Exploring Hydroponics

INTRODUCTION

Hydroponics, in its simplest form, is growing plants by supplying all necessary nutrients in the plants' water supply rather than through the soil. The word derives from the Greek root words "hydro," meaning water, and "ponics," meaning working. Growing plants hydroponically helps gardeners and farmers grow more food in smaller areas (classrooms, greenhouses, rooftops, and living rooms, for instance) and to produce food in parts of the world where space, good soil, and/or water are limited.

When students grow plants hydroponically, they begin to investigate plant needs through a different lens and have the chance to develop a deep understanding about the conditions required for healthy plant growth and development. Hydroponic gardening also offers the opportunity to explore foundational engineering and design principles. Guiding questions emerge such as: How can we provide support for plants without soil? How do plants grown with just water and nutrients compare with plants grown in soil? How can we get the tallest plants using a hydroponics setup? These questions lead to experimentation and problem-solving in the classroom. Recordkeeping becomes a natural outgrowth of these endeavors. Concepts related to basic plant parts and needs, nutrition, food production, recycling, agricultural technology, and other areas come to life in these soilless growing environments. These studies may even lead to classroom business opportunities or fuel student career interests.

Additional benefits can be realized when edible crops are grown and students experience the joy and excitement of sampling the fruits of their labor! Edible gardening, along with food and agriculture education and local procurement, is one of the core elements of farm to school which enriches the connection students and communities have with fresh, healthful food and local food producers. Lessons in this guide help support integration of these core elements into the classroom and school community.

This guide includes

- basic how-to information for growing plants hydroponically in your classroom;
- lesson plans to help students learn through hands-on investigations;
- construction plans for simple hydroponics setups; and
- additional reference materials to support your endeavors.

The lessons are designed to align with third through fifth grade Next Generation Science Standards; however, they can be adapted for both younger and older students and those with different abilities. The lessons are sequenced so that each topic builds upon the previous topics. However, the activities can also be used independently, in any order.

LESSON 1
Hydroponics 101

Guiding Questions:

- What is hydroponics?
- Why grow plants hydroponically?

LESSON 2
Plant Needs

Guiding Questions:

- What do plants need to grow?
- How do hydroponic growing systems meet plants' needs?

LESSON 3
Exploring Hydroponic Systems

Guiding Questions:

- What are some of the basic growing techniques used in hydroponic systems?
- How do we evaluate different hydroponic system designs?

LESSON 4
Hydroponic Farm to Table

Guiding Questions:

- What are some of the challenges facing our food system today?
- How can hydroponics help us meet these challenges?

LESSON 5
Water versus Soil: A Hydroponic Investigation

Guiding Questions:

- How do traditional growing techniques compare to hydroponic growing systems?
- What factors do we need to consider to evaluate our findings?

How to Use the Guide

Each lesson begins with a summary and basic background information for educators including:

- Guiding questions
- Learning outcomes
- Links to Next Generation Science Standards Performance Expectations
- Estimated time for completion
- Materials list

To fully engage students in the topic, there are three distinct activities for them to participate in for each lesson. These are:

Laying the Groundwork — The lesson will begin with an activity or discussion to grab students' attention with a real-world connection so that they can see the relevance of what they are going to be learning before completing the exploration. The Laying the Groundwork activities will provide a practical foundation for understanding the concepts presented.

Exploration — Each Exploration includes hands-on activities for exploring the guiding questions of the lesson. Most of these explorations involve growing plants using different hydroponic techniques and can be conducted in either indoor or outdoor classrooms and with or without an existing school garden space.

Making Connections — The final activity for each lesson is designed to help students process the information they discovered in the Exploration and apply it to real-world situations. The goal of this activity is to provide students with a personal connection between hydroponics and their every day lives.

At the conclusion of each lesson, you will find multidisciplinary ***Extension Ideas*** for follow-up projects and activities that can be conducted to extend students' understanding of the topic. Ideas for scaffolding the lessons for middle school and high school students are also included. Lesson 2 includes a "Hydroponics Happenings" newsletter to send home to students families to engage them in hydroponics activities.

By the end of the lesson series, students will have:

- developed a solid knowledge foundation to be able to understand the benefits and challenges presented by hydroponic growing systems and the potential impact they may have on our future food systems;

- grown in their understanding of plant needs and the complexity of growing and providing a secure food supply;
- sharpened their observation and investigation skills through hands-on explorations; and
- had fun participating in engaging activities!

Let the discoveries begin!

LESSON 1
Hydroponics 101

Guiding Questions

What is hydroponics?
Why grow plants hydroponically?

Materials

Laying the Groundwork:

- Scrap paper
- Printed copies of "Hydroponic Time Line"

Exploration:

- Milk cartons
- Rockwool*
- Looseleaf lettuce seeds (as opposed to lettuce varieties that form tight heads)
- Hydroponic nutrient solution*
- Tray
- Printed Copies of "Hydroponic Garden Journal"

*Rockwool is made from molten rock that is spun into fibers and then compressed into mats or cubes. Both rockwool and hydroponic nutrient solutions are available online from hydroponics suppliers.

Making Connections:

- Printed copies of "What? No Soil"
- Video (optional)

Time

Laying the Groundwork: 30 minutes
Exploration: Planting Time – 1 hour; Growing Time – 3 to 4 weeks
Making Connections: 30 minutes

Lesson Summary

Hydroponics, in its simplest form, is growing plants by supplying all necessary nutrients in the plants' water supply rather than through the soil. It is a growing technique that has been used for thousands of years to produce food in parts of the world where space, good soil, and/or water are limited. Hydroponics is being explored as a way to meet the challenges presented by our growing urban populations and ease the demands on our environment and natural resources.

Learning Outcomes

After completing this lesson, students will:

- Understand that hydroponics is a horticultural growing technique where plants receive nutrients through water rather than soil that can be used as an alternative to traditional growing techniques in environments where space, soil, and water are limited.
- Be able to list some of the benefits of hydroponic growing techniques and discuss how it allows people to overcome natural environmental

challenges (like weather and poor soil conditions) and manmade environmental challenges (such as limited space).

- Be able to explain how hydroponics can help reduce human impact on the environment, by conserving water resources when using systems that recycle water, and by decreasing energy demands by decreasing the travel time of harvested fruits and vegetables.

Links to Next Generation Science Standards Performance Expectations

3-ESS3 Earth and Human Activity

3-ESS3-1. Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.

4-ESS3 Earth and Human Activity

4-ESS3-2. Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

5-ESS3 Earth and Human Activity

5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Background Information

Records show that plants have been grown without soil for many thousands of years. The hanging gardens of Babylon reportedly used hydroponic techniques. Hydroponics systems have been used in China for at least the last 800 years. To protect crops from enemies and expand their growing space, the Aztecs in what is now Mexico took to the lakes and maintained large floating rafts woven of rushes and reeds on which they raised food crops.

Hydroponics began to emerge as a scientific pursuit in 1699 when 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 era of hydroponics began in the 1930s with the work of Dr. William Frederick Gericke. Gericke, a professor at the University of California, raised tomatoes and other crops on floating rafts, applying previously developed principles in a commercial way. He officially coined the name hydroponics. **The word derives from the Greek root words "hydro" and "ponics," meaning "water working."** University of California, Berkeley researchers Dennis Hoagland and Daniel Arnon continued to advance the use of hydroponics through the development of nutrient solution formulas that are still in use today.

Why Hydroponics?

What is the motivation behind developing alternative growing techniques when soil-based cultivation is clearly demonstrated by nature? Using hydroponic techniques to grow plants certainly appeals to our sense of curiosity. It is intriguing to watch plants grow successfully in conditions that are so different than what is found in nature. **However, the development of hydroponics is rooted in practical application and the need for creating alternative growing solutions to tackle environmental challenges.** Hydroponic techniques offer numerous benefits, including:

- **They can be used in locations where quality soil is not available.** From concrete-paved urban areas to sand-covered deserts, hydroponic farms create growing space in inhospitable environments.
- **They can be placed in urban locations close to population centers so that food does not need to travel far from harvest to market.** This can decrease transportation costs and environmental impacts and also offer consumers fresher produce.
- **They are free from seasonal constraints.** Systems can be set up outdoors or indoors. Indoor systems allow growers more control over the plants' environment, including light availability and temperature, which allows growers more flexibility in timing of planting and harvesting of crops.
- **They can be designed in different sizes depending on the space available.**
- **They allow growers more control over nutrient availability.** In hydroponic systems, nutrients are added to water and then provided direct access to plant roots. In soil, roots must search for the nutrients stored in the soil and there are many more organic, inorganic, and weather-related factors determining nutrient availability.
- **They can maximize the growth rate of plants.** Because plants are being provided with optimal amount of nutrients, water, and light, they can grow faster than crops grown using traditional horticultural techniques resulting in increased production rates.
- **They can be designed to conserve water.** Excess water can be recaptured and reused, allowing for a more efficient use of this precious resource. In most cases, hydroponically grown crops require less water than traditionally grown crops.
- **They offer better control over weeds, insects, and disease.** Unlike soil, hydroponic systems can be thoroughly cleaned to remove potential plant pests. This can make it easier to grow crops organically without herbicides and pesticides.
- **They can decrease the amount of cleaning harvested crops need before consumption.** This can save both time and water.

As our global population grows and urban areas expand, farmers and scientists are increasingly interested in finding ways to boost food production, especially in dense population centers, while also decreasing environmental impacts and increasing efficient use of natural resources. Hydroponic growing techniques are at the forefront of current research regarding food production of the future. **By adding hydroponics growing systems to your classroom studies or garden program, you are giving students the opportunity to combine lessons in basic plant biology with the latest technology which can stimulate their interest in the fields of botany, horticulture and agricultural engineering.** Perhaps some of your students will become hydroponic farmers one day!

Laying the Groundwork

Begin your hydroponic adventure with an anonymous vote. Pass out small slips of scrap paper and ask students, Do plants need soil to live? Have your students write down their answers and then collect the papers in an envelope to discuss at the end of this lesson.

Next, ask students if they have ever heard of hydroponics. What is hydroponics? *Hydroponics, in its simplest form, is growing plants by supplying all necessary nutrients in the plants' water supply rather than through the soil. The word derives from the Greek root words "hydro" and "ponics," meaning "water working."*

Share the Hydroponic Time Line worksheet at the end of this lesson. After reading the short descriptions about each historical example of hydroponic use and development, discuss why hydroponics was used instead of traditional growing techniques in each situation in more detail using the resources listed below. As a class, summarize the reason why hydroponic growing techniques were used in one or two words for each situation in the third column.

Aztec Civilization:
Aztec Agriculture: Floating Farms Fed the People." History on the Net, Salem Media. April 5, 2020.
https://www.historyonthenet.com/aztec-agriculture-floating-farms-fed-the-people

Ascension Island Air Force Base:
Thacker, Zoe. "Ascension Island's Hydroponics Lab is Revitalizing Life on the Volcanic Island." U.S. Air Force, 29 September 2019.
https://www.af.mil/News/Article-Display/Article/1973447/ascension-islands-hydroponics-lab-is-revitalizing-life-on-the-volcanic-island/

NASA:
"Basil Orbits Earth." NASA. 16 August 2007.
https://science.nasa.gov/science-news/science-at-nasa/2007/16aug_basil

Educational Payload Operations – Kit C: Plant Growth Chambers. NASA.
https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Investigation.html?#id=179

Exploration

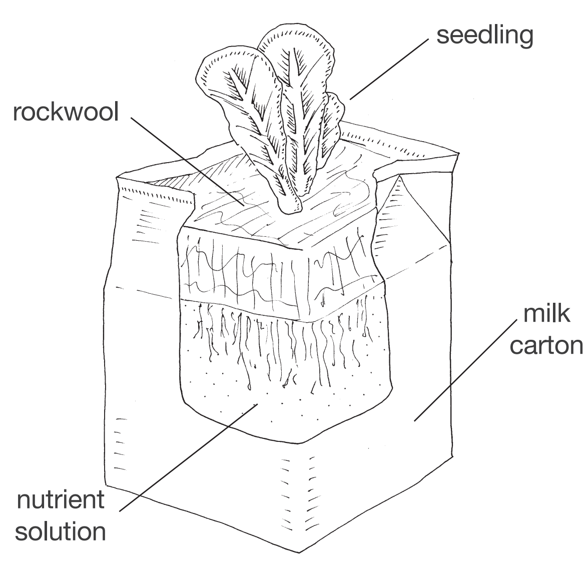
Your class can begin their hydroponic exploration by creating a very simple hydroponic system for observation using rockwool (an inorganic, spongy, fibrous substance made from rock that holds large amounts of water and air) and milk cartons. **For additional background information on growing plants hydroponically to aid your delivery of the Exploration activity, please reference the Hydroponic Basics resource in the Appendix.**

1. Collect empty milk cartons. Thoroughly wash cartons, and then disinfect them by rinsing in a 10% bleach solution (1 part bleach to 9 parts water) before using.

2. Cut rockwool into pieces sized so they will fit snugly into the milk cartons, and then soak the pieces of rockwool in a dilute hydroponic solution. Hydroponic nutrients are available in dried or liquid form. Most are concentrated and must be mixed with 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 it. When mixing nutrient solutions, always dilute them to the concentration recommended by the manufacturer.

3. Plant lettuce seeds 1/4 inch deep in the rockwool, and then place the rockwool in a tray of dilute hydroponic water until seeds germinate, which will usually take 2 to 7 days. If using individual-sized milk cartons, 5 to 10 lettuce seeds per rockwool piece should be plenty. For the best success with lettuce seeds, keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 F.

Milk Carton and Rockwool System



4. Once seeds have sprouted, move the rockwool with the seedlings to an empty milk carton. Each day, transfer the rockwool to a new, clean carton and pour new nutrient solution over the rockwool into the new carton to a level that can reach the bottom of the rockwool. As students will learn in Lesson 2,

roots need both air and water and this process of changing out the carton and solution daily provides them to the plants. Additionally, this process will discourage algae buildup in the solution and on the rockwool.

Any remaining diluted nutrient solution from the original milk container can be used to water indoor plants or container gardens. **Nutrient Disposal Caution:* Take care where you dispose of nutrient solutions. Houseplants, indoor plants, and container gardens are fine places to recycle the liquid. However, aquatic ecosystems are quite sensitive and the balance of minerals is very delicate. If there is a stream, lake, or other water source nearby, do not dispose of liquid nutrients on the ground. After disposing of any remaining solution, you can then wash, disinfect, and reuse the carton.

❺ Track the growth of your plants. You can use the Hydroponic Garden Journal page at the end of this lesson to record your observations.

❻ Once lettuce plants have developed several sets of leaves, you can begin harvesting the outer (largest) leaves by cutting them off with scissors and allowing the plant to continue growing. Or you can harvest all the leaves at one time. Enjoy!

Making Connections

Pique students' interest in growing plants using hydroponic techniques by sharing how it is being used to grow plants for space travel. Ask students to read "What! No Soil?" located at the end of this lesson individually or as a class, then ask the following discussion questions:

- According to this reading passage, do plants need soil to grow? No, they can get all the nutrients they need from water and air.
- What are some examples of environments where it is hard to grow plants in soil? In outer space, in a desert, in a city, in places where it is really cold, like Antarctica.
- If traditional planting methods do not work, why is it important for people to be able to find other ways to grow plants? Plants provide us with food and oxygen and can help clean our water. People would not be able to survive without plants. Studies have also shown that plants help us feel happy and peaceful.

You may want to show your class the following videos for additional discussion:

Space Station Live: Cultivating Plant Growth in Space
https://www.youtube.com/watch?v=9MfWARdoF-o

Space Station Live: Lettuce Look at Veggie:
https://www.nasa.gov/mission_pages/station/research/news/meals_ready_to_eat

Space Station Live: Everything's Coming Up Veggie:
https://www.youtube.com/watch?time_continue=21&v=9JDAZBoLJUc&feature=emb_logo

Doug Ming on Technologies for Required for Living on Mars:
https://www.nasa.gov/offices/marsplanning/faqs/

After watching their lettuce seeds grow and reading the passage, ask your class to brainstorm benefits of growing plants in hydroponic systems. You can use the information in the Background Section to help them with ideas. Make sure your discussion covers the following points:

- Hydroponics can help people grow plants in environments that do not provide optimal conditions.
- Hydroponic growing systems can be designed to decrease the impact of weather on growing crops.
- Hydroponics can help gardeners and farmers use resources like water and soil more efficiently.

Extension Ideas

Math and Science: Extend the Exploration by also growing lettuce seeds in soil-filled milk cartons (make sure to add drainage holes in the bottom before planting) alongside your hydroponic units and compare their growth. Weigh the two types of cartons for comparison and also track any differences in seed germination time, plant height, approximate water usage, and amount of harvest (measured by number of leaves or by weight). If harvest is large enough, your class can also hold a blind taste test so students can compare the hydroponically grown lettuce and the lettuce grown in soil.

Social Studies: Learn how hydroponic growing is used in environments on Earth that pose challenges to traditional growing methods. The following videos provide stories from hydroponic gardens in Antarctica:

Exploratorium Subzero Water Works in McMurdo Station on Ross Island, Antarctica:
https://www.exploratorium.edu/video/subzero-water-works

Exploratorium Polar Paradise:
https://www.exploratorium.edu/video/polar-paradise?autoplay=true

Australian Antarctic Division: Hydroponics:
http://www.antarctica.gov.au/living-and-working/station-life-and-activities/food/hydroponics

Science and More: Scientists in Antarctica have harvested the first crop of vegetables grown without soil or light:
https://www.youtube.com/watch?v=MSJF5t0xX6Y

English Language Arts: Have students keep observation journals as their plants grow. The entries can be kept from the perspective of the gardeners or, for a creative angle, ask students to pretend the plant is writing the journal.

Middle School and High School Ideas:
Spread the Word. Encourage students to make posters, short videos or a PSA about hydroponics for your morning announcements to teach other students about hydroponics. Alternatively or additionally, create informational brochures about hydroponic growing techniques to take home to share with their families and other community members.

Check Out the Research. Watch the TEDX Talk highlighting the Growing Beyond Earth® Program, a collaboration between NASA and the Fairchild Tropical Botanic Garden, through which middle and high school students are helping NASA prepare to grow plants in space. Ask students to brainstorm topics for and then design their own experiments using hydroponic growing techniques to solve a local, national, international or interstellar challenge.

Growing Beyond Earth® Program
https://www.fairchildgarden.org/Science-Conservation-/Growing-Beyond-EarthNasa-and-Fairchild

Hydroponics 101

WORKSHEET

What! No Soil?

Planning a trip to Mars? What do you need to pack? Since there are no grocery stores in outer space, food and water should be at the top of your list.

For short trips, like to the moon, astronauts can pack all the food and water they will need. But what about a trip to Mars, which could take up to a year round-trip?

The ability to grow plants in space would be very important for longer space travel. Plants can provide food, help make oxygen, and also help filter water. Plants can also lift our spirits when we are far from home.

Soil is both heavy and bulky – two qualities to avoid when packing for space travel. Besides, in low-gravity environments, water can't be poured directly onto the soil because, rather than sinking into soil, it hits the surface, breaks into smaller droplets, and bounces off. So, how can you grow plants without soil? As a solution, scientists are using a special technology called hydroponics to grow plants in space.

What is hydroponics? Instead of growing in soil, plants get most of the nutrients they need from nutrient-enriched water.

People have actually been growing plants in water for a long time. The Aztecs, who lived in Mexico over 700 years ago, grew food crops on large floating rafts made of woven rushes and reeds because they were surrounded by lakes and needed a safe location and more space to grow enough for food for all their people.

Hydroponic gardens can be used to grow plants in special conditions, like on a spaceship where room to grow is limited and soil is not present. Hydroponic gardens can also be grown indoors under artificial light if sunlight is not available. Hydroponic systems can be designed to conserve water if the water supply is limited.

There are lots of places on Earth where growing plants using hydroponics can be useful. You can use it in cities or deserts where there is little soil for gardening or farming. You can also use it to grow plants indoors during winter months or in places that are always cold, like Antarctica.

Hydroponics is why gardeners can say “No soil, no problem!”

LESSON 2
Plant Needs

Guiding Questions

What do plants need to grow?
How do hydroponic growing systems meet plants' needs?

Materials

Laying the Groundwork:

- Chalkboard or dry-erase board

Exploration:

- Rockwool or cotton balls
- Lettuce seeds
- Small plastic containers with lids (such as margarine, cottage cheese, or yogurt containers)
- Hydroponic nutrient solution
- Plastic drinking straws
- Printed Copies of "Hydroponic Garden Journal"

Making Connections:

- Paper, pencils, and markers

Time

Laying the Groundwork: 30 minutes
Exploration: Planting time – 1 hour; Growing Time – 3 to 4 weeks
Making Connections: 30 minutes

Lesson Summary

Hydroponics growing systems fulfill the basic needs of plants in a different way than traditional growing techniques.

Learning Outcomes

After completing this lesson, students will:

- Be able to list all the resources plants need for healthy growth and explain how they obtain those materials through the functions of different plant parts.
- Understand that plants get most of the nutrients they need to grow from the air and water.
- Be able to demonstrate and share how hydroponic growing techniques provide for a plant's needs and support plant growth using a simple hydroponic system they will construct.

Links to Next Generation Science Standards Performance Expectations

4-LS1 From Molecules to Organisms: Structures and Processes

4-LS1-1. Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.

5-LS1 From Molecules to Organisms: Structures and Processes

5-LS1-1. Support an argument that plants get the materials they need for growth chiefly from air and water.

Background Information

Plants, like all living things, have certain requirements that need to be met for them to grow and thrive. These include water, nutrients, light, air, and structural support for the roots. Here is a description of why each of these is important to a plant:

Water

Water is required for photosynthesis (production of food) and transpiration (evaporation of water from leaves into the air, cooling the plant and creating pressure to move water from roots to leaves). It also aids in the absorption of some nutrients.

Air

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. Although we mostly think of plant leaves taking part in this air exchange, plant roots are also part of this process and typically take in oxygen that is available in the small spaces in between soil particles.

Light

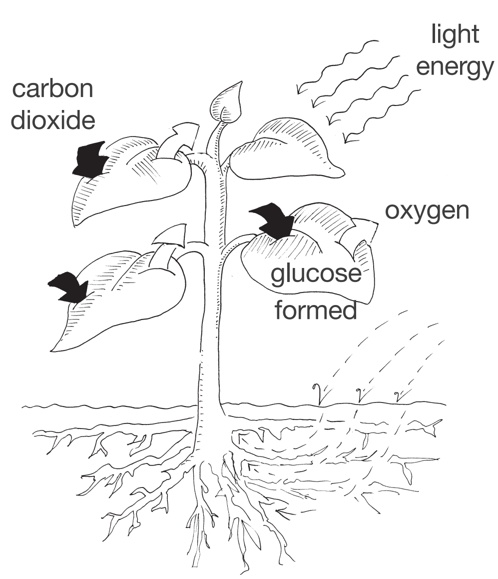
Plants capture light energy for use in photosynthesis – the process by which plants make their food.

Nutrients

Plants require certain minerals for proper growth and function of biological processes. In nature, plants obtain most of their needed nutrients from the soil. Nutrients occur naturally in the soil as a byproduct of decomposition of organic matter or derived from parent rock, or can be added through fertilizer* applications. These nutrients or minerals are not actual food, but rather are elements vital to helping the plant utilize the sugars (the real food) that it produces during photosynthesis.

*Fertilizer is sometimes referred to as "plant food," but plants actually make their own food through the process of photosynthesis. Fertilizer is more accurately compared to a multivitamin.

Photosynthesis



A Place to Grow

Plants need a place to call their own. They need a way to anchor their roots so that their top growth is secure against environmental conditions such as wind, the leaves can expand to capture light, and the plant has the ability to reach its full growth potential.

Hydroponic Adaptations

In traditional gardening, plants get root support, nutrients, water, and oxygen from the soil. Adaptations of hydroponic growing techniques to fulfill these critical plants needs include:

Water and Air: In the soil there are naturally occurring pockets of air and water, both of which contribute to proper root growth and functioning. It is important for students to understand that even roots must have oxygen for the plant to survive, so hydroponic systems can not merely submerge the roots in a bath of water for a plant to function properly and survive long-term.

There are many different ways for hydroponic systems to deliver this mix of water and oxygen to the roots. In some setups, water and nutrients reach the roots via a wick made of absorbent material, and part of the roots are continually exposed to air. Others actually grow the plants in a porous medium like rockwool, which acts as a soil substitute due to its capacity to offer similar pockets of air and water for roots. Some hydroponic systems use a pump to infuse oxygen into the water, similar to how a fish tank aquarium works. Another option is for the medium and roots to be periodically splashed or flooded with a nutrient solution, allowing oxygen to bathe the roots in the interim.

A Place to Grow – Root Support: The material that a plant lives in or on is called its medium or substrate. For most plants, the medium is soil. As stated above, soil naturally provides pocket of both water and air and provides plant roots with the structure necessary so the plant can anchor itself securely.

Hydroponic growers find other ways to support growth — and to prevent drowning roots by allowing them to remain sitting in water. Many setups use an inert, sterile medium to serve as a base (like a soil substitute). Some of the more popular choices included gravel, clean sand, perlite (volcanic material that is heated until it expands into a lightweight, styrofoam-like material), a lightweight pebble-like aggregate, and rockwool (an inorganic, spongy, fibrous substance that holds large amounts of water and air). These materials provide passages among the particles or fibers where air and water can circulate.

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 to avoid this.) Rockwool holds water and air nicely and makes it easy to move plants around, but breaks down fairly quickly.

Some hydroponics systems have no real support media, but rather incorporate more or less elaborate ways of suspending plants in nutrient solutions. In the commercial nutrient film 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.

Nutrients: In soil, nutrients come from rock and mineral leaching and organic matter decomposition. They are "held" by the soil particles and dissolved in the surrounding water before being absorbed the roots. In hydroponics, growers add nutrients to the irrigation water being applied to the roots.

Hydroponic Nutrient Solutions: The easiest way to supply these nutrients is to purchase prepared hydroponic nutrients in dried or liquid form. Most are concentrated and must be mixed with 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 it. Your students might want to explore this themselves by comparing plants grown in nutrient solutions made with distilled water versus those made with tap water.

Testing Water pH: The pH of the nutrient solution is an important factor in hydroponics. It 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 unavailable to plant roots. The range that allows the plant to use the dissolved minerals most effectively is just slightly acidic. pH levels vary in different nutrient mixes and water sources.

You can determine the pH of a solution in numerous ways. Two of the easiest ways to obtain an accurate pH reading are to use specially designed pH test papers (fairly inexpensive, but each can only be used once) or purchase a pH meter (more expensive, but multi-use).

Mixing Nutrient Solutions: When mixing nutrient solutions, always dilute them to the concentration recommended by the manufacturer. The amount of nutrients you use will depend on the type of system you have, temperature, light, and type of plants you are growing.

Replacing and Disposing of Nutrient Solutions: In hydroponic systems, nutrient solutions need to be replaced periodically. The frequency will depend on the type of system as well as other factors. Nutrient concentrations, for example, will vary as nutrients are taken up by the plant, and as water evaporates and transpires from plant leaves. 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. These solutions can be recycled for watering other classroom or outdoor plants.

Take care where you dispose of nutrient solutions. Houseplants, indoor plants, and container gardens are fine places to recycle the liquid. However, aquatic ecosystems are quite sensitive and the balance of minerals is very delicate. If there is a stream, lake, or other water source nearby, do not dispose of liquid nutrients on the ground.

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. If your plants are getting leggy, which means they are growing quickly and producing skinny stems and sparse leaf growth, or not growing at all, the light source is the first factor to check. Keep a close eye on how your plants are responding to light and adjust exposure accordingly. Hydroponic systems can be designed to provide light from numerous sources.

Natural Light: The sun radiates the full spectrum of light essential to plant life. A greenhouse allows sunlight to reach plants and is a great location for growing hydroponically. A sunny windowsill will suffice for many non-fruiting vegetables, herbs, and flowers if you place your hydroponic unit 1 or 2 feet away from the glass. In climates with a lot of sunlight, make sure your plants get at least four hours per day of shade.

Artificial Light: Fluorescent or LED light bulbs can also be used to deliver needed light to indoor hydroponic crops. These lights will typically be hung from the ceiling or a structure specifically built for the plants and kept on 14 to 16 hours per day.

Laying the Groundwork

Explain to students that growing plants hydroponically is based on the concept that we can provide all of the plants needs through water and air without the presence of soil. So, what do plants need?

Ask students to brainstorm a list of all the things plants need. Your list should include:

- Water
- Light
- Air
- Nutrients
- A place to grow

Next, create a chart comparing how traditionally grown plants and hydroponically grown plants meet their needs. Here is sample of what your chart might look like:

Need	Plants Grown in Soil	Plants Grown Hydroponically
Water	Water is applied to the soil by nature (rain) or humans (irrigation) and then roots absorb the water from the soil	Water is supplied by humans and roots are either submerged in water continuously or periodically splashed with water
Light	Sunlight or artificial light (usually through sunlight)	Sunlight or artificial light (usually through artificial light)
Air	The soil contains pockets of air for the roots	If submerged in water, air is provided by air pumps; if splashed with water, air is continuously available
Nutrients	Organic matter decomposes and releases nutrients which must then be dissolved into water and absorbed by the roots	Nutrients needed by plants are added directly to water in the form they can be used and immediately available
A Place to Grow	The soil helps anchor the plants	Humans must provide a substance such as rockwool, gravel or a plastic basket to provide support for plant roots

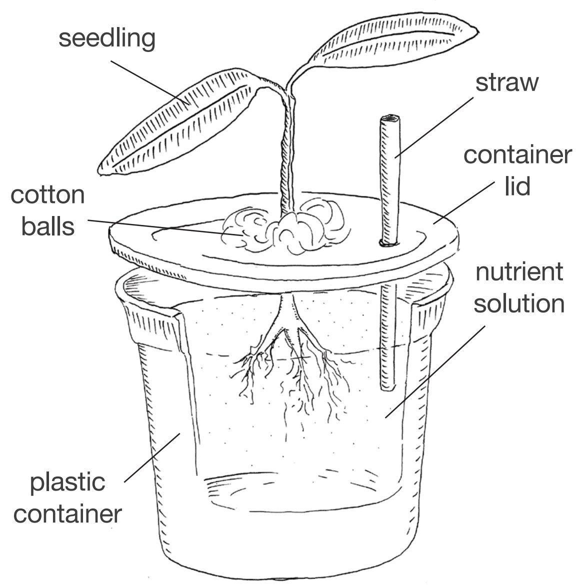
Exploration

Because the grower is providing so many of a plant's needs directly, hydroponically grown plants make excellent test subjects for experiments. You can easily withhold one or more of the plant's needs and see the results. In this exploration, the class will use a simple straw aeration hydroponic system to grow lettuce and observe the importance of nutrients on plant growth. Below are instructions for making this hydroponic system. **For additional background information on growing plants hydroponically to aid your delivery of the Exploration activity, please reference the Hydroponic Basics resource in the Appendix.**

1. Soak some small squares of rockwool or cotton balls in a dilute hydroponic nutrient solution (dilute according to product directions) and others in water. Plant two or three lettuce seeds in each one, and then place them on waterproof trays or shallow containers and keep moist with water or nutrient solution until seeds germinate (use two separate trays for those receiving each treatment). As with any experiment, growing as many samples as possible for each treatment will provide you with the best results. Depending on supplies, time available and student ability levels, you can grow one for each student or just a few to use as class examples.

2. Find small plastic containers with lids to repurpose, such as margarine, cottage cheese, or yogurt containers for each square or ball.

Straw Aeration Hydroponic System



3. Have an adult use a utility knife to carefully cut a 1-inch X shape in the center of the lid. Then cut a smaller X shape in the lid, about 1 inch from the edge, large enough to insert a drinking straw.

4. Gently insert the rockwool or cotton ball with the seedlings halfway through the large X so that it is held securely in place in the lid.

5. Fill half the containers with a dilute nutrient solution and the other half with water (match the treatment you gave it prior to planting the seeds) so that just the very bottom of the cotton ball or rockwool square will touch the solution, then secure the lid.

❻ Insert a drinking straw through the smaller holes in the lids of the containers and into the solution. Twice a day, gently aerate the solution by blowing into the straw. *Classroom Note: Consider the ability and maturity level of your students when assigning this job. If you think your students may drink the liquid, rather than blow bubbles into the liquid, this needs to be a task for the teacher. If you think your students can be trusted to perform the aeration properly, make sure to prevent students from using the same straws and sharing germs, either label each container clearly so they know which one is theirs or remove and replace straws between treatments.

❼ Monitor fluid levels and add water or nutrient solution as needed so it is just touching the bottom of the cotton ball or rockwool. Every 1 to 2 weeks, drain and refill the corresponding liquid.

❽ Provide students with times to observe the growth of their lettuce plants and have them record such information as plant height, leaf color, and number and size of leaves. You can use the Hydroponic Garden Journal found at the end of Lesson One to record your observations. Grow the plants for at least 4 weeks and compare. Are there differences between the plants grown in the nutrient solution and those grown in water?

Making Connections

In groups or as individuals, inspire students to find creative ways to remember the basic needs of plants. Ask them to create posters, poems, songs or brochures that can be shared with other students or family members.

Extension Ideas

Science: Repeat the experiment, but change the variables to test the impact of withholding other needs. For example, you can try growing plants in different light levels or without the aeration provided by the straw.

Science: Compare plant and people needs. In addition to your list of plant needs from the Laying the Groundwork, create a list of the things people need including: water, air, food, nutrients and shelter. Make a Venn diagram to compare the two lists. Discuss why plants are classified as producers while people are classified as consumers. You can ask the following questions to inspire discussion: Do we compete with plants for any of the same resources? Do plants provide any of our needs for us? Do we need plants? Do we provide any of the plants' needs for them? Do plants need people? What happens if our needs are not met? What happens if plants' needs are not met?

Learn at Home: Follow up this activity by having each student make a simple straw aeration hydroponic system. Have them create a set of care instructions to go with their unit based on what they have learned about plant needs during the Exploration.

If supplies are not available, you can also simply send home the sample hydroponic newsletter at the end of this lesson that includes instructions for making their own unit.

Middle School and High School Ideas: Ask students to write an article for your school's newsletter, website, or blog detailing the results of their hydroponic gardening experiments. Also consider creating a presentation or workshop about hydroponics to share with younger students.

LESSON 3
Exploring Hydroponic Systems

Guiding Questions

What are some of the basic growing techniques used in hydroponic systems? How do we evaluate different hydroponic system designs?

Materials

Laying the Groundwork:

- Types of Hydroponic Systems Worksheet
- Hydroponic Systems Guide (Appendix)

Exploration:

- Lettuce seeds
- Rockwool or cotton ball
- A hydroponic growing medium (such as gravel, clean sand, perlite, lightweight pebble-like aggregate, or rockwool)
- Cotton or nylon wick
- Two small containers that can fit inside of each other
- Hydroponic nutrient solution
- 2 liter soda bottle
- Aquarium pump and tubing
- Air stone (optional)
- Garden Journal Handout
- Hydroponic System Comparison Worksheet

Making Connections:

- Paper, pencils, and markers

Time

Laying the Groundwork: 30 minutes
Exploration: Planting time – 1 hour; Growing Time – 3 to 4 weeks
Making Connections: 1 hour

Lesson Summary

This lesson will provide an overview of the basic types of hydroponic systems currently available.

Learning Outcomes

After completing this lesson, students will be able to:

- Build at least two different types of hydroponic growing systems.
- Evaluate the design of the selected hydroponic systems in terms of successful plant growth along with a comparison of additional factors to consider such as materials, time, and cost.
- Analyze the pros and cons of different hydroponic systems and how well they may fit the needs or wants of growers, and specifically the needs and wants of your classroom or school.

Links to Next Generation Science Standards Performance Expectations

3-5-ETS1 Engineering Design

3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

Background Information

Hydroponic systems are broadly divided into two different categories: passive or active systems. Each of these can then be further defined as being media-based or water-culture.

Passive Systems

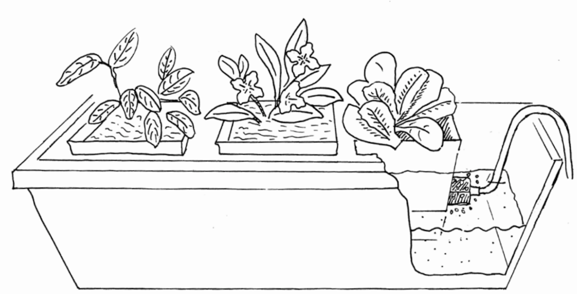
These systems use no energy to move nutrients and water. Passive systems often use a “wicking” material to draw up the liquid nutrients for the roots to access, or they simply suspend the plants in the solution with an air space around some of the root zone. They can also be as basic as a perlite-filled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

Passive System

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 and nutrient concentrations. Systems with pumps to aerate and deliver more oxygen to roots tend to produce healthier plants more quickly than do passive systems.

Active System



Media-Based versus Water-Culture

Passive and active systems are further divided into either media-based or water-culture categories.

Media-Based Systems

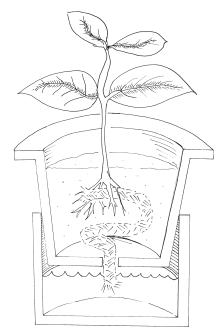
These types of hydroponic systems rely on some material, such as gravel, aggregate, perlite, vermiculite, or rockwool to support the plants and the roots in the nutrient solution. Such systems can be active or passive and may or may not recycle the nutrients.

The 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. 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.

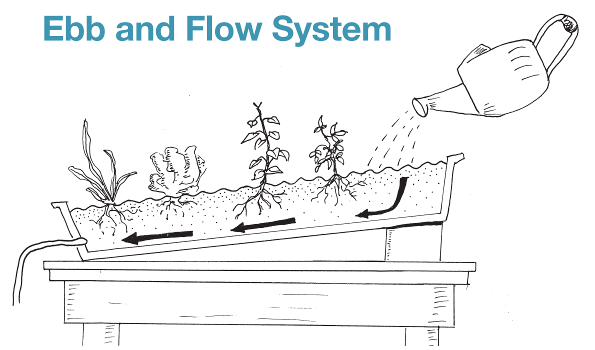
Wick System



Ebb and Flow Systems (active)

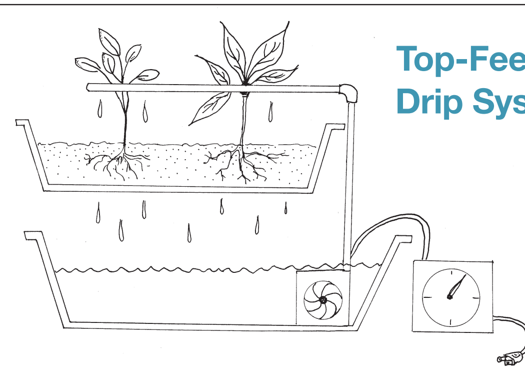
The plants and medium are flooded up to six times per day with the nutrient solution, then allowed to drain. As it drains, the system draws oxygen into the medium. These systems most often incorporate automatic timers, but can be flooded by hand if you are very consistent. Every several cycles, you must wash the roots and tank to remove any built-up, crusted salts.

Ebb and Flow System



Top-Feed or Drip Systems (active)

A timer-controlled pump delivers nutrient solution on a regular schedule through "emitters" (pipes with holes) to the top of the plant medium and allows the excess solution to drip down into a catch basin below.



Top-Feed or Drip System

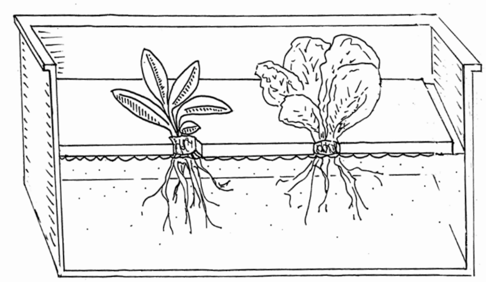
Water-Culture Systems

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 solution. 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 with an air pump, to provide the roots with greater exposure to oxygen.

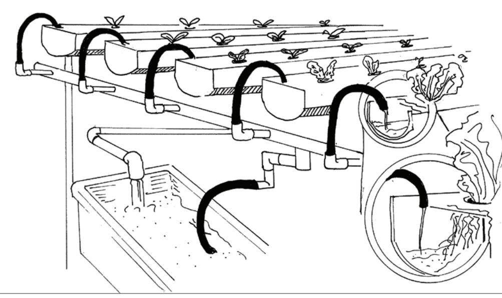
Raft System (active or passive)



NFT (Nutrient Film Technique) (active)

Plants are suspended in the nutrient mix, which is pump-circulated past the roots, aerating the solution. Commercial growers often place seedlings in plastic net pots inserted in holes cut in PVC pipe channels.

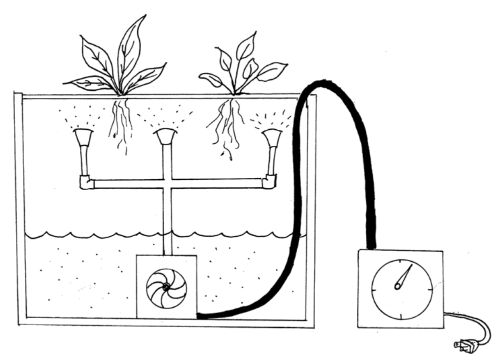
Nutrient Film Technique



Aeroponics Systems (active)

At regular intervals, plants suspended in the air are sprayed or misted with the nutrient solution.

Aeroponics System



Laying the Groundwork

Project on a screen or handout copies of the Types of Hydroponic Systems worksheet found at the end of the Lesson. Ask students to compare and contrast the different types of growing techniques by looking at the diagrams. You can reference the Background Information or for additional educator support, full descriptions of each system can also be found in the Hydroponic Systems Guide in the Appendix. Possible questions you can ask students to inspire thought and discussion:

- Do the materials for making these systems look expensive?
- Would this take us a lot of time to build? Would it take us a lot of time to maintain?
- How much space do you think this system would take? How many plants could be grown?
- How does water move in each of these systems? Explain the difference between active and passive systems as described in the Background Information.
- How are the roots secured in this system? Explain the difference between media-based and water-culture systems as described in the Background Information.
- Do you see a system you would like to make?

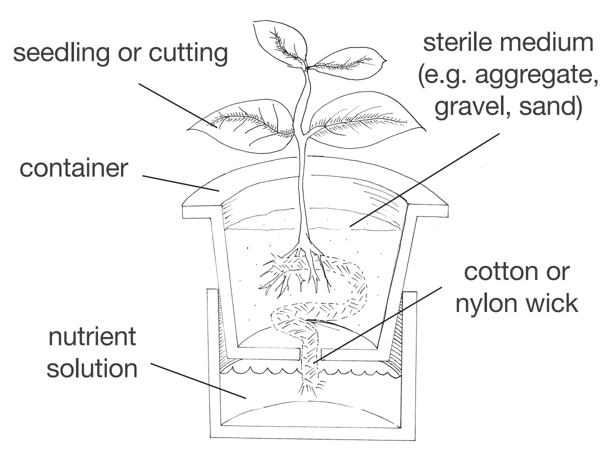
Exploration

To help students further understand the difference between the basic types of hydroponic systems, build and compare an example of a passive system and an example of an active system. The following instructions are for some simple units you may want to try: a basic wick system (passive example) and a simple soda bottle system (active example), but feel free to substitute other units to best fit your needs (more examples can be found in the Appendix Hydroponic Systems Guide). Lettuce is an easy crop to grow for your experiment.

Basic Wick System (Passive)

Step 1: Plant lettuce seeds in small squares of rockwool or cotton balls soaked in a dilute hydroponic nutrient solution. Plant two or three lettuce seeds in each one, and then place them on a waterproof tray or shallow container and keep moist until seeds germinate. After they have started to grow and have some root formation, they are ready to transplant into your basic wick system.

Basic Wick System



Step 2: Obtain 2 small containers that can nest inside of each other with the top container suspended over the bottom, as shown in the diagram,

Step 3: Make a drainage hole in the top container and then fill it with a hydroponic growing medium (such as gravel, clean sand, perlite, lightweight pebble-like aggregate, or rockwool) and carefully transplant your lettuce plants into it. Insert a wick that will reach from the top container into the bottom container. Make sure to place the wick an inch or two into the top container so it will contact the plant roots, then thread the wick down through the drainage hole into the bottom container holding nutrient solution.

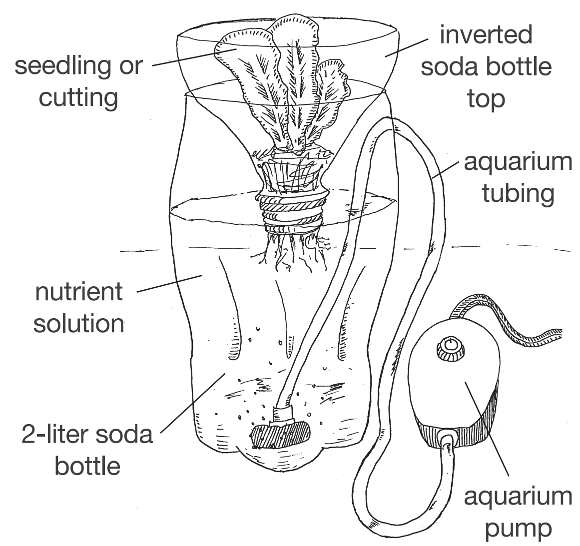
Step 4: Water the top pot to make sure the medium and wick are moist and then after that provide water by refilling the nutrient solution in the bottom container.

Step 5: 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 F. **For additional background information on growing plants hydroponically to aid your delivery of the Exploration activity, please reference the Hydroponic Basics resource in the Appendix.**

Soda Bottle System (Active)

Step 1: Plant lettuce seeds in small squares of rockwool or cotton balls soaked in a dilute hydroponic nutrient solution. Plant two or three lettuce seeds in each one, and then place them on a waterproof tray or shallow container and keep moist until seeds germinate. After they have started to grow and have some root formation, they are ready to transplant into your soda bottle system.

Soda Bottle System



Step 2: Cut the top off of the soda bottle leaving a bit of the sloping neck. For this system, you will invert the top of the bottle into the bottom. The inverted top will hold your plant while the opening of the bottle will allow access to nutrient solution you will place in the bottom of the 2 liter bottle. After making your cut, check to make sure your top will securely fit inside of the bottom and also make a notation of where the bottom of the inverted bottle opening falls. You will need your nutrient solution to reach this point

Step 3: On the side of the bottom half of the 2 liter bottle above the future nutrient solution line, create a small hole so you can insert an aquarium pump tube. Insert aquarium tubing through the hole you made so that it reaches near the bottom of the bottle, but not touching the bottom. As an optional feature, you may want to consider attaching the submerged tubing to an air stone. Air stones can be made of different types of materials, but in general are porous stones used to diffuse the air being pumped into water into smaller bubbles. The stone will also add weight to your bottle and help your tubing stay in place. It may also decrease the sound produced by your system.

Step 3: Connect the other end of the tubing not in the water to your pump.

Step 4: Fill the bottom of the bottle with a nutrient solution until it reaches the point where the bottom of the inverted bottle top will be located. Place the rockwool or cotton ball containing your lettuce seedlings so that it securely fits into the main hole of the inverted bottle top. Then place the inverted top into the bottom half of the 2 liter bottle.

Step 5: To discourage algae growth, wrap aluminum foil, dark plastic, or paper around the setup to exclude light from the water and roots.

Step 6: Try to keep the nutrient solution pH between 5.8 and 6.5 and the temperature at about 70 F, and change it every two weeks or so. Some people suggest using a half-strength solution for the first week.

For additional background information on growing plants hydroponically to aid your delivery of the Exploration activity, please reference the Hydroponic Basics resource in the Appendix.

➊ Once you have both units set up, begin to observe the growth of the lettuce plants in each using the steps listed below. Ask students to record their observations about the differences between the two systems for 3 to 4 weeks. You can use the sample garden journal at the end of this lesson

➋ At the end of the experiment, in addition to comparing the growth of your lettuce, expand your discussion to look at additional benefits and challenges of each system, including supplies needed, cost, and ease of construction and operation. You can use the hydroponic unit comparison sheet at the end of this lesson to help guide your discussion.

➌ Give students a chance to weigh in on which type of unit they prefer and why. Ask them to base their opinion on the growing data you have collected and the facts you have collected in your comparison worksheet. Ask, Which one seems to support the best plant growth? Which one costs less? Which one requires fewer supplies? Which one is easier to maintain?

Making Connections

Based on what they have learned about different types of hydroponic systems in this lesson, ask students to design their own system. Would they choose a passive or active system? Media-based or Water-culture? Or perhaps they have their own innovative idea for a hydroponic garden. What would they grow? Where would they place it?

Inspire some creativity by showing them pictures from the hydroponic systems at Walt Disney World. Disney's Epcot Center features an attraction called *Living with the Land* that offers a demonstration of numerous innovative hydroponic, aeroponic, and aquaponic (growing plants in water with fish) systems. Tell your students you are going to go on a virtual tour of Disney World and get a glimpse into the wide variety of hydroponic systems available. Show them the photos and information available from the following resources:

Disney World's "Living with the Land" Website:
https://disneyworld.disney.go.com/attractions/epcot/living-with-the-land/

The PhotoGardenBee's Interview with Disney Horticulturist Les Frey:
Disney's Epcot Greenhouses are Amazing! Part I: The Land:
http://thephotogardenbee.com/disneys-epcot-greenhouses-are-amazing-part-i-the-land/

Growing for the future utilizes innovative techniques here at Epcot's Greenhouses! Part II: The Land:
http://thephotogardenbee.com/growing-for-the-future-utilizes-innovative-techniques-here-at-epcots-creative-greenhouses-part-ii-the-land/

Here at Epcot they are using various hydroponics systems to help change the world: Part III: The Land:
http://thephotogardenbee.com/aeroponics-gardens-at-epcot-part-iii-the-land/

Extension Ideas

English Language Arts and Math: Prefabricated hydroponic gardens are becoming popular items for homeowners. As a class, search through some of the models currently available. Next, ask students to create an advertisement for the hydroponic units you made during the Exploration or the units they create for the Making Connections activities. Using information about supply costs and pricing of similar products, have students devise a product price and then calculate net profits possible per unit. They can also discuss who would be their target audience and what other accessories they might sell with the units.

Middle School and High School: Hydroponic gardens are becoming an increasingly popular way to add plants into schools, homes, and other public spaces. The increase in interest has led to the development of numerous brands of prefabricated hydroponic growing systems. Have students use the comparison worksheet at the end of this lesson to research different types of prefabricated hydroponic units on the market. After collecting the information, they can compare these prefabricated units with the units they made for the Exploration. Discuss the pros and cons of making your own systems versus buying a prefabricated one.

LESSON 4
Hydroponic Farm to Table

Guiding Questions

What are some of the challenges facing our food system today? How can hydroponics help us meet these challenges?

Materials

Laying the Groundwork:

- Land Use Worksheet

Exploration:

- Internet Access
- Map My Plate Worksheet

Making Connections:

- Guest Speaker or Internet Access

Time

Laying the Groundwork: 30 minutes
Exploration: 1 hour
Making Connections: 30 minutes

Lesson Summary

Increasing population numbers are leading to an interesting dilemma. As the demand for food grows because there are more people to feed, the amount of land available to grow our food will decrease as more of that land is used for housing and industry. Farmers are faced with the challenge of finding a way to grow a larger harvest on less land — land that is also further away from urban centers. Hydroponic farms are being explored as a possible solution to this problem.

Learning Outcomes

After completing this lesson, students will be able to:

- Track the path their school food takes from the farm to the cafeteria.
- Explain how we use land in the United States and specifically how much of our land is used to produce food and how much is used as living space for humans.
- Discuss some of the challenges facing our food system and evaluate possible solutions.
- Describe the potential ways hydroponic farms can impact our community and environment.

Links to Next Generation Science Standards Performance Expectations

5-ESS3 Earth and Human Activity

5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

3-ESS3 Earth and Human Activity

3-ESS3-1. Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.

3-5-ETS1 Engineering Design

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

Background Information

A century or so ago, people had firsthand experiences about the connections between the environment and their food supply. They witnessed the negative impacts of a late frost in the spring or a heavy hailstorm at fruit set and then experienced how those events impacted the food they had on their table. They understood the skill and labor needed to produce an abundant harvest and the importance of that harvest for their health and survival.

Our food system has changed dramatically over the last century, and even more so in recent decades. Most Americans are not directly involved in food production, and their concepts of food obtainment is limited to experiences of stocked grocery store shelves with a wide selection of fresh fruits and vegetables available year-round. Today much of our fresh produce is shipped thousands of miles and we rely heavily on processed and packaged foods. Food moves across the globe in ships, planes, trains, trucks, and, ultimately, in cars on the ride home from the grocery store. Most kids growing up in our society have only a vague idea of where food comes from and how it is produced. Additionally, very few understand the important link between the environment, their food, and their health.

With the majority of our population living in urban areas, it is easy to argue that in many cases, it is just not possible to grow a majority of foods locally because of limited land availability — though this would decrease travel time and resources and allow people to be more in touch with their food origins. Traditional growing methods require good soil, a steady water supply, and lots of space. Hydroponic farms are being explored as a way to overcome some of these challenges to producing foods in urban areas.

Hydroponic farms can offer the following benefits to our food supply:

- **Food can be grown indoors under artificial grow lights in spaces of all different sizes and shapes.** Gardens can be stacked on top of each other and/or located in multi-floor buildings to take advantage of vertical space and decrease the land footprint needed for a sizeable production rate.
- **Many hydroponic farming techniques use little water and/or recycle water, resulting in a reduction in overall usage compared to plants grown using traditional methods.** Access to high-quality water supplies are a pressing concern for many areas around the globe and efficient use of water is a growing priority.

- **Hydroponic farms can be placed in urban areas where populations are highest so that crops do not have to travel a long distance to the end consumer, decreasing the cost and environmental impact of transportation.**
- **Indoor hydroponic farms are protected from the environment.** This means they are not subject to unfavorable weather conditions, and with proper hygienic practices and safety precautions in place, they experience fewer disease and weed problems than traditionally grown crops.
- **Hydroponically grown produce usually does not require the same amount of pre-consumer cleaning as crops grown in soil, which is another water savings.**
- **Because systems can be designed so that the optimal amount of light, nutrients, and water reaches the plant, harvest size can also be optimized (efficient input-to-output ratio).**
- **Plants grown hydroponically grow faster than plants grown through traditional farming methods.** Because plants are being provided with optimal amounts of nutrients, water and light, they can grow faster than crops grown using traditional horticultural techniques resulting in increased production rates per square foot of space.
- **Beyond larger farm production, hydroponic systems are available for homes and schools to increase production of fruits and vegetables.**

Although there are many benefits, hydroponic farming is not without its challenges. Some of those challenges include:

- Currently there are very few crops that have been cultivated to thrive in hydroponic conditions. Edible crops commonly grown hydroponically include lettuce and other greens, herbs (especially basil), peppers, tomatoes, cucumbers, and strawberries. For the use of hydroponic farming to increase, scientists must work to identify existing or develop new plant varieties that will grow well hydroponically. New hydroponic system designs may also help increase the number or crops that can be grown successfully through hydroponic techniques.
- Most hydroponic farms are very reliant on a secure source of electricity both to maintain temperature and to provide water and air to plant roots. Under normal conditions, weather may not be a factor for hydroponic crops; however, extreme weather conditions like a blizzard or hurricane that impacts energy sources can also impact hydroponic farms. (Most farms will likely have fossil fuel-powered back up generators to be able to cover short-term loss of electricity).
- Cost is another big challenge to hydroponic production. In most cases, hydroponic farming operations are still more expensive than traditional farms, even when factoring in their associated transportation costs. The cost comparison between the two methods could change as land availability decreases and if transportation costs increase. Cost

is a driving force in the supply and demand process, so even though there may be environmental benefits, until the cost of hydroponic production is closer to the cost of traditional production, it will struggle to gain a larger portion of the market.

As world populations grow and agricultural crops are impacted by environmental concerns such as climate change and water shortages, the security of our food supply will continue to be a major issue in the 21st century. Currently food resources are not equally distributed and there are inequities by geographic location and income. This gap is projected to widen as costs increase due to rising demand and shrinking supplies. Alternatives to traditional farming practices such as hydroponic operations will definitely be part of the discussion as scientist and farmers begin looking for solutions to our food supply needs.

Laying the Groundwork

Ask students to consider the different rooms in their school. Do they all serve the same purpose? Could we use some of the rooms in other ways? Could we use the bathrooms to hold classes or vice versa?

Just like we assign different indoor spaces with different tasks, we also use land in different ways. In some cases the land can be used for multiple purposes; however, not all land is best suited for all jobs. Ask the class to brainstorm some of the ways we use land.

Next, provide copies of the Land Use worksheet to look at the data collected by the U.S Department of Agriculture Economic Research Services. Ask the following questions:

- What is the largest percentage of the land in our country used for? *Animal pasture/range currently demands the most amount of land in the United States.*
- What percentage of our land is used as cropland? *About 17%.*
- What region is most of our cropland located in? *The Midwest.*
- What region of our country has the least number of acres of cropland per person? *The Northeast.*
- What region do we live in? How many acres of cropland do we have per person?
- What does this information tell us about where our food comes from? *Our food is not grown equally across all regions. This means much of our food is grown in one place, but must be transported to another place for consumption.*
- If our population continues to grow, what will that mean about the amount of cropland we need? *We would need to convert other land to cropland or learn how to make our existing cropland more productive.*
- Is all land suitable to be cropland? *No.*

If you would like to provide students with information about your state, additional details about land use from the USDA Economic Research Service is available at: https://www.ers.usda.gov/data-products/major-land-uses/major-land-uses/#Summary%20tables
Download *Summary Table 1: Major uses of land, by region, State and United States*.

Exploration

❶ Challenge students to map the food on their plate. For one or multiple days depending on time available, record the menus for your school's breakfast and lunch using the Map Your Meals Worksheet at the end of this lesson. For items with multiple ingredients, just list the top 3 ingredients (for example pizza could be listed as wheat, tomato sauce, and cheese).

❷ Connect with your school food service staff to find out if any of the items on the menu were obtained from a local source. If your school participates in a farm to school initiative, some of the items may be coming from local farmers. Also ask your food service staff if they have access to information about any of the other sources of food on the menu.

❸ If you do not have a food service staff member available to provide information about the origins, another resource you can use to approximate where your food might have come from is the USDA's Food Purchases Resource available at: https://www.fns.usda.gov/fdd/food-purchase-resources. Although not all school foods are procured through the USDA, some are and from this web page you can download spreadsheets under the "State of Origin Information" heading for many of their purchases organized by fiscal year.

❹ Once you have approximated the origin of your foods, you can use a mapping program to estimate the miles each food traveled to get to your school. Use this data to spark discussions about the benefits and challenges of obtaining and consuming local foods. Use the Background Information above to explain how hydroponic farms fit into the picture of increasing local produce availability and potentially decreasing the environmental impact of food production. Possible questions to spark discussion include:

- Is the number of people living in the United States increasing or decreasing?
- Where do most of the people in the United States live? Where does their food come from?
- What are some of the challenges facing our food system today?
- How could hydroponic farms help solve some of the problems facing our food system?
- What are some other solutions that could help with the distribution of food in the United States? How do these compare to the use of hydroponic farms in terms of cost and environmental impact?

5 As an extension of this activity, it would be interesting to hold a class taste test of foods that have been harvested from different locations and grown using traditional and hydroponic methods. Hydroponic and traditionally grown lettuce, tomatoes, and cucumbers are often available in grocery stores, you can grow your own in your school gardens or you can also do a search for local food resources like farmers markets at: www.ams.usda.gov/services/local-regional/food-directories or connect with your National Farm to School Network Core Partner through http://www.farmtoschool.org/our-network.

Making Connections

Invite a local farmer (if possible, a hydroponic farmer) to come in to speak to the class about the journey of food from farm to table. If you are unable to locate a guest speaker, the following videos provide interviews with hydroponic farmers offering tours of their facilities:

Go Green Agriculture in Encinitas, California
Pierre Sleiman from Go Green Agriculture has a number of videos available spotlighting their spinach and lettuce production facilities:

1. Go Green:
https://www.youtube.com/watch?v=3O8WgmYO2A0

2. Harvest of the Month – Organic Bloomsdale Spinach - Pierre Sleiman
Go Green Agriculture in Encinitas, California

3. San Diego Hydroponic Farm
https://www.youtube.com/watch?v=zod-246VCkg

Bowery Farming, New Jersey
This video from Bloomberg Technology provides an interview and tour of a hydroponic facility growing greens and herbs in New Jersey.

This High-Tech Farmer Grows Kale in a Factory:
https://www.youtube.com/watch?v=AGcYApKfHuY

Additional information about hydroponic production can be found on the Bowery Farming website at: https://boweryfarming.com/

Extension Ideas

English Language Arts: As a class, create a brochure that shows what fruits and vegetables are currently grown in your area and when they are ready for harvest.

Geography/History: This lesson looks at locally grown foods, but just because a crop is grown in a location does not mean it has always been grown there. Research the history and origins of common plants. Just like people, every plant has its own story: its unique parts; growth habit and growing requirements; country of origin; list of uses by different cultures (the study of the uses of plants is called ethnobotany); and a log of travels as it was moved to different areas of the world. Texas A&M offers a fascinating publication from National Geographic called "Our Vegetable Travelers" available at: https://aggie-horticulture.tamu.edu/plantanswers/publications/vegetabletravelers/ that offers engaging historical commentary on many of our most common vegetable plants.

Middle School and High School Extension: Learn more about our food system and how it is impacting and being impacted by climate change. Check out the Understanding Food and Climate Change Interactive Guide by the Center for Ecoliteracy at: https://www.ecoliteracy.org/download/understanding-food-and-climate-change-interactive-guide. After studying this publication, encourage students to prepare a presentation for a target audience in your community (such as peers, family members or younger students), sharing their findings. Additionally or alternatively, ask students to brainstorm ways your community could help your local food system through changes in every day practices and discover ways to advocate for larger policy changes to help mitigate the impact of climate change.

LESSON 5
Water Versus Soil: A Hydroponic Investigation

Guiding Questions

How do traditional growing techniques compare to hydroponic growing systems?
What factors do we need to consider to evaluate our findings?

Materials

Laying the Ground Work:

- Site Analysis Worksheet

Exploration:

- Garden Journal
- Growing System Comparison Worksheet
- Garden supplies needed will vary based on type of garden systems designed

Making Connections:

- Paper, pencils and markers

Time

Laying the Groundwork: 30 minutes

Exploration: Planting Time – 2+ hours; Growing Time – 4+ weeks

Making Connections: 1 to 2 hours

Lesson Summary

Students will grow the same crop using hydroponic techniques and traditional gardening techniques. They will collect and analyze data to compare the different growing systems.

Learning Outcomes

After completing this lesson, students will be able to:

- Create a fair test to compare hydroponic growing techniques with traditional soil-based growing systems.
- Discuss the benefits and challenges of hydroponic systems and evaluate their impact on environmental resources and their potential to solve current food system problems.

Links to Next Generation Science Standards Performance Expectations

5-ESS3 Earth and Human Activity

5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

4-ESS3 Earth and Human Activity

4-ESS3-2. Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

3-ESS3 Earth and Human Activity

3-ESS3-1. Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.

3-5-ETS1 Engineering Design

3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Background Information

There are many different gardening techniques used to grow edible crops in both home landscapes and in commercial operations. Common soil-based bed systems include container gardening (indoor and outdoor), raised beds, in ground rows, and vertical gardens (a form of container gardening that takes advantage of vertical space). Hydroponics is an alternate growing technique that uses water to meet plant needs rather than soil. Hydroponic growing systems can be either passive or active and either media-based or water culture.

Comparing soil-based bed systems and hydroponic units does not result in a ranked order or selection of the "best" growing system for all situations. Choosing a system depends on numerous factors, such as space available, soil quality, water access, environmental conditions, type of crop you plan to grow, time for planting and maintenance, and budget. Deciding on a growing technique is more about choosing the best technique for your circumstances and environment. This is the reason why learning how to conduct a site analysis and evaluate needs and available resources are such important skills for any gardener or farmer.

Additional background information about gardening can be found at www.kidsgardening.org and www.garden.org. You can also reach out to your local Cooperative Extension service at www.nifa.usda.gov/Extension.

Laying the Groundwork

Explain to your students that you are going to design an experiment to compare soil-based and hydroponic growing systems. Begin your experimental design process by visiting all of the potential sites available for your growing systems and conduct a site analysis for each one. A site analysis involves measuring and mapping the space, creating an inventory of existing features, and summarizing the site conditions. Before you begin, you may want to review the needs of plants students learned in Lesson 2 of this guide. You can use the Site Analysis Worksheet at the end of this lesson as a guide. Bring your results back to the classroom and use this information to decide on a location for your gardens.

Let students know that when deciding on your location, you will want to control for differences in factors that can impact how plants grow (like the amount of light and temperature) as closely as possible since both can change your results. These factors are called variables. Explain that in an ideal situation, you would want the two types of systems to be growing side by side. Realizing this may not be practical, if you do use two different locations, you will want to make sure to track and record information about conditions such as temperature along with light and water availability so that you can discuss the impact the differences/variables had on your final results.

Create a list of all the variables you need to account for during your experiment and discuss how you plan to ensure you have created a fair test.

Exploration

1 Use the information you collected in the site analysis to design your garden systems. Allow your students to be as involved in the design process if possible. Here are a few possible suggestions:

For your soil-based bed, utilize existing garden space if it is available to you. If you do not already have available space, consider either outdoor or indoor container gardens. KidsGardening offers resources to help you plan and plant container gardens at:

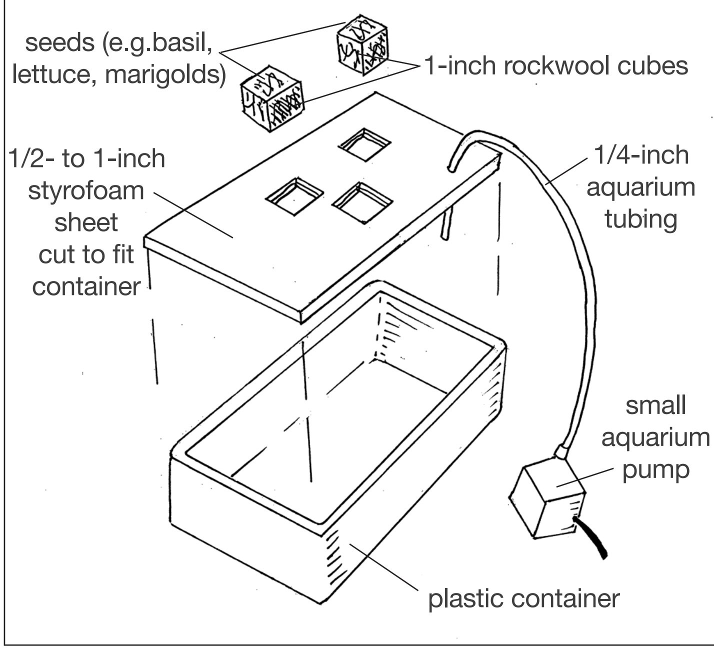
Container Gardens:
https://kidsgardening.org/designing-a-school-garden-consider-container-gardening/

Indoor Gardening:
https://kidsgardening.org/gardening-basics-indoor-gardening/

For your hydroponic unit, a number of different options have been provided in this guide, or you can also research additional options online. There are also numerous prefabricated hydroponic systems available for school and home use designed to make hydroponic growing simple. You can find prefabricated units available in a wide range of sizes and prices from online and local retailers.

If building your own system is more practical for you, here are some instructions for a Floating Styrofoam Raft System, a simple system that has been used by many schools and can be designed to be used indoors or outdoors:

Floating Styrofoam Raft System



To build a floating Styrofoam raft hydroponic system:

Soak rockwool cubes with a dilute nutrient solution 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. An optional attachment, you can add an air stone to the submerged end of the tubing. Air stones are made of porous materials and are designed to disperse the air into smaller bubbles. Air stones can help with the circulation of the water, help keep the tubing in place and may also decrease the noise of your system. Attach the other end of the tubing to the aquarium pump that is kept outside the base.

Fill the container with water (around 70 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 and maintain a constant level. Change the entire solution every 2 weeks. **For additional background information on growing plants hydroponically to aid your delivery of the Exploration activity, please reference the Hydroponic Basics resource in the Appendix.**

Check out this video from 2017 Carton 2 Garden Winner Bethel Elementary in Midland, North Carolina for ideas on how to create a raft system using repurposed milk cartons: https://www.youtube.com/watch?v=8Sr8TOnkH74

❶ Decide what kind of plants you want to grow. To control your variables, you need to plant the same variety of plants and approximately the same quantity of plants in both gardens. Lettuce and basil are two easy-to-grow options that should perform well in both types of systems and in many climates.

❷ Track growth and make observations. Provide time to track your plants at least once a week and preferably every other day (Monday, Wednesday and Friday would be a good schedule). Any data you can collect may be useful during your analysis of the systems. A sample Garden Journal page for tracking data is provided at the end of this lesson.

❸ After approximately 4 to 6 weeks, compile your results and create a graph to compare the growth of your plants growing in the two systems. Also compare the vigor of your growth (leaf color and number is one way to compare this information). Discuss your findings.

❹ Although this information may tell you which system resulted in the healthiest plant growth in your conditions, explain to your students that there are other factors to consider related to your design. Use the Growing System Comparison Worksheet to record information about the cost, supplies needed, and ease of building and maintaining each system to support your discussion of the results.

❺ Before making any final conclusions, create a list of uncontrolled variables that you think may have influenced your results. This may include things like differences in light or water availability. Also make an additional list of benefits and challenges of each system based on their growing experience.

❻ Finally, ask students to consider all of this collected data to come to a conclusion about which type of growing system is the best fit for the conditions and needs of your school. Brainstorm a list of questions or additional investigations they would like to conduct to further explore the Water versus Soil discussion. How could your experiment be improved or enhanced?

Making Connections

Plan a garden celebration to enjoy your experiment's harvest and share all your hard work! Students can make the invitations and also help you put together a slide presentation, sharing pictures of your experiment and the data collected. Invite other students, teachers, administrators, and parents and let your young gardeners share what they learned. You might also want to add in a tour or demonstration of your growing systems and a taste test of your harvest. Additional ideas for using your hydroponic garden harvest can be found in Appendix D.

Extension Ideas

English Language Arts and Math: Create a planting calendar for your future gardening efforts to coincide with your school calendar and special events.

Math and Art: Ask students to design their dream garden — either soil-based or hydroponic (or who knows what they will come up with, maybe even a combination of both). They should use graph paper and make sure the design is to scale.

Middle School and High School Extension: Throughout this series of lessons, students have explored the benefits and challenges of using hydroponic growing techniques versus traditional crop production. As a culmination of their work, ask students to write a research paper exploring the feasibility of hydroponics becoming a sustainable and viable food production system in the future. Ask them to conclude their paper with a personal opinion based on facts collected answering the question: Will hydroponic farms become a primary source of food in our future?

APPENDIX A
Hydroponic Basics

Introduction

Hydroponics, in its simplest form, is growing plants by supplying all necessary nutrients in the plants' water supply rather than through the soil. The word derives from the Greek root words "hydro" and "ponics," meaning water working. Growing plants hydroponically helps gardeners and farmers grow more food more rapidly in smaller areas (greenhouses, living rooms, classrooms, and rooftops, for instance) and to produce food in parts of the world where space, good soil, and/or water are limited. In hydroponics, water with dissolved nutrients is applied as a bath, periodically irrigated through the growing medium, or sometimes sprayed directly on the roots. The following information is designed to provide you an overview of growing plants using hydroponic techniques.

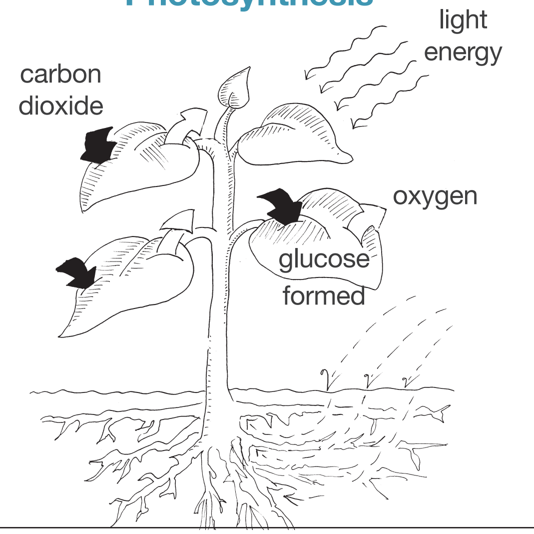
Meeting Plant Needs

Plants, like all living things, have certain requirements that need to be met for them to grow and thrive. These include water, nutrients, light, air, and structural support for the roots. In traditional gardening, plants get root support, nutrients, water, and oxygen from the soil. Without soil, hydroponic growers must find ways to provide water and the right balance of nutrients directly to the plants' roots, enabling the plants to concentrate their energy on producing leaves and fruits rather than searching for water and nutrients. Another challenge is designing ways of providing the support and oxygen that plants need. Before reading more about plant needs and some of the innovative ways hydroponic gardeners meet them, read this refresher on plant plumbing.

Roots and Shoots

The most important function of plant roots is to absorb water and nutrients. How does it happen? Covering the growing tip of each root are hundreds of tiny root hairs. The cell walls and membranes of the hairs are porous, thereby allowing water containing dissolved minerals nutrients to enter. The movement of the molecules through the cell membranes is called osmosis. Osmosis occurs because the water seeks balance in the concentration of nutrients inside and outside of the plant.

Photosynthesis



Plant roots deliver the necessary water and nutrients (via the stem) to the plant's leaves where photosynthesis – carbohydrate production – occurs. During photosynthesis carbon dioxide enters the plant through the leaf's surface. Carbohydrates (glucose) are produced from carbon dioxide and a source of hydrogen (water) in chlorophyll-containing plant cells when they are exposed to light. This process results in the release of oxygen. These carbohydrates fuel plant growth and reproduction. Only a small amount of the water sent to the leaves is used in photosynthesis; the rest is given off into the air through transpiration.

Water

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. 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! As stated above, transpiration uses up the majority of a plant's water intake.

Nutrients

Whichever type of hydroponic system you select or create, you must supply the plants with nutrients. In soil, these elements come from rock and mineral leaching and organic matter decomposition. They are "held" by the soil particles and dissolved in the surrounding water. In hydroponics, the liquid solution is taken in directly by the roots and provides the leaves with nutrients through the transportation system in the stem. These nutrients or minerals are not actual food, but elements vital to helping the plant utilize the sugars (the real food) that it produces during photosynthesis.

Important Nutrients: Plants need about 16 different essential elements for optimum growth. Macronutrients, which are ordinarily found in soil, are needed by plants in rather large amounts. (Hydrogen, oxygen, and carbon are also necessary in large amounts, but are available to plants from the air and water.) The following are essential macronutrients and some of their most important functions in plants:

- nitrogen (N)–Promotes development of leaves
- phosphorus (P)–Aids in growth of roots
- potassium (K)–Helps plant resist disease
- calcium (Ca)–Helps promote new root and shoot growth
- magnesium (Mg)–Contributes to leaf color and helps absorb sunlight
- sulfur (S)–Contributes leaf color

Trace elements, or micronutrients, including manganese, iron, copper, and others, are important to the total well-being of the plant, but are needed in much smaller amounts.

Hydroponic gardeners must provide plant roots with a nutrient solution containing an appropriate balance of necessary nutrients. 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.

Mixing Solutions: When mixing nutrient solutions, always dilute them to the concentration recommended by the manufacturer. 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 it.

How Much to Use: 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 simple system such as a floating raft, 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.

Maintaining Nutrients: 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 general rule for most classroom and/or home systems is to replace the mixture with a fresh batch every 10 to 21 days. 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.

Nutrient Disposal Caution: Take care where you dispose of nutrient solutions. Houseplants, indoor plants, and container gardens are fine places to recycle the liquid. However, aquatic ecosystems are quite sensitive and the balance of minerals is very delicate. If there is a stream, lake, or other water source nearby, do not dispose of liquid nutrients on the ground.

pH: The Acid Test: The pH of the nutrient solution is an important factor in hydroponics. It 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 unavailable to plant roots. The range that allows the plant to use the dissolved minerals (nutrients) most effectively is just slightly acidic. pH levels vary in different nutrient mixes and water sources. If you change your nutrient solution every 10 to 21 days, as suggested, you needn't be concerned with adjusting pH.

To determine pH of your solution, you can use narrow-range pH paper, reagent type test kits, or a pH meter to do so. These can be found through many online retailers and aquarium suppliers or science supply catalogs. Simple ways to change the pH: drops of white vinegar can lower the pH while baking soda can raise it. Hydroponic suppliers offer other products for adjusting pH.

Mixed Media

The material that a plant lives in or on is called its medium or substrate. For most plants, the medium is soil. Hydroponic growers find other ways to support growth to prevent drowning plants. Many setups use an inert, sterile medium. Some of the more popular choices included gravel, clean sand, perlite(volcanic material that is heated until it expands into a lightweight, styrofoam-like material), a lightweight pebble-like aggregate, and rockwool (an inorganic, spongy, fibrous substance that holds large amounts of water and air). These materials provide passages among the particles or fibers where air and water can circulate.

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 to avoid this.) Rockwool holds water and air nicely and makes it easy to move plants around, but breaks down fairly quickly.

Some hydroponics systems have no real media, but more or less elaborate ways of suspending plants in nutrient solutions. In commercial nutrient film 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.

Oxygen

Getting Oxygen to the Roots: Even roots buried in soil must have oxygen for the plant to survive. 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.

In short-term passive hydroponic systems, there are other means of getting oxygen to the roots. In some setups, water and nutrients reach the roots via a wick made of absorbent material, and part of the roots are continually exposed to air. A porous medium like rockwool has a tremendous capacity for retaining oxygen while also absorbing nutrient solution. Greens such as lettuce and herbs seem to be the best bets for a minimally aerated environment.

Many hydroponic systems use a pump to infuse oxygen into the water. For small setups, aquarium pumps and tubing do the trick. In larger systems (particularly commercial ones), the medium and roots are periodically splashed or flooded with a nutrient solution, allowing oxygen to bathe the roots in the interim.

In systems using aquarium pumps and tubing, an optional attachment to the end of the tubing placed in the water is an air stone. Air stones are made of porous material and are designed to help disperse the air into smaller bubbles. They are used to improve water circulation, keep the tubing in place and may also decrease the noise produced by the system.

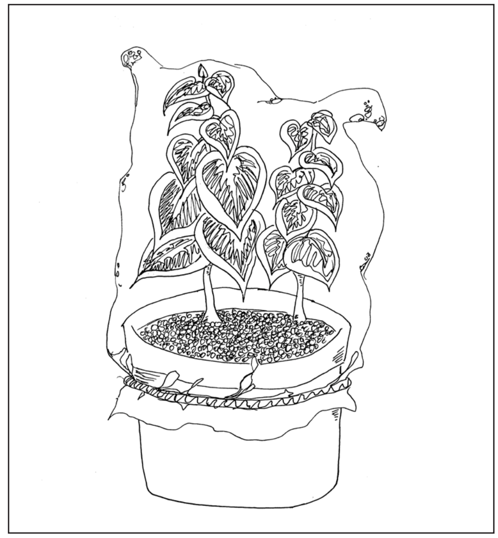
Light

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. If your plants are getting leggy (thin stems and small leaves) or not growing, the light source is the first factor to check. Keep a close eye on how your plants are responding to light and adjust exposure accordingly.

Natural Light: The sun radiates the full spectrum of light essential to plant life. A greenhouse is great for growing hydroponically. A sunny windowsill will suffice for many non-fruiting vegetables, herbs, and flowers if you place your hydroponic unit 1 or 2 feet away from the glass. In climates with a lot of sunlight, make sure your plants get at least four hours per day of shade.

Artificial Light: Fluorescent and LED lights hung from shelves or other setups will suffice for certain crops if kept on 14 to 16 hours per day. While many houseplants and smaller plants with low light requirements (e.g., seedlings, lettuce, or herbs) will thrive in a hydroponics setup under basic 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 lights designed to provide bright, efficient light closely approximating sunlight.

Growing From Cuttings



Houseplants such as coleus, tradescantia, heartleaf philodendron, pothos, and geranium grow quite well from cuttings. Rockwool cubes soaked in a 25 percent nutrient solution are nice for starting cuttings. 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.

Plant Care Tips

As with plants grown in soil, your hydroponic unit seedlings and cuttings require ongoing care. Here are a few general suggestions:

- Plan space accordingly. Leafy and vining plants need room to spread out; provide support or trellising for such plants as tomatoes and cucumbers.
- Grow disease- and pest-resistant plant varieties. (Good growing practices should minimize disease and pest problems.)
- Practice good hygiene. (Without soil to filter contaminants, the liquid solution can transport impurities.) Wash hands before and after working with plants. Start with clean containers (a cleaning solution of 1 part bleach to 9 parts water is recommended).
- Observe plants carefully for signs of insect pests. Aphids, spider mites, and white flies go for lush growth. Either hand-pick pests, wash plants gently with a mild soap solution, or remove infested plants from the setup.
- Change the nutrient solution 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 F, and the reservoir full.
- Plan ahead for vacations. If the setups are small enough, you might be able to 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 let someone know it is on. 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 semesters or terms, to avoid the problem altogether.