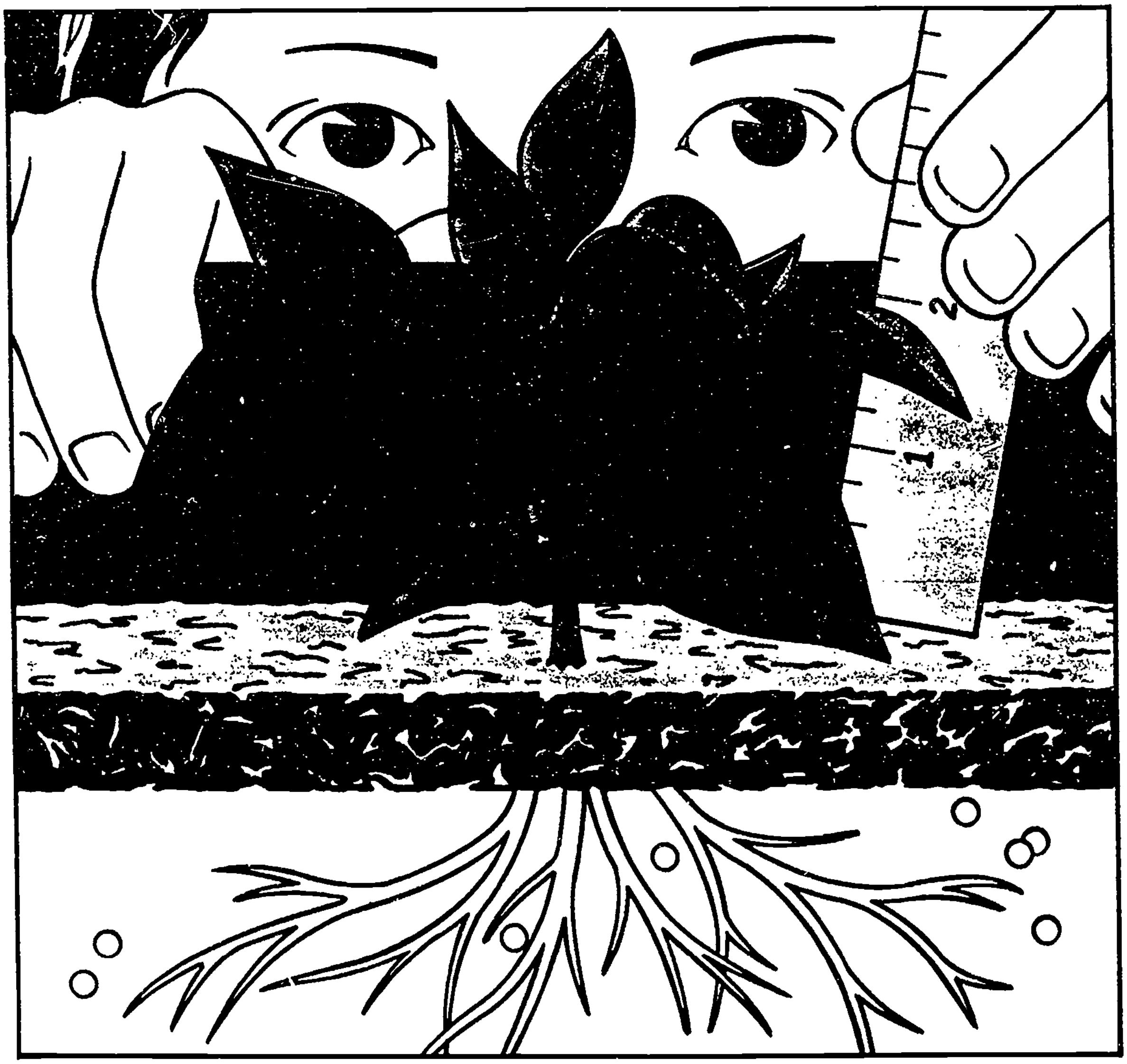
ABSTRACT

Growing Ideas, the National Gardening Association's series for elementary, middle, and junior high school educators, helps teachers engage students in using plants and gardens as contexts for developing a deeper, richer understanding of the world around them. This volume's focus is on hydroponics. It presents basic hydroponics information along with suggestions for helping students discover concepts on their own, and includes numerous examples from actual classrooms where teachers explore this growing technique with their students. Also included are suggestions for supporting students' varied learning styles in both cooperative and individual activities. Chapter titles are: "The What and Why of Hydroponics"; "Meeting Plant Needs"; "Choosing and Nurturing Plants"; "Exploring Hydroponics in Your Classroom"; "Choosing Systems"; "Simply Super School-Made Soilless Systems"; "Resources and Suppliers"; and "Appendix: Homemade Nutrient Mix." (MKR)

Growing Ideas

Exploring Classroom Hydroponics



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The *Growing Ideas* series is an extension of the National Gardening Association's National Science Foundation-funded GrowLab garden-based science program. *Growing Ideas* booklets are designed to help teachers use plants and gardens to engage students in thinking and acting like scientists and to develop a deeper, richer understanding of the world around them.

We would like to thank Don Coleman, Chuck Erickson, Peter Wardenburg, Ray Patacca, and Brandy Bolt for their input and careful review of this material. Our sincere thanks also go to the educators whose soilless-growing experiences have informed this booklet. Many of their stories and suggestions appear throughout its pages.

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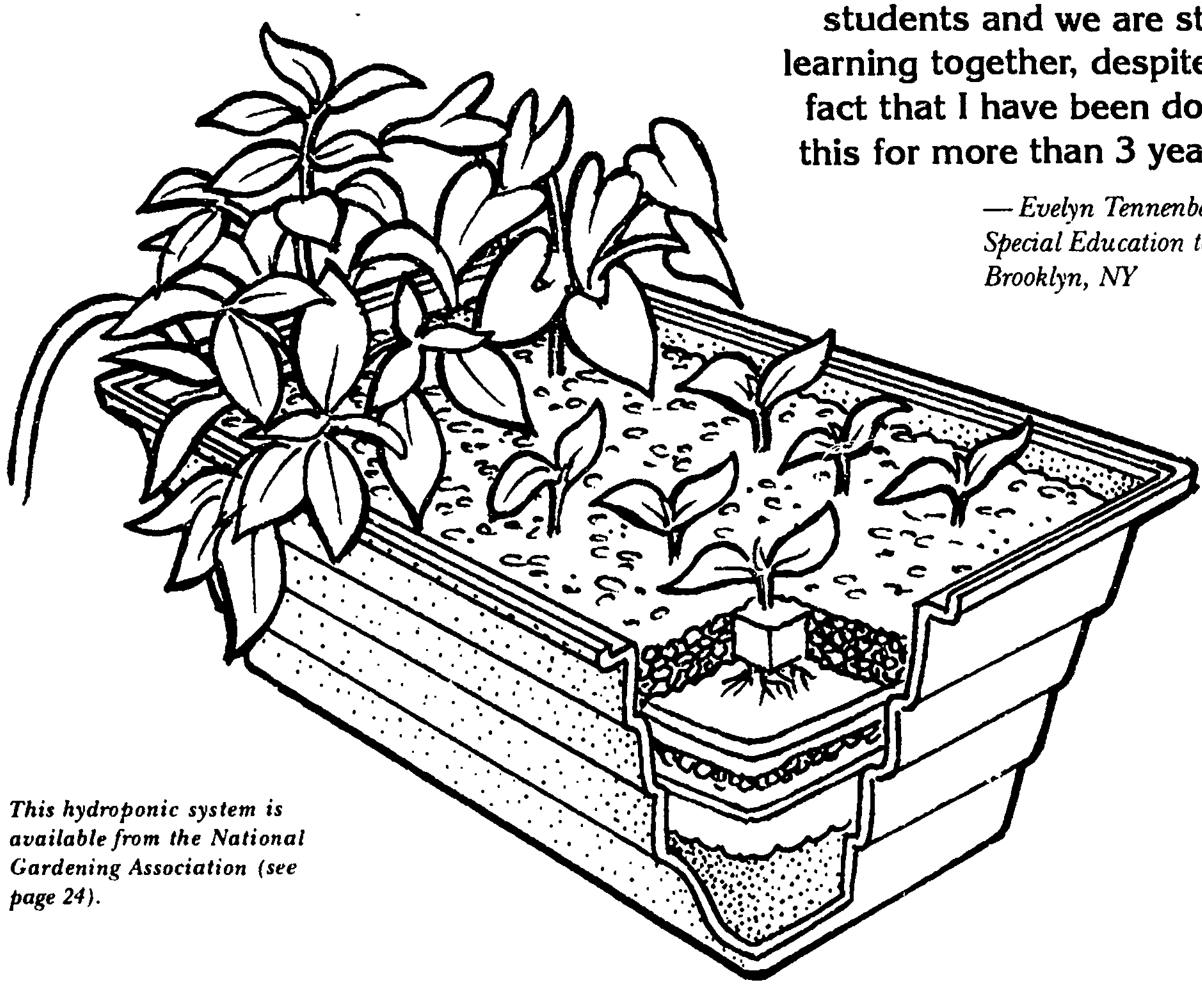
PREFACE

At a time when our education system is under fire — from students, parents, politicians, special interest groups, and national educational reformers — it is reassuring to know that some truths about learning endure. What is true is that children enjoy thinking, raising questions, manipulating, sorting, testing, and investigating for themselves. What can be more engaging than nurturing and exploring living things? *Growing Ideas*, the National Gardening Association's series for elementary, middle, and junior high school educators, helps teachers engage students in using plants and gardens as contexts for developing a deeper, richer understanding of the world around them. This volume's focus is on **hydroponics** (from the Greek root words meaning *water working*).

This booklet does not profess to be a complete "how-to," but rather a synthesis of ideas from people who explore hydroponics with real children in real classrooms. It presents basic hydroponics information along with suggestions for helping students discover concepts on their own, and includes numerous examples from actual classrooms where teachers explore this growing technique with their students. You will also find suggestions for supporting students' varied learning styles in both cooperative and individual activities. How you approach a hydroponics unit will depend on your own teaching style, curriculum objectives, classroom space, and finances. You can explore hydroponic gardening using minimal recycled materials, or make elaborate use of technologically advanced systems. This booklet is a springboard. Our resource section (see page 22) lists outstanding materials to help you dig deeper.

"Don't let lack of experience or familiarity with hydroponics deter you. I learned with my students and we are still learning together, despite the fact that I have been doing this for more than 3 years."

— Evelyn Tennenbaum
Special Education teacher
Brooklyn, NY

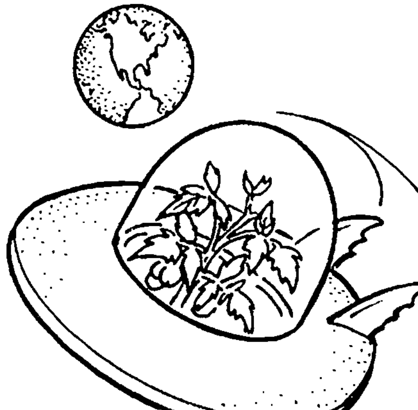


This hydroponic system is available from the National Gardening Association (see page 24).

The What and Why of Hydroponics

Hydroponics, in its simplest form, is growing green plants without using soil. Hydroponic growers provide a solution containing minerals directly to plant roots, allowing the plant to expend its energy on growth rather than on seeking and competing for water and nutrients. The methods of suspending the plant in that nutrient solution, delivering and renewing nutrients and oxygen, and meeting the plant's other needs (light, temperature, and so on) are all variables that lend themselves to creative exploration.

Why bother? Because hydroponics can help gardeners and farmers grow more food more rapidly in small areas — living rooms, greenhouses, even rooftops. It's a challenging and engaging home hobby, and an important agricultural technique. In arid regions, for instance, where arable space and water are limited, the use of efficient hydroponic systems supports high yields and rapid growth in relatively small spaces year-round. Weeds and soil-borne pests are almost eliminated, reducing the use of certain herbicides and pesticides. NASA has even established hydroponic systems in Antarctica and plans to experiment with such systems on space stations as a potential source of food and oxygen for space travelers.



In the classroom, the potential value of exploring hydroponics is great. Many students and teachers have heard about hydroponics, but most have not actually experienced it. New technologies bring new challenges; hydroponics can inspire active investigations into the union of science and technology, and can incorporate recycling concepts.

Students raising plants without soil must consider basic plant needs and experiment with and examine plant growth, providing a concrete, real-life context for [illegible]ng problems and devising experiments to test their own questions. Record-keeping becomes a natural outgrowth of these endeavors. Ultimately, these studies may lead to classroom business opportunities or fuel student career interests. Not least of the benefits is the joy of students' harvesting a crop of their own incredible edibles!

Hydroponic gardening doesn't have to be hard (remember starting houseplant cuttings and avocado seeds in jars of water?), but it isn't fool-proof, either. You and your students can move together into an area that's new to many schools. You can become botanical pioneers.

A Growing Controversy

Some people are concerned that the reliance on technology and the energy input required by many hydroponic systems may diminish the benefits, or that promoting this method as a superior growing technique might lessen people's appreciation for the vital role of soil and their concern for good soil conservation practices. Others maintain that the ability to grow high-quality, pesticide-free produce in little space is vital to the future quality and availability of our food supply. The controversy is a healthy one that might inspire your students to do research, launch debates, and come to their own conclusions.

Soilless Classroom Profile

Sixth grade teacher Vonneke Miller from Sunnyvale, CA, has designed an unusual project that combines hydroponics and students' fascination with space travel. The classroom has two simulated space capsules including a hydroponic unit to grow food for the journey. Grant money was provided by Hewlett-Packard and members of the Hydroponics Society of America. Students learn basic and applied science as they mix the nutrients, test and adjust pH, hand-pollinate tomatoes, and document the yields. The school cafeteria serves the vegetables grown in the capsule.

Meeting Plant Needs

(Or, The Nitty Gritty With no Grit!)

Like you and me and the dog next door, plants have certain requirements that need to be met for them to grow and thrive. These include water, nutrients, warmth, light, air, and support. In traditional gardening, plants get support, nutrients, water, and oxygen from the soil. Without soil, hydroponic growers must find (sometimes innovative) ways to provide water and nutrients directly to plant roots, enabling the plant to concentrate its energy on producing leaves and fruits rather than expending it searching for water and nutrients. They're also challenged to design ways of providing the support and oxygen that plants need.

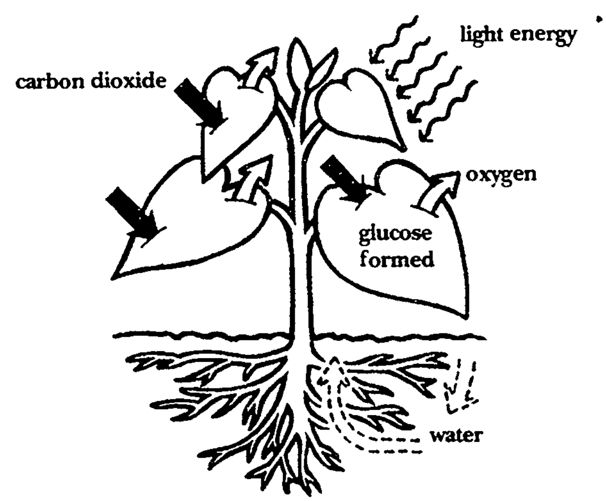
In this section we discuss some of these key plant needs and describe how hydroponic gardeners meet them. On pages 18 to 21 we illustrate some systems that you and your students can create to fulfill plants' basic needs. You may wish to delay sharing these setups with your students, to first allow them to use their new understanding of plant needs to invent their own unique setups.

(Green) Thumbnail History

Records show that plants have been grown without soil for many thousands of years. The hanging gardens of Babylon used hydroponic techniques. Marco Polo observed hydroponics in China. To escape enemies, the ancient Aztecs reportedly took to the lakes and maintained large floating rafts woven of rushes and reeds on which they raised food crops. In 1699 the British scientist John Woodward grew plants in water to which he added varying amounts of soil. He concluded that while there are substances found in soil that promote plant growth, the bulk of the soil is used for support. By the late 1800s, horticultural scientists were successfully raising plants in solutions of water and minerals. The modern science of hydroponics began in the 1930s when Dr. W. E. Gericke at the University of California raised tomatoes and other crops on floating rafts, applying the earlier principles in a commercially successful way. He coined the name "hydroponics" as he "worked with water." What more can your students discover about the history of soilless growing?

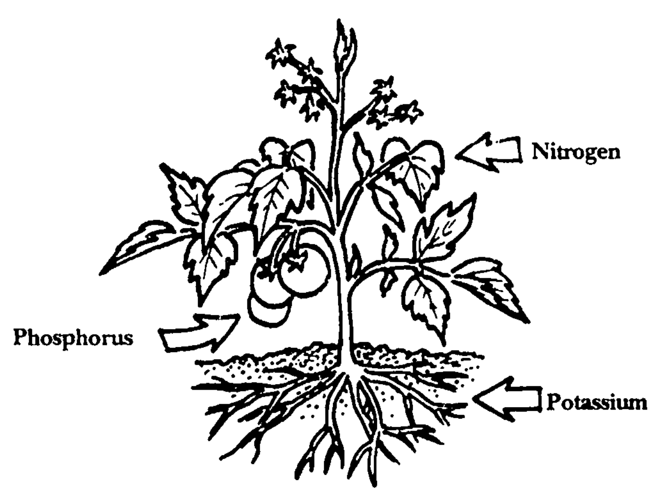
Nutritionally Speaking

Whichever type of hydroponic system you and your students select or create, you must supply the plants with nutrients. These are certain chemical elements or minerals that are normally found in soil and supplied in commercial fertilizers. In soil, these elements come from rock and mineral leaching and organic matter decomposition. They are "held" by the soil particles, dissolved in the surrounding soil-water solution, then transported through root hairs to the entire plant. These nutrients or minerals are not actual food, but elements vital to helping the plant utilize the sugars (the *real* food) that it produces itself during photosynthesis.



Plant nutrients or fertilizers are not really food. A green plant actually makes its own food (sugars) in the presence of sunlight using CO_2 and water. The food-making process is known as photosynthesis. Mineral nutrients help the plant use this food to maintain its life processes.

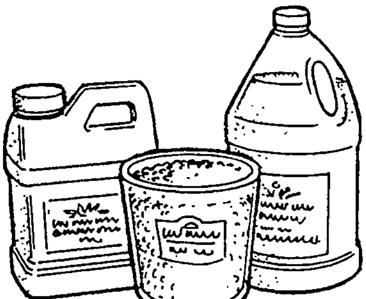
Nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium, called **macronutrients**, are needed by the plant in rather large amounts. Others are called trace elements, or **micronutrients**, meaning they



are important to the total well-being of the plant, but in very small amounts. These include manganese, sodium, sulfur, iron, zinc, copper, molybdenum, boron, and chlorine. Hydrogen, oxygen, and carbon are also necessary in large amounts, but are available to plants from the air and water.

Growing Tips: Nutrients

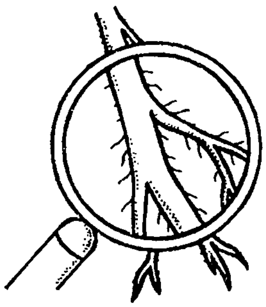
Without soil to provide and release nutrients, how do hydroponic gardeners supply them? Hydroponic gardeners provide plant roots with a nutrient solution containing an appropriate balance of necessary macro- and micronutrients — a "super nutrient soup," suggests one fifth grade teacher. The easiest way to supply them is to purchase prepared hydroponic nutrients in dried or liquid form. Most are concentrated and must be mixed with water. (See pages 22 to 23 for a list of suppliers.) Some classrooms have used commercial houseplant fertilizers for hydroponics, with mixed results (many do not contain enough of the trace elements that plants require). How do they compare with special hydroponic fertilizers? We're curious to hear about your experiences! Upper-grade students might want to experiment with varying proportions of individual nutrients to make their own "super secret soup." A sample recipe appears in the appendix.



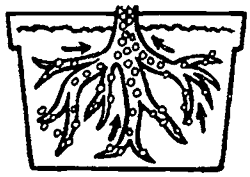
Although different plants achieve ideal growth with different nutrient mixtures, practically speaking, a well-balanced mix of hydroponic nutrients will serve you well for most classroom needs. When mixing nutrient solutions, always dilute them to the concentration recommended by the manufacturer, typically 1 or 2 teaspoons per gallon of water. Water between 65 and 75 degrees F makes nutrients most available to plants. Tap water may contain significant concentrations of chlorine, which can adversely affect plant growth. If your water has a lot of chlorine, you can use distilled water or simply let water stand uncovered for a couple of days before using. Your students might want to explore this themselves by comparing plants grown with distilled- versus tap water-based nutrient solutions.

The amount of nutrient solution you use depends on the type of system, temperature, light, and other factors. If you're growing plants like lettuce, herbs, or flowers in a

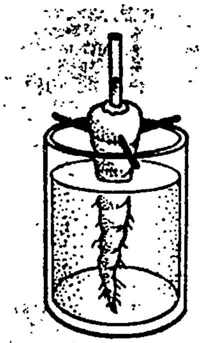
Getting to the Root



The most important function of roots is to absorb water and minerals. How does it happen? Just behind the growing tip of each root are hundreds of tiny root hairs. The cell walls and membranes of the hairs are so thin that they easily allow water molecules containing dissolved minerals to pass in. The movement of the molecules through the cell membranes is called **osmosis**. Osmosis occurs because the higher concentrations of water and minerals outside cause a kind of "pressure difference." The molecules, seeking equilibrium, move from a lesser concentration of nutrients outside the root hair to a greater concentration of nutrients inside the hair, carrying nutrients and water into the roots.



You can explore this phenomenon with your students by inserting a clear straw into the hollowed-out top of a fresh carrot, dripping candle wax around the straw to serve as a seal. Set the carrot in a jar of water, then drop a small amount of sugar water down the straw and mark its position. Students should be able to see the fluid in the straw, which simulates the carrot stem, rising under osmotic pressure.



simple system such as a floating raft (see page 19), a good rule of thumb is to provide 2 quarts of nutrient solution per plant. If you're trying to raise larger, fruiting crops in a more sophisticated system, you'll need to supply closer to 2 gallons of nutrient solution per plant.

You'll have to replace the nutrient solution at different intervals depending on the type of system you set up, because nutrient concentration will vary as nutrients are taken up by the plant and as water evaporates and transpires from plant leaves. (Commercial growers use special equipment to measure the concentration of nutrients in a solution.) A good rule of thumb for most classroom systems is to replace the mixture with a fresh batch every 10 to 21 days. Invite students to consider ways in which these resources can be recycled, such as by watering other classroom or outdoor plants. As the water in your system evaporates and transpires, you may also want to top off the solution with more water to avoid building up concentrations of mineral salts. Suggestions for investigating such factors as evaporation are offered on pages 13 to 15.

Water Works

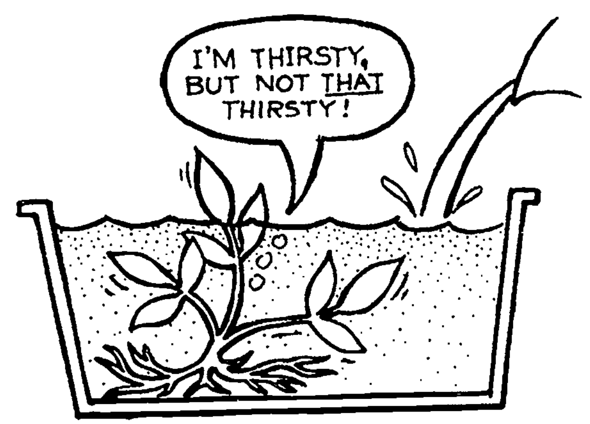
Did you know that most plants are composed of about 90 percent water? It's an essential component of photosynthesis, necessary for normal cell function, and is the medium in which nutrients are transported throughout the plant. Different plants need water in different amounts during different growth stages. A large cucumber plant, when fruiting, can use up to a gallon of water a day! In hydroponics, water with dissolved nutrients is applied as a bath, periodically irrigated through the growing medium, or sometimes sprayed directly on the roots. Invite your students to imagine a range of ways in which water might be delivered to plant roots in a soilless system.

pH: The Acid Test

The **pH** of the nutrient solution is an important factor in hydroponics. The pH is a measure of the acidity and alkalinity on a scale from 1 to 14, with 1 being very acidic, 7 being neutral, and 14 being very alkaline. Most of the plants in your classroom hydroponics projects grow best when the pH of the nutrient mix is between 5.8 and 6.5. At pH readings above or below this range, certain nutrients become locked up or unavailable to plant roots. The range that allows the plant to use the dissolved minerals most effectively is just slightly acidic.

Growing Tips: pH

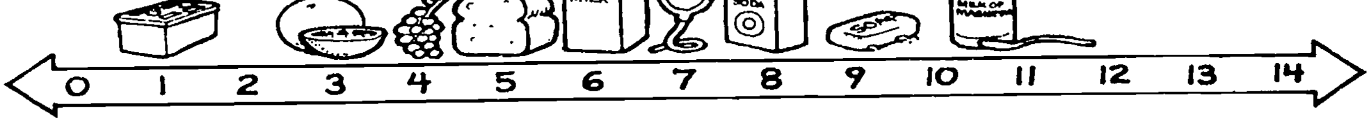
pH levels vary in different nutrient mixes and different water, so it is important to teach your students how to regularly measure and adjust the pH in the nutrient solution to the appropriate range. You can use narrow-range pH paper, reagent type test kits, or a pH meter to do so. Check with aquarium suppliers or science supply catalogs for these items. In the classroom, drops of white vinegar can lower the pH while baking soda can raise it. You can also safely use phosphoric acid or potassium hydroxide (from hydroponics suppliers) to adjust pH. The medium rockwool (see page 7) tends to have a high pH, so it should be soaked in a dilute nutrient solution to lower its pH before using. Pages 13 to 15 offer suggestions for activities to investigate pH and other important variables.



If you eliminate the soil and try to raise plants on water alone, what keeps the plant from drowning?

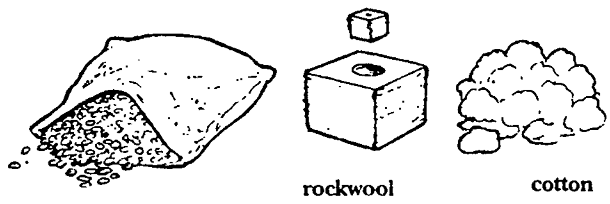
Mixed Media

The material that a plant lives in or on is called its **medium** or **substrate.** For most plants, the medium is soil. Soil, a dynamic material, contains living things such as bacteria, mites, and worms along with non-living substances like small rock particles, sand, and clay. Soil stores and releases nutrients, holds roots, and supports the entire plant. Good soil also contains air and water passages.



Growing Tips: Media

Hydroponic growers find many ways to support growth without drowning the plant. Many setups use an inert, sterile medium — something other than soil — that contains no microbes or pathogens. Some of the more popular choices include gravel, **perlite** (a lightweight expanded mica), a lightweight pebble-like **aggregate** (such as Geolite), **rockwool** (an inorganic, spongy, fibrous substance that holds large amounts of water and air), or clean sand. Some students even report successfully using cotton balls as growing media. These materials provide passages among the fibers or particles where air and water can move.



Each medium has strengths and weaknesses. Gravel and sand, for instance, provide support and good drainage, but can be heavy when wet and will dry out fast. Perlite is light and holds water well, but its fine dust can irritate lungs. (Sprinkle it lightly with water before using to avoid this.) **Vermiculite** is similarly light and absorbent, but breaks down and can clog hydroponic systems. Rockwool holds water and air and is easy for moving plants around, but breaks down fairly quickly and must be particularly well drained. Organic materials (such as cotton and cloth) will eventually be destroyed by bacteria. Your student scientists will benefit from exploring the properties and performance of a range of standard and invented media.

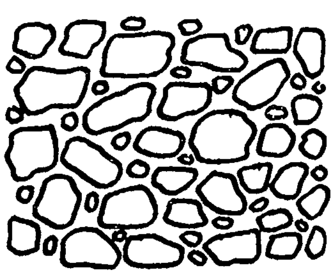
Some hydroponics systems have no real media, but more or less elaborate ways of suspending plants in nutrient solutions. In commercial **nutrient flow technique** (NFT) and **aeroponics**, for instance, the roots lie or are suspended in a dark channel and nutrients are sprayed or trickled along the root zone. A simple way to set up a classroom water culture system is to float plants on styrofoam trays in containers of nutrients (see Floating Styrofoam Raft system, page 19, for instructions).

Clingy Plants

Many plant species grow naturally without soil. Challenge your students to find out more about epiphytes, plants that grow on other plants, particularly in tropical forests. What are they? How do they survive? Where do they get their nutrients, air, and water? Why are they important to the total biosphere?

A Breath of Fresh Air

It is sometimes difficult for students to realize that even roots buried in soil must have oxygen for the plant to stay alive. Plants respire by taking in oxygen, which triggers plant cells to release and use the energy manufactured during photosynthesis, while also releasing carbon dioxide and water. Plant roots typically take in oxygen that's available in the small spaces between soil particles.



Plant roots draw oxygen, water, and nutrients from the spaces between soil particles.

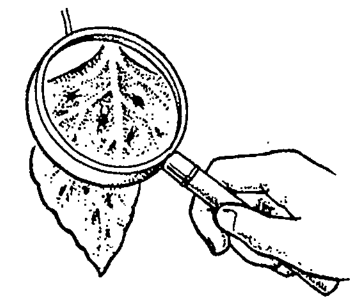
Soilless Classroom Profile

"Don't let lack of experience or familiarity with hydroponics deter you," advises Evelyn Tennenbaum, a Brooklyn, NY, Special Education teacher. "I learned with my students and we are still learning together, despite the fact that I have been doing this for more than 3 years. Hydroponics is continual exploration. We are constantly testing new products, constructing new

Continued on next page

PROFILE. *Continued from previous page*

systems, and making new friends by contacting people by letter or telephone. We had no failures, only new problems that required investigation, like the time our lettuce was attacked by aphids. This prompted research and an exploration of pest management.

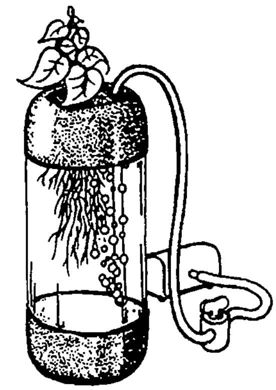


Students tried various homemade sprays and a beneficial insect, the green lacewing, which became our hero! My resource room students became teachers and grew self-esteem as they set up experiments in their own classrooms."

Limited by funds and space, Evelyn's students constructed their own hydroponic system from a 2-liter soda bottle, then germinated vegetable and herb seeds in rockwool cubes and Jiffy 7 pellets. When several strong roots developed, they inserted seedlings into an opening cut in the plastic base. Since they had no pumps, they decided to shake the bottle several times daily to provide aeration. This sparked questions and ultimately an experiment on how roots and plants responded to different levels of aeration. Students worked in teams and rotated duties, such as preparing nutrient solutions and testing pH.

Things grew so well, reports Evelyn, that they began a business selling hydroponically grown basil complete with recipes, then created additional soda bottle growing systems to sell to teachers, parents, and other students. "Eventually they needed an adding machine to total their earnings," says Evelyn. Students used the money to purchase a cart to transport and share hydroponic units with other classrooms.

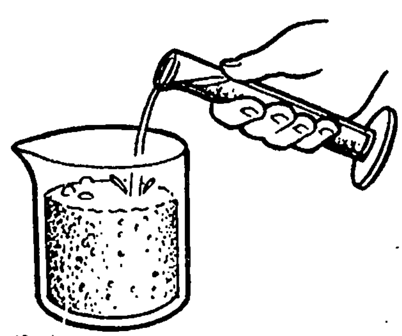
Growing Tips: Air



How do roots submerged in water get the necessary oxygen? It's a challenge for hydroponic gardeners. Water contains a small amount of dissolved oxygen, but it is used up quickly by the roots. There are different methods of ensuring that air reaches the plant's roots. In some small setups, aquarium pumps are used to infuse oxygen into the nutrients and medium. In large-scale commercial hydroponics operations, the nutrient solution, along with air, may be splashed or dripped on the roots at regular intervals, so that the plants are not completely submerged at all times. In some systems, the medium and roots are periodically flooded with a nutrient solution, allowing oxygen to bathe the roots in the interim. In other systems, water and nutrients reach the roots via a wick made of absorbent material, with part of the roots continually exposed to air. A porous medium like rockwool has a tremendous capacity for retaining oxygen while also absorbing nutrient solution. For short-term classroom studies, there may be air in the water and medium (e.g., rockwool) sufficient for the length of the investigation. Greens such as lettuce and herbs seem to be the best bets for a minimally aerated environment. Your students may wish to explore how different types of plants respond to different levels of aeration.

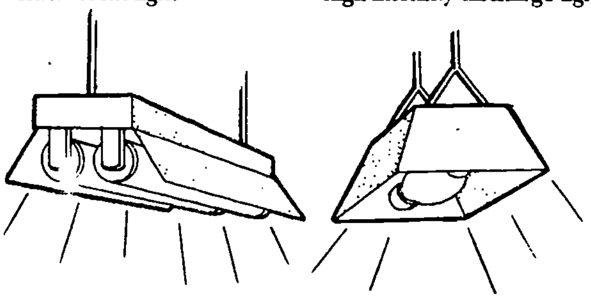
Air . . . Where?

To explore how much air can be contained in soil, have your students place a measured amount of coarse sand in a beaker or graduated cylinder. Ask them to determine how much water they can add before the water begins to puddle at the top, and to note the air bubbles that come to the surface as the air is displaced by the water. The volume of the water absorbed is an indication of the volume of air previously contained in the soil.



Let There Be Light

All green plants require light to drive the process of photosynthesis. The higher the light level, the potentially larger your hydroponic harvest, as long as you're adequately meeting other basic needs. Strong but diffuse sunlight at a window, or steady light (14 to 16 hours per day) from a GrowLab or other artificial light unit will suffice for certain crops. While many houseplants and smaller plants with low light requirements like seedlings, lettuce, or herbs will do fine in a hydroponic setup under fluorescent lights, commercial hydroponic gardeners and home gardeners wanting to grow larger fruiting and flowering light-loving crops (e.g., tomatoes) to maturity often use special high-intensity discharge lights with metal halide or high-pressure sodium lamps. These provide bright, efficient light closely approximating sunlight, but are significantly more expensive than fluorescents.

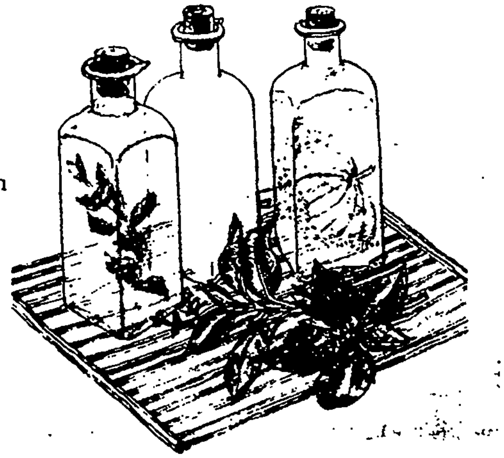


Your students' curiosity might lead to controlled investigations of light intensity or duration. For example, they might ask: How many hours of light will produce the fastest growth rate? If you use a classroom windowsill, in which plants receive light primarily from one direction, your class may notice the plants' gradual bending toward the light, a response known as **phototropism**. Consider

rotating the units every couple of days, if practical, and using the phototropic response to fuel investigations. For more background and activities on light, see pages 74 to 96 in *GrowLab: Activities for Growing Minds* (referenced on page 22 of this booklet).

Soilless Classroom Profile

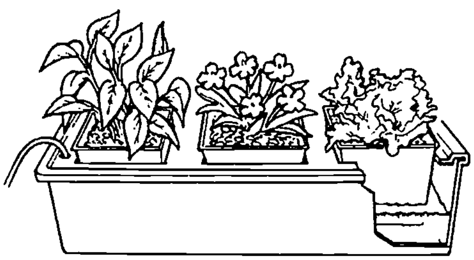
Terry Mushovic, Garden Advisor for Philadelphia County Friends of 4-H and the Pennsylvania Horticultural Society, helped to set up two hydroponic units in a school library. About 300 third and fourth graders grew herbs, keeping growth charts and observing plant changes. After about 6 weeks, reports Terry, they made herbal vinegars and herb cream cheese with their harvest. A follow-up planting of lettuce was harvested in a month and served with their own herbal vinegar dressing. "Students loved sampling their own harvest," says Terry. "Kids were fascinated and teachers delighted to participate."



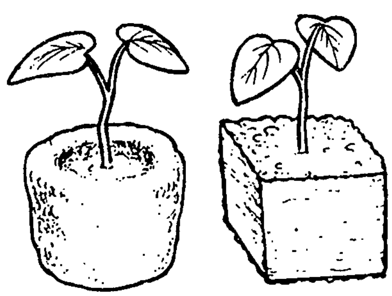
All the units were productive, she adds, but some problems in temperature swings in the schools adversely affected the plants. Low night temperatures in some schools during winter months had to be raised with heating cables. The school organized an end of the year trip to a commercial hydroponic greenhouse system in the Bronx, where students applied principles they'd gained working with their own units to an understanding of commercial production.

Choosing and Nurturing Plants

The plants you choose for your classroom hydroponic garden may be grown from seed or from cuttings of older plants. Popular classroom plants to grow from seed include lettuce; herbs such as basil, dill, and thyme; and flowers such as marigolds, zinnias, and nasturtiums. A number of classrooms have also succeeded with larger crops such as tomatoes and beans, and some report raising unusual crops such as ryegrass and alfalfa. If you have a passive, noncirculating system (see page 16), your best bets are leafy crops such as lettuce, herbs, and houseplants, and annual flowers such as marigolds and zinnias. If you have a more sophisticated active homemade or commercial system, you might also try crops like tomatoes and cucumbers. If you're purchasing seeds, look for varieties that are designated for greenhouse growing, as these should perform best in an indoor, soilless environment.

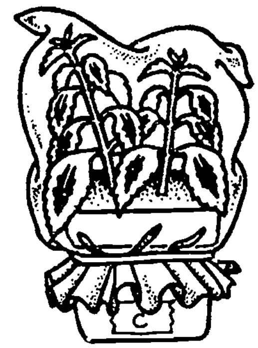


You can start seeds in cotton, cubes of rockwool, Jiffy peat plugs, perlite, or sand. When seedlings have several roots showing, they're ready to transplant into your system. What happens next depends upon the type of soilless garden you have. If it is simply a water-based system, gently rinse the seedlings clean of all attached particles and transplant them into your soilless garden. Otherwise, transplant them directly into the medium you will be using. Some hydroponic gardeners recommend transplanting late in the day to allow roots to settle into the new medium before being exposed to bright morning light. Some also recommend using half-strength nutrient solution for the first week or so after transplanting.



peat plug **rockwool cube**

Growing plant parts without soil — potatoes, bulbs, and houseplants, for instance — is a familiar home and classroom practice. Houseplants such as tradescantia, heartleaf philodendron, pothos, and geranium do quite well from cuttings. Rockwool cubes soaked in a 25 percent nutrient solution are nice for starting cuttings, although you can also use moist perlite or sand. Cuttings root more quickly if they're covered with a plastic dome or misted regularly to maintain a humid environment.



As with plants grown in soil, your seedlings and cuttings require ongoing care. For more ideas on what to grow, information on specific crops' needs, and growing advice, consult references listed on page 22. Here are a few general comments.

♦ **Plan space accordingly.** Leafy and vining plants need room to spread out. Challenge your students to figure out how to provide support or trellising for such plants as tomatoes and cucumbers.

♦ **Practice good hygiene.** Urge students to wash their hands before and after working with plants. Start with clean containers. Observe plants carefully for signs of insect pests. Aphids, spider mites, and white flies appreciate lush growth. Either hand-pick pests, wash plants gently with a mild soap solution, or remove infested plants from the setup. You can also expand students' learning possibilities by using biological controls (beneficial insects), available from many of the suppliers listed on pages 22 to 23.

♦ **Change the nutrient solution and check pH regularly.** Depending on the type of system you're using, you should change the nutrients every 1 to 3 weeks or so. Try to keep the pH between 5.8 and 6.5, the water temperature at around 70 degrees F, and the reservoir full.

♦ **Plan ahead for vacations.** If the setups are small enough, you might send hydroponic gardens home with students. If your unit is large and has an automatic aeration/circulation pump, it can be left running, but be sure to notify the custodian so the system won't accidentally be turned off. Make sure the nutrient solution container is filled before you leave, and that automatic lights are correctly working on a timer. Some schools plan hydroponics projects to coincide with terms, to avoid the problem altogether.

Everything and the Kitchen Sink

The containers to hold your plants can be as large or as small as your ambition, time, and creativity allow. Classes have adapted rain gutters, margarine containers, plastic bottles, old plastic flowerpots, bathtubs — even sinks.

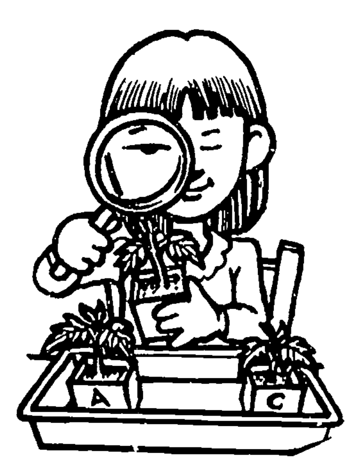
Exploring Hydroponics in Your Classroom

How simple or how complicated should this be? What challenges can I present to my class? What tools, materials, and skills do they need? All of these questions are important to a hydroponics unit or lesson. This section offers some ideas for planning hydroponics experiences to help students explore key concepts and generate their own investigations. The Soilless Classroom Profiles throughout this guide describe how some of your colleagues have integrated hydroponics into their classrooms and curricula.

Nurturing Learners

How you begin to study hydroponic gardening with your students depends on your own philosophy, your curriculum objectives, and the developmental levels of your students. You may wish to have one large hydroponic setup in your classroom to which each child contributes ideas and materials. Or you may ask small groups or individuals to choose a design or invent their own setup based on their understanding of plant needs and hydroponics. Research suggests that students learn in various ways. Some students prefer a personal approach, learning best when they can discuss their thoughts and work with other people. Others are happiest working alone. Some students want to be able to research what other authorities have to say, thriving on using books and articles to get ideas. Some students are "engineers" who must get right in there to invent, test, and mess around with materials. Still other students are happiest when they are pulling parts of a project together and designing reports or displays of their experiences.

Hydroponics projects can support these different learning styles and provide an opportunity for students to appreciate one another's differences. Consider establishing small cooperative groups of two to four students, while still allowing children to work alone for short periods of time. Make reference materials available in your classroom or in the school library. Encourage students to bring in materials (especially recycled ones) to build their hydroponic systems. Create a climate in which students share their discoveries with the class. Invite final reports and creative presentations.



Some teachers adopt a constructivist approach, by challenging students to pursue their own questions and

Soilless Classroom Profile

"Hydroponics investigations allowed my students to gain a concrete understanding of the basic needs of plants," says seventh grade teacher Melanie Boulet from New Orleans, LA. After reading and discussing a textbook article on hydroponic farming, Melanie challenged small groups of students to set up classroom hydroponic farms. Each group listed plant needs, then decided what materials they could use to meet those needs.

Armed with aluminum pie pans, cotton balls, marbles, test tubes, tape, bean seeds, carrot tops, and more, student groups had 2 days to create soilless setups. Based on information from resource books and local nursery contacts, each student group also created a "secret soup" fertilizer mix they hoped would send their plants skyward. The whole class designed data sheets and were allowed 5 to 10 minutes twice per week to care for the farms and collect data. Data sheets included one column for problems that arose and one for steps taken to redress them.

Group

Day	A	B	C	D
10				
8	7	4	4	0
6	7	3	4	0
4	6	3	3	0
2	4	3	2	0

Average Plant Height (cm)

"Students learned a lot from creating their own designs," reports Melanie. "Some had to devise ways to prop up their waterborne plants, and came to appreciate the support role typically played by soil. They also welcomed the independence I gave them and the knowledge that they were forging new ground, since none of us had done this type of technological problem solving before." In the future, Melanie says, she'd like to have the students visit a commercial hydroponic greenhouse operation, but only after they'd had the opportunity to mess around with their own ideas and designs.

establish a knowledge base through active investigation. The teacher facilitates the process, introduces concepts, and supplies technical vocabulary as needed to support student inquiry. Other teachers approach a hydroponics unit by dividing the important factors affecting plant growth into mini-lessons or study stations, and inviting small groups of students to become "experts" in one area. Still other teachers present relevant concepts in a prescribed order or have students rotate through learning stations (to become comfortable with all aspects of the hydroponics project). Others involve the entire class in setting up one or more comparisons of hydroponic and soil-based systems. In the following section, we share some thoughts on how you might plan, lay the groundwork, and engage students in exploring some key concepts of hydroponic gardening.

Developing Objectives

In planning a hydroponics unit, it's important to identify what you hope students will gain from the activities and investigations, including certain skills, knowledge, and attitudes, recognizing that a range of unintended outcomes will also emerge as students explore based on their own interests. Making certain objectives the basis of your planning will help you clarify expectations, bring coherence to the unit, and assess student gains.

The following key concepts and student performance skills, adapted from the draft 1995 New Standards Project, are some examples of outcomes you might target in a hydroponics unit.

Student Understanding of Life Science Concepts

- ♦ characteristics of organisms (needs and environments that meet them)
- ♦ life cycles
- ♦ changes over time

Student Understanding of Scientific Connections

- ♦ big ideas and unifying concepts (order, change, cause and effect, etc.)
- ♦ the designed world (agriculture and technology)
- ♦ science as a human endeavor

Student Ability to Use Scientific Thinking Skills

- ♦ ask questions about objects, organisms, and events
- ♦ seek information from reliable sources, including observation and trying things out
- ♦ recognize a fair test
- ♦ work individually and in teams to collect and share information and ideas
- ♦ identify problems, propose and implement solutions

Laying the Groundwork

Before you introduce the topic of hydroponics, you may wish to determine what students already know about the basic needs of living things. One way of gathering information about students' knowledge and curiosities is to have the class start a KWL chart, as illustrated.

KWL		
WHAT WE KNOW	WHAT WE WANT TO KNOW	WHAT WE'VE LEARNED

Another way some teachers introduce the topic is to show their students a photo or graphic of an animal near a green plant, asking the students to list and discuss what the animal needs to stay alive and healthy. They may suggest: food, water, love, space, air, and so on. Then ask them how the green plant's needs are similar. Students

Materials and Supplies

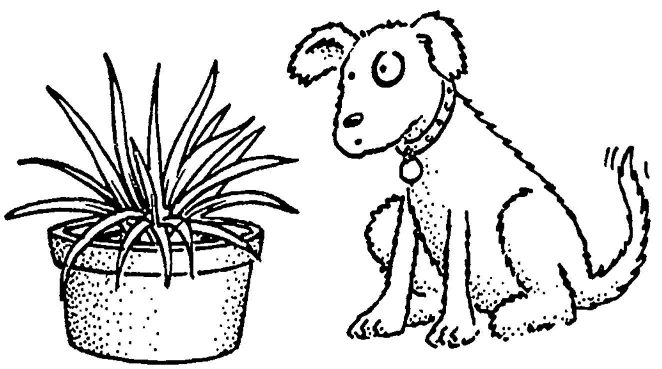
Hydroponics units involve a lot of materials, particularly when students invent or construct their own setups. If you purchase a commercial home hydroponics unit from a supplier, it will probably include things like nutrient solution, media, and containers. The following is a list of supplies you might have available if your students will be experimenting with different types of homemade hydroponics systems.

- ♦ containers (dish pans, plastic shoe boxes, flowerpots)
- ♦ styrofoam sheets
- ♦ hydroponic nutrient solutions (or individual nutrients)
- ♦ seeds or cuttings
- ♦ buckets
- ♦ wicking material (cotton cloth, rope, capillary matting)
- ♦ media (gravel, Geolite, rockwool cubes and/or slabs, perlite, cotton, clean sand)
- ♦ small aquarium or submersible pump
- ♦ pH paper and chart or test kit
- ♦ hardware cloth or other wire mesh for support
- ♦ plastic for liners
- ♦ gutters or PVC pipe
- ♦ tray with humidity tent for starting seedlings and cuttings

Soilless Classroom Profile

Seventh grade teacher Gayle Svets from Painesville, OH, has designed an exciting and unusual way to introduce hydroponics to her classes. In her project "The Svetsville Controversy," Gayle asks her students to imagine that they are citizens of Svetsville, a quiet seaside community that, because of an ongoing drought, has had problems supplying fresh water to its vegetable fields. Only limited amounts of water can be processed at the desalination plant, so only half of the fields can be irrigated. About half the citizens favor expanding the desalination plant to provide more water and jobs. The other half favor the development of hydroponic systems to maximize crop yields. Gayle divides her class into two groups, one to investigate geoponic (soil-based) systems and desalination methods, the other to investigate hydroponic systems. Within each group, she assigns roles of Biology Teacher, Field Harvester, Fertilizer Salesperson, and Local Politician. Each of these works with the rest of the group to research the pros and cons, set up controlled investigations, and ultimately report to the Planning Commission. The Commission consists of students from another class who vote on a "solution" after hearing presentations by both sides.

may name food, water, air, soil, and sunlight. Ask: Is there anything in either list that might not be absolutely necessary? Ask them to think about what might happen if any one factor were eliminated, and suggest that they'll have opportunities to find out for themselves what happens



when a plant is grown without soil. You might also begin a unit by asking students to imagine what a plant, if it could talk, might say about life without soil, and encourage them to write, design cartoons, or create short skits to dramatize their ideas.

Mini-Lesson Stations

Before setting up a complete hydroponic system, you may want to involve students in some short hands-on activities to explore some of the key factors affecting hydroponic setups. This section offers some ideas for "stations" that could be set up as learning centers before or during your hydroponics study. The stations are in no particular order and can be modified easily to suit your students' abilities, interests, and prior knowledge.

Station 1: Super Soup: Mixing the Nutrient Solution

Purpose: To learn correct procedures for combining the materials for a hydroponic nutrient solution.

Materials: Nutrients, in the form of commercial powdered or liquid hydroponic mixtures or as individual mineral salts (see pages 22 to 23 for suppliers), water, containers, measuring equipment, stirring rods.

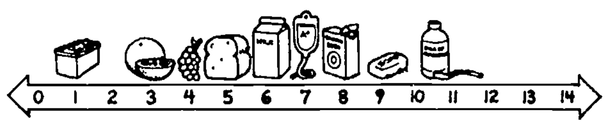
Procedure: Have students follow container directions or a recipe for mixing nutrients (see page 23), being careful to measure exactly.

Challenge Questions: *What questions do you have about nutrients? Which of these might you investigate in the classroom? What do you think might happen if you use a stronger nutrient solution than called for? A weaker solution? How might you design your own "secret formula" to grow plants? How would you measure your success?*

Station 2: pH: The Acid Test

Purpose: To learn how to measure and change pH in a liquid.

Materials: pH paper or test kit (available in pet stores and pool-supply stores), vinegar, baking soda, containers, distilled water.



Procedure: Teach students how to find pH. Provide about 100 mL of distilled water per container. Dip a pH paper strip into the liquid being tested and compare the color change to the chart provided with the paper, or follow directions on your pH test kit. Then challenge students to change the pH in some prescribed way (e.g., lower pH to 6 or raise it to 7), keeping track of the number of drops or pinches of baking soda needed. (The solution will fizz when vinegar and baking soda mix, much to students' delight.) Ask students to test and experiment

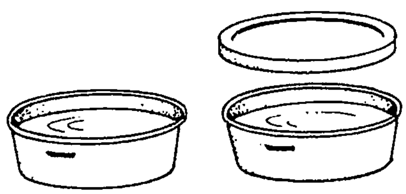
with the pH of the different nutrient mixtures. **Note:** You may want to precede this activity by encouraging students to brainstorm, then gather common solutions to test (e.g., orange juice, shampoo, household cleaners) to give them a better foundation for understanding the range of pH numbers.

Challenge questions: *How might a very acidic solution affect your hydroponically grown plants? A solution with a higher pH? How could you set up an investigation to find the answers to these questions? In what other situations might you need to know the pH of a solution? How else might scientists use pH?*

Station 3: Where's the Water?

Purpose: To discover the effect of evaporation in a hydroponic setup and to infer how it might change the system.

Materials: Two small containers (e.g., clean plastic margarine tubs), one lid, water, 2 teaspoons of salt, marker.



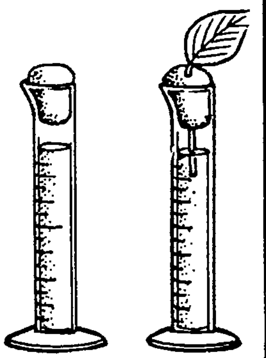
Procedure: This investigation takes at least a week, depending on the temperature and humidity when you conduct it. Have students add the same amount of water to each container and stir 1 teaspoonful of salt into each. Mark the level of the liquid inside the containers, then cover one container with a lid. Place both containers in a sunny window, then ask students to observe the changes in water level over the week. (In the open container the liquid level will drop as the water evaporates into the air. In the closed container, the liquid level should remain fairly fixed, with perhaps some evaporation and condensation appearing on the inside of the lid.) Consider asking students to invent ways to measure the amount of liquid lost. If you allow the water to evaporate completely in the open container, you'll see a white crusty salt residue left on the bottom. (You might let them taste the salty residue.)

Challenge questions: *How did the final water levels in the containers compare? How do you think the concentration (thickness) of salt varied in the two containers? How could you tell? How might evaporation affect the nutrient solutions that you mix for your hydroponic unit?* (Nutrients become concentrated.) *How could you "thin out" the mix? What does this investigation tell you about how to design or treat your own hydroponic unit?* (Students may add distilled water to bring up the water level in their units or design a way to decrease evaporation.)

Station 4: Plant Perspiration?

Purpose: To discover that water can be lost from leaves through transpiration in a hydroponic setup, and infer how to compensate for that loss.

Materials: Samples of different leaves with stems, graduated cylinders (one more than you have leaf types), modeling clay, water.



Procedure: This investigation takes about 2 days. Fill each graduated cylinder to the same level, and mark the water line. Wrap the clay around each leaf stem and insert the leaf and clay into the mouth of the graduated cylinder. Make sure that the leaf stem is well below the water level and that there is no air space between the stem and the clay or between the clay and the cylinder. As a control, simply plug one cylinder without a leaf. Place all graduated cylinders in a sunny windowsill and observe the level of the water in each over the 2 days. Water will move up the stem of the leaf and out through small pores in the leaves (called stomates). Students will see varying amounts of water loss from the cylinders.

Challenge questions: *What does this investigation indicate about leaves and water? Why did we have a plain cylinder with no leaf in it?* (This served as a control, to show that all water loss was actually through the stem and leaf). *What do your observations tell you about what might happen in a hydroponic system that you set up? How might you deal with the water loss?*

Station 5: A Medium Well-Done

Purpose: To investigate different kinds of media for their water-retaining properties.

Materials: A variety of potential hydroponic media (e.g., cotton balls, sand, perlite, cloth, rockwool, aggregate), magnifying glasses, water, containers, waxed paper or recycled foam trays for a work surface.

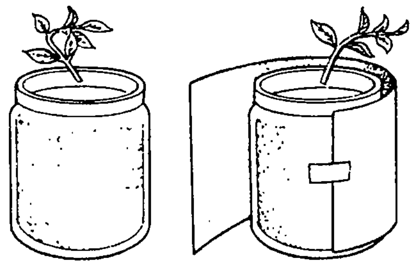
Procedure: Provide or ask the students to bring in a range of materials other than soil that they think might support plant growth. Have them examine the various media with hand lenses, making observations and sketches of the different structures. Have them predict which might absorb the most water, then choose one to try using in a simple hydroponic system.

Challenge questions: *Can you explain why you chose what you did? Can you invent ways to compare the water-absorbing properties of each medium? If you could design the perfect hydroponic medium, what would it be like?*

Station 6: Let There Be No Light

Purpose: To observe the effect of light on plant root development.

Materials: Two identical clean glass jars, polycrystals (sold in catalogs and garden centers under names such as Hydrosource and SuperSorb), two similar ivy cuttings, black plastic or other dark material sufficient to wrap one of the jars.



Procedure: This will take about three weeks. Add 1 to 2 teaspoons of polycrystals to each jar and fill it with water. After the crystals have swelled to fill each jar, gently poke a piece of ivy into each. Cover one jar with black material and leave the other uncovered. Place both jars on a window and observe. (Students should note that the roots in the covered jar form more strongly and fully. This is because light is actually a deterrent to active root growth.)

Challenge questions: *How do the roots in the two jars compare? Why do you think roots formed the way they did? How might the results of this investigation influence the way you build your own hydroponics unit?*

Digging Deeper

Once your students have gotten their fingers wet with hydroponics, their experiences and observations are likely to spark a variety of questions they can actively investigate. For instance: How do plants grown in a soil-based (geoponic) system differ from those grown in a hydroponic system? What might happen if we leave out a specific plant nutrient, or put in too much of another? Can we use houseplant fertilizers for hydroponic growing? How will plants grown with different amounts of aeration compare? Can we invent an automatic hydroponic unit from recycled materials? Can we grow enough herbs to share or sell? Can we simulate a pond or other wetland environment using what we know about hydroponics? When possible, encourage them to follow through with controlled investigations, observations, and/or additional research.

As students conduct and begin to make meaning from their investigations, it's important to help them reflect on their experimental setups. Encourage them to review and critique their own and others' science process (asking questions, in journals and in group discussions or reviews, such as: Was this a fair test? What other variables besides those we tested could have influenced our results? How could we revise this experiment if we were to do it again?

It's also important to help students make connections between their classroom experiences and broader concepts and issues in science and technology. Communicating with others can help them make these connections. For example, they might write a series of directions or produce visual or dramatic displays to demonstrate their understanding of an aspect of hydroponics. Involving a real audience such as parents and other community members can serve as a powerful learning tool, good public relations, and a way for you to assess what your students have learned.

Hydroponics units may spark an interest in learning more about the real-life and potential applications of hydroponic technology, as well as its limitations. Keep an eye on local supermarkets for hydroponically grown vegetables, and look for hydroponic facilities to visit at commercial or public greenhouses and nurseries. Also consider using hydroponics explorations to simulate or investigate relationships and changes in natural systems. The Soilless Classroom Profiles throughout this guide suggest ways in which other classrooms have branched out with hydroponics.

Soilless Classroom Profile

Sixth graders working with Joseph Kiefer's Vermont-based Food Works project had been doing an interdisciplinary "survival" unit and used hydroponics to simulate and monitor natural systems. One student group decided to combine raising fish with raising plants. They floated 2-inch-thick styrofoam rafts on a fish tank and grew basil and lettuce in rockwool cubes embedded in the foam. The plants used the nutrients from the fish manure and the Tilapia fish nibbled on the tips of the roots suspended below the raft, reports Joseph. "This project was truly authentic. We listened to student questions and encouraged them to set up reliable data collecting and monitoring systems." Students learned that until they got the right nitrogen cycle, the fish couldn't survive. "At the conclusion, we wondered about how to apply what we'd learned to the real world," says Joseph. "Students visited the State House and presented some of what they discovered about food supply — an important lesson in becoming responsible citizens."

Choosing Systems

So, you're intrigued by the concept of sowing and growing *sans* soil, but not sure what type of setup makes sense. This section gives an overview of some general types of commercial and homemade hydroponic systems, and illustrates a few classroom-designed systems that you and your students might consider creating. If you want to do short-term explorations, raising crops like lettuce, herbs, houseplants, or annual flowers, consider basic systems like those illustrated on pages 18 to 21. If you have visions of producing mature fruiting plants like tomatoes, cucumbers, and so on, and have the funds to do so, you might purchase a commercial hydroponic unit or locate a design for a more sophisticated unit (see pages 22 to 23 for resource materials and suppliers).

Hydroponic Systems Overview

There are a range of designs for hydroponic systems. Some use media, while others use only water. Some recycle nutrient solutions, while others rely on regular flooding with fresh solution. The following explains key hydroponic system terms and some general types of systems that are used commercially and by home gardeners.

Passive Systems

These systems use no energy to move nutrients and water. They can be as simple as a perlite-filled flowerpot that is hand-watered regularly with nutrient solution. Passive systems often use a "wicking" material to draw up the liquid nutrients, or they simply suspend the plants in the solution with an air space around some of the root zone. They can be media-based or pure water-culture systems.

Active Systems

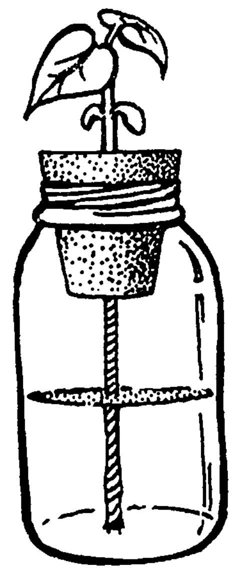
A hydroponic system is active if it relies on some type of energy (usually electricity via a pump) to move the nutrients in and out of the root zone area and to provide aeration. These systems, which can also be either media- or water-based, are generally used for larger plants (e.g., tomatoes and cucumbers) and tend to be more sophisticated. In recirculating or recycling systems, the nutrient

solution is conserved by being recirculated either manually or electrically through the medium. These systems require closer monitoring of pH, nutrient concentration, and so on. Systems with pumps to aerate and deliver more oxygen to roots tend to produce healthier plants more quickly than do passive systems.

Media-Based Systems

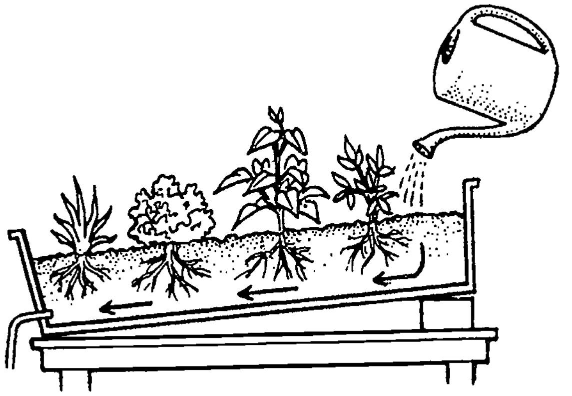
These rely on some material, such as gravel, aggregate, perlite, vermiculite, or rockwool to support the plants and the roots in the nutrient solution. Such systems can be active or passive and may or may not recycle the nutrients. Following are descriptions of some common types of media-based systems.

Wick Systems (passive): This is probably the simplest media-based system and a good one for exploring capillary action. A nutrient mix is drawn up into the medium through nylon or cotton wicks immersed in a reservoir.



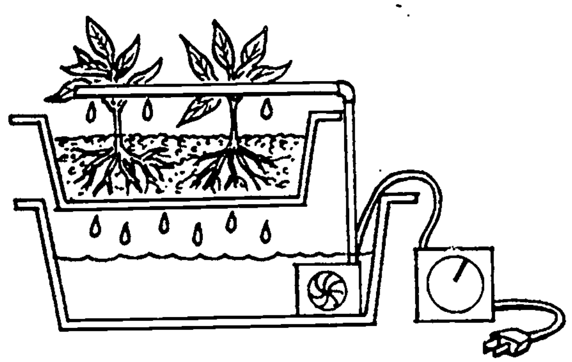
This is commonly used in schools where the biggest challenge is making sure that the plant roots get sufficient air and that the nutrient mix is diluted with water when the level drops. (See page 18.)

Ebb and Flow Systems (active): The plants and medium are flooded up to six times per day with the nutrient mix, then allowed to drain. As it drains, the system draws oxygen into the medium. These systems most often incor-



porate automatic timers, but can be flooded by hand if you are very consistent. Every several cycles, you must wash the roots and tank to remove any built-up, crusted salts. (See page 20.)

Top-Feed or Drip Systems (active): A timer-controlled pump delivers nutrient mix on a regular schedule through

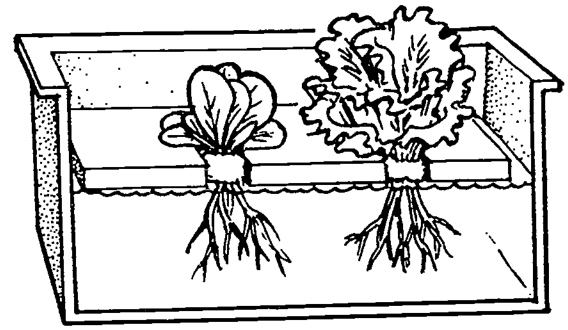


"emitters" (pipes with holes) to the top of the plant medium and allows the mix to drip down into a catch basin below.

Water-Culture Systems

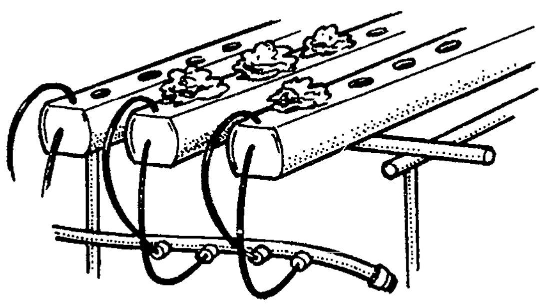
These systems do not use any medium other than water, so they require a support material such as wire mesh to keep the plants from drowning. These systems rely on regular contact between plant roots and the nutrient broth. Leafy crops like lettuce and herbs tend to do better in water culture than do fruiting crops like tomatoes, cucumbers, or peppers.

Raft System (active or passive): In this system, plants float on rafts above a reservoir of nutrient solution. (Styrofoam rafts work well in the classroom.) The tips of the roots reach the liquid and the holes cut in the raft for



the plants allow some air exchange. Many raft systems also aerate the water automatically, to provide the roots with greater exposure to oxygen.

NFT (Nutrient Flow Technique) (active): Plants are suspended in the nutrient mix, which is pump-circulated



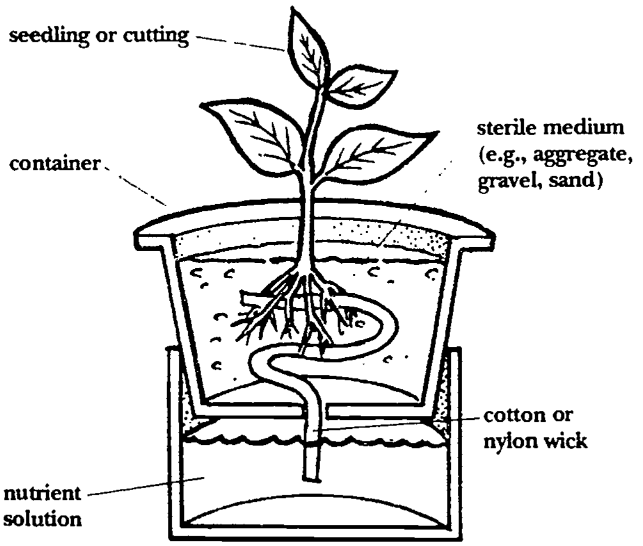
past the roots, aerating the solution. Commercial growers often place seedlings directly into rockwool cubes within holes cut in PVC pipe channels.

Aeroponics Systems (active): At regular intervals, plants suspended in the air are sprayed or misted with the nutrient solution. This technique, dependent on high-tech growing methods, is the one demonstrated in large scale at Disney's Epcot Center.

Simply Super School-Made Soilless Systems

You and your students may want to experiment with your own designs, or try some that other classrooms have used successfully. The following are a few systems used by classrooms in our growing network. We encourage you and your students to try them out or create a variation, then share your experiences with us!

Basic Wick

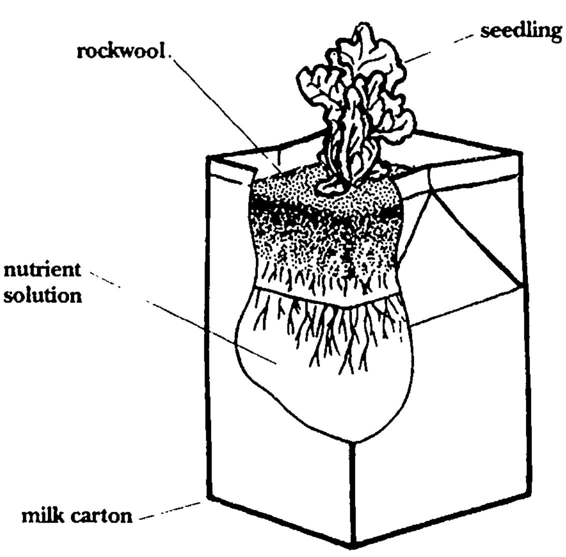


Growing Tips

♦ Place one end of the wick an inch or two into the container, then thread the wick down through the drainage hole into another container holding nutrient solution. Fill the top container with the growing medium.

♦ Keep the nutrient solution level constant by adding water as it evaporates and is transpired, and change the solution every week or two. Try to keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 degrees F.

Milk Carton and Rockwool

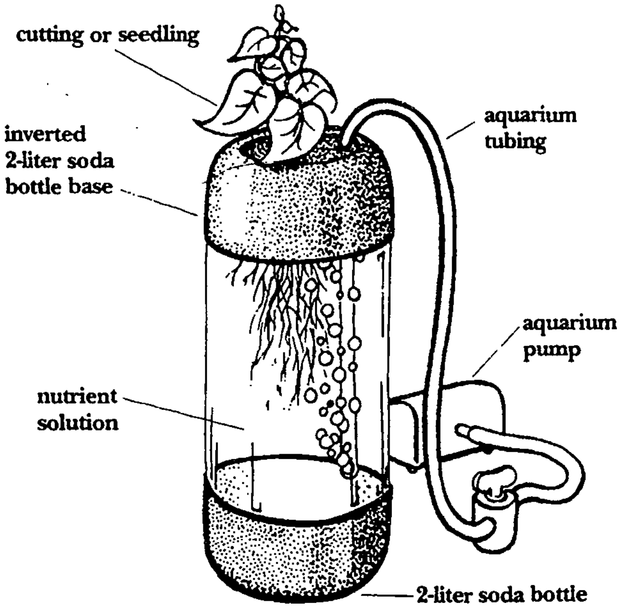


Growing Tips

♦ Plant seeds 1/4 inch deep in rockwool that has been soaked in a dilute nutrient solution and cut to fit in the milk carton. Try to keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 degrees F.

♦ Once seeds have sprouted, move the rockwool with the plant to an empty carton every day, pouring new solution over the rockwool into the new carton.

Soda Bottle



Growing Tips

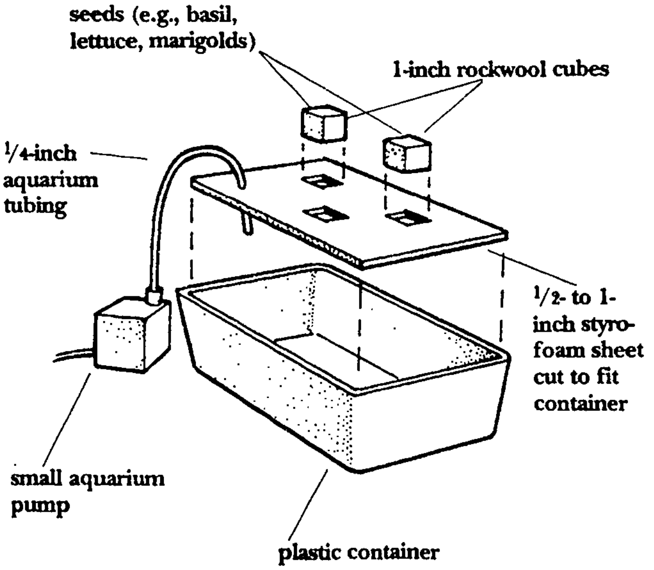
♦ Cut the top from one soda bottle, then remove the black base from another bottle. (Do this by filling the bottle with hot water to soften the glue, then prying the base loose.) Cut a hole in the base for your seedling or cutting, and another one to insert aquarium tubing, as illustrated.

♦ Insert aquarium tubing through the hole and connect the other end to your pump.

♦ Gently insert a seedling or cutting through the center hole in the top of the setup and wrap aluminum foil, dark plastic, or paper around the setup to exclude light from the roots.

♦ Try to keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 degrees F, and change it every two weeks or so. Some people suggest using a half-strength solution for the first week.

Floating Styrofoam Raft



Growing Tips

♦ Soak rockwool cubes with a dilute nutrient solution, then make a 1/4-inch hole and place a seed in the top of each cube.

♦ Cut a styrofoam raft to fit in the container, then cut holes in the raft, spaced 6 to 9 inches apart, to snugly fit the rockwool cubes. Be sure the cubes extend to the bottom of the raft.

♦ Poke the aquarium tubing through the raft into the solution. Keep the aquarium pump outside.

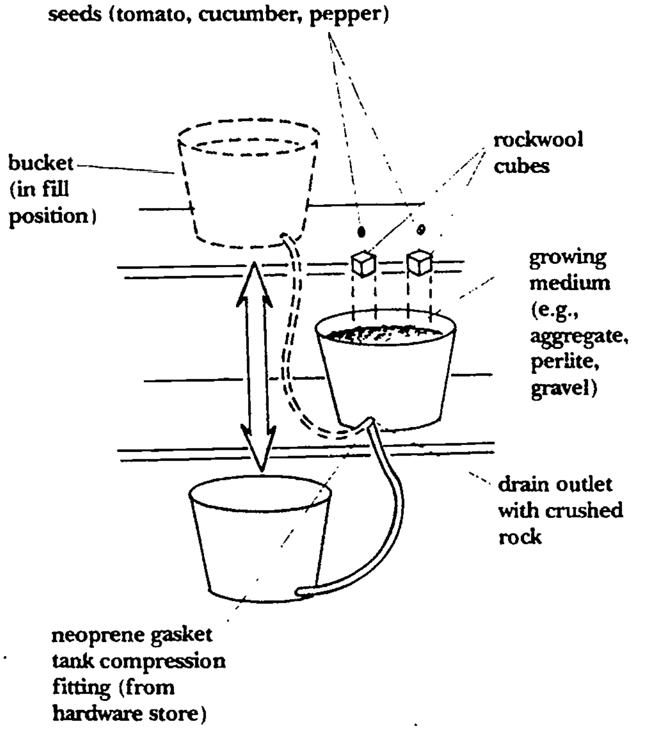
♦ Fill the container with water around 70 degrees F to within 1 inch of the top, then float the raft with planted cubes on the surface. When seedlings appear, add nutrients to the water at half the recommended strength. Try to keep the pH between 5.8 and 6.5.

♦ Let the air pump run continuously.

♦ After a week, raise the nutrient solution to full strength.

♦ Maintain a constant level. Change the entire solution every 2 weeks.

Basic Ebb and Flow



Growing Tips

♦ Soak rockwool cubes in dilute nutrient solution before planting seeds 1/4 inch deep. Place cubes in a tray of water until seeds germinate.

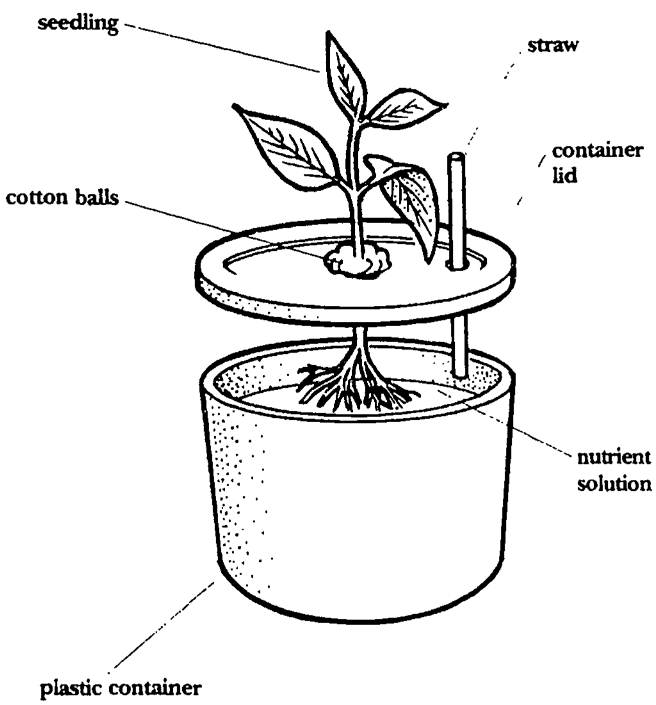
♦ Protect the drain outlet in the planting bucket from clogging by placing some crushed rock around it.

♦ Place cubes with seedlings in the moistened growing medium. Then put the bucket of nutrients into the fill position and allow the medium to fill to approximately 1 inch below the surface.

♦ Allow the solution to remain for about 20 minutes, then put the bucket in the drain position. Repeat this three to six times per day.

♦ Always keep a lid on the nutrient bucket. Try to keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 degrees F, and change the entire solution every two weeks.

Simple Straw Aeration



Growing Tips

♦ Use a utility knife to carefully cut a 1-inch X shape in the center of the lid.

♦ Cut a smaller X shape in the lid, about 1 inch from the edge, large enough to insert a drinking straw.

♦ Carefully clean the roots of a 4- to 6-inch-tall seedling (cucumber, lettuce, herb, etc.), washing off the perlite or other medium used to start it.

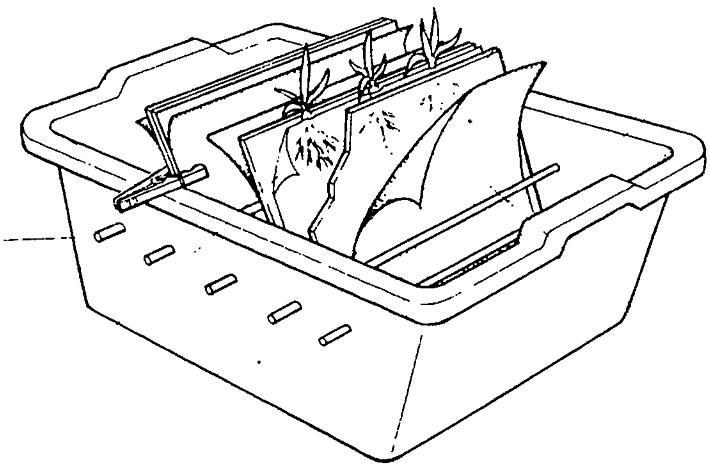
♦ Gently insert the seedling's roots through the large X, then insert some cotton balls between the stem and the hole to protect and secure the plant.

♦ Fill the container with a dilute nutrient solution, then secure the lid. Make sure that the root system, but not the stem, is completely immersed.

♦ Insert a drinking straw throug. the smaller hole into the solution. Twice a day, gently a rate the solution by blowing into the straw.

♦ Try to keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 degrees. Change the nutrient solution every 2 weeks, using a full-strength mix.

Plexiglas Slants



Growing Tips

♦ Drill holes about 2 inches apart on either side of plastic container to accommodate dowels.

♦ Cut Plexiglas with a utility knife to fit in container, as illustrated (or have it cut at hardware store).

♦ Wash fabric interfacing (to remove the flame retardant which is toxic to plants), then cut it the same size as your Plexiglas slants.

♦ Make a "sandwich" to lean against each dowel by placing a moistened square of interfacing between two pieces of Plexiglas. Wrap the sandwich side to side with black plastic to prevent light from reaching roots.

♦ Use clothespins to hold the sandwich together and to help maintain it at about a 45-degree angle in the container to maximize absorption of the solution.

♦ Start seeds (lettuce, alfalfa, beans, etc.) by placing them between the interfacing and the Plexiglas, about 1/4 inch below the top edge. (You can also start seeds in moist perlite, then gently clean the roots and transplant them to the slants.)

♦ Fill the container with 2 inches of nutrient solution with a pH between 5.8 and 6.5. Keep the level of the solution constant, and replace it with fresh solution every 2 weeks.

♦ You may want to cover the open solution with black plastic to reduce light and keep down algal growth. If you do have a lot of algae, remove slants and clean out the container with a dilute bleach solution before putting in your next batch of nutrients.

Note: System designer Don Coleman says that you can also use this method to make student-sized units with small plastic storage containers and scraps of Plexiglas.

Resources and Suppliers

Organizations

The Hydroponics Society of America
2819 Crow Canyon Rd., Suite 218
San Ramon, CA 94583
510-743-9605

The HSA offers support and information to educators, including a comprehensive hydroponics curriculum and wide range of resource books.

National Gardening Association
Education Department
180 Flynn Ave.
Burlington, VT 05401
800-LETSGRO (800-538-7476)

The NGA developed GrowLab — an indoor, garden-based science program for kindergarten through eighth grade that features indoor gardening equipment and supplies, inquiry-based curriculum materials, and the *Growing Ideas* teachers' newsletter. Its *Growing Ideas* catalog offers a range of resources for plant- and garden-based learning including a hydroponic unit. See page 24 for more information.

Cooperative Extension Service

This government network provides gardeners with a wealth of information and advice. It also supplies many gardening publications free or at a reasonable price. Many offices have school programs and/or a network of Master Gardener volunteers. To contact your local Extension Service Office, look under "Cooperative Extension" or under your county name in the phone book.

Resource Books, Journals, and Articles

Beginning Hydroponics: Soilless Gardening, by Richard E. Nicholls, Running Press Book Publishers, 1990, Philadelphia, PA.

Bottle Biology, by The Bottle Biology Project, Kendall/Hunt Publishing Co., 1993, Dubuque, IA. (Available from The National Gardening Association.)

GrowLab: Activities for Growing Minds, by the National Gardening Association, 1990, Burlington, VT. (See page 24.)

GrowLab: A Complete Guide to Gardening in the Classroom, by the National Gardening Association, 1990, Burlington, VT. (See page 24.)

Hydroponic Gardening, by Raymond Bridwell, Woodbridge Press Publishing Co., 1989, Santa Barbara, CA.

Hydroponic Home Food Gardens, by Edward M. Resh, Woodbridge Press Publishing Co., 1994, Santa Barbara, CA.

Hydroponic Instructional Package, by Stephen Butz and Andrew Fagan, 1994, Instructional Materials Service, Kennedy Hall, Cornell University, Ithaca, NY 14853-4203. Phone: 607-255-9252.

This instructional package includes student workbooks, a teacher's manual, and hands-on materials to help middle and junior high school teachers engage students in interdisciplinary hydroponics explorations. Write or call for a complete description of components and prices.

National Gardening magazine, 180 Flynn Ave., Burlington, VT 05401. Phone: 800-538-7476.

The National Gardening Association's bimonthly publication for home gardeners features occasional articles and regular advertisements from hydroponic equipment suppliers.

Plant Biology Science Projects, by David R. Hershey, John Wiley & Sons, Inc., 1995, New York, NY.

"Pardon Me, But Your Roots Are Showing," by David R. Hershey, in *The Science Teacher,* Volume 57, February 1990, pages 42-45.

The Growing Edge, P.O. Box 1027, Corvallis, OR 97339. Phone: 503-757-0027.

This quarterly publication for home and commercial growers features articles on hydroponic techniques and advertisements from suppliers.

Suppliers

The following suppliers carry commercial hydroponic units and supplies including lighting, growing media, nutrients, and air pumps.

Crop King, Inc., P.O. Box 310, Medina, OH 44258, Phone: 216-722-3958.

Diamond Lights, 628 Lindoro St., San Rafael, CA 94901, Phone: 800-331-3994.

General Hydroponics, 3789 Vine Hill Rd., Sebastopol, CA 95472, Phone: 800-374-9376.

Homegrown Hydroponics, 800 N. C.R. 427, Longwood, FL 32750, Phone: 407-830-GROW.

Hydrofarm-West, 3135 Kerner Blvd., San Rafael, CA 94901, Phone: 800-634-9999.

Hydrofarm-East, 208 Route 13, Bristol, PA 19007, Phone: 800-227-4567.

Hydrofarm-Ohio, 1967 N. High St., Columbus, OH 43214, Phone: 800-833-6868.

National Gardening Association (see organizations).

Science Supply Catalogs.
Most large school science supply catalogs carry a range of equipment, supplies, educational materials, and plants for hydroponic systems.

Suncor Systems Inc., P.O. Box 613, Beavercreek, OR 97004, Phone: 503-632-7599.
Although it doesn't sell retail hydroponic equipment, the company is interested in supporting school-based hydroponics with information and sample supplies.

Worm's Way, 3151 So. Highway 446, Bloomington, IN 47401, Phone: 800-274-9676.

APPENDIX

Homemade Nutrient Mix

Carefully measure and mix the following macronutrient and micronutrient ingredients in a clean bowl. This will make enough nutrient mix for 25 gallons (approximately 95 liters) of water. When you're ready to make a fresh batch of nutrient solution, add approximately 7 grams of mix per gallon (approximately $3^3/4$ liters) of water.

MACRONUTRIENT MIX

FERTILIZER SALTS	QUANTITY (GRAMS)	NUTRIENTS SUPPLIED
Calcium nitrate	65	Calcium/nitrogen
Potassium nitrate	32	Potassium/nitrogen
Magnesium sulfate	30	Magnesium/sulfur
Monopotassium phosphate	21	Potassium/phosphorus
Potassium sulfate	25	Potassium/sulfur

MICRONUTRIENT MIX

FERTILIZER SALTS	QUANTITY (GRAMS)	NUTRIENTS SUPPLIED
Boric acid	.15	Boron
Manganese sulfate	.30	Manganese
Copper sulfate	.02	Copper
Zinc sulfate	.05	Zinc
Sodium molybdate	.01	Molybdenum
Iron chelate	3.2	Iron

More Growing Resources from the National Gardening Association

The National Gardening Association's Education Programs include instructional materials and equipment and a national network of educators, community partners, and professional developers exchanging ideas and helping young minds grow.

GrowLab Garden-Based Science Program

In thousands of classrooms nationally, teachers use our GrowLab indoor garden laboratory and kindergarten through eighth grade curriculum materials to help students think and act like scientists, develop environmental responsibility, and explore subjects across the curriculum. GrowLab's inquiry-based teaching approach encourages students to use their own questions and observations as springboards for learning. GrowLab includes fully equipped light gardens, curriculum resource books (*Activities for Growing Minds* and *A Complete Guide to Gardening in the Classroom*), posters, teacher training videos, and the *Growing Ideas* newsletter that's a continuing source of inspiration for educators.

Growing Science Inquiry Program

Through our Growing Science Inquiry program, we provide workshops, materials, and support to local leadership teams of teachers and horticultural educators. These professionals become local resources for teaching colleagues who want to incorporate an inquiry-based approach to teaching with plants.

Partnerships for Professional Growth

Through our national database network, we can help you find "partners" in your area, such as botanic garden staff or other teachers who can help you get started with a garden-based initiative, or we can locate consultants who can conduct GrowLab/Growing Science Inquiry Workshops.

If you provide workshops or otherwise help classroom teachers integrate plants and gardens into the curriculum, our *Growing Partnerships: GrowLab Professional Development Update* will alert you to effective strategies for supporting teachers.

Youth Garden Grants Program

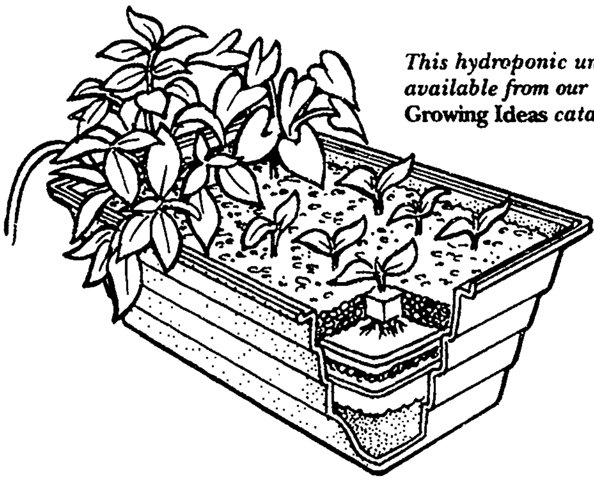
Through our Youth Garden Grants Program, we annually award grants of gardening equipment and supplies valued at more than $500 to each of 300 exemplary new or existing youth gardening programs. Grant recipients are selected based on need, the strength of their project plan, and the existence of community support. Applications are available each summer for a November deadline.

For More Information . . .

Write, call, fax, or e-mail our education department to request free copies of:

♦ 1995/96 *Growing Ideas* catalog of instructional resources including:

- GrowLab Program materials: GrowLab Indoor Gardens, *Activities for Growing Minds, A Complete Guide to Gardening in the Classroom,* instructional posters, and videos
- *Bottle Biology, Exploring with Wisconsin Fast Plants,* and other indoor growing resources
- Hydroponic equipment



This hydroponic unit is available from our 1995/96* Growing Ideas *catalog.

- Worm kits and instructional materials
- Outdoor gardening books and videos
- A school greenhouse kit
- *Guide to School Greenhouses*

♦ *Growing Ideas: A Journal of Garden-Based Learning,* teachers' newsletter

♦ *Growing Partnerships: GrowLab Professional Development Update,* newsletter

♦ Youth Garden Grants Program information

National Gardening Association
180 Flynn Avenue
Burlington, VT 05401
Phone: 800-538-7476
Fax: 802-863-5962
E-mail: nga@together.org

Share Your Soilless Experiences with Us

We're eager to hear about *your* classroom hydroponics experiences and to share them with other educators through our *Growing Ideas* newsletter and future revisions of this booklet. Please photocopy this page and use it to briefly describe hydroponic setups, lessons, and investigations that have engaged your students. **Return it to: Eve Pranis, National Gardening Association, 180 Flynn Ave., Burlington, VT 05401. Fax: 802-863-5962. E-mail: eve.pranis@together.org.**

Name	Title	Grade
School/Organization	Street	
City	State	Zip
Phone	E-mail Address	

Above address location is: ❑ home ❑ work

NATIONAL GARDENING ASSOCIATION