Engineering Everywhere™

Growing Up: Engineering Vertical Farms

Agricultural Engineering for Out-of-School Time • Grades 6–8

Written by the Engineering is Elementary® Team
Illustrated by Ross Sullivan-Wiley and the Engineering is Elementary® Team

EiE Engineering is Elementary®
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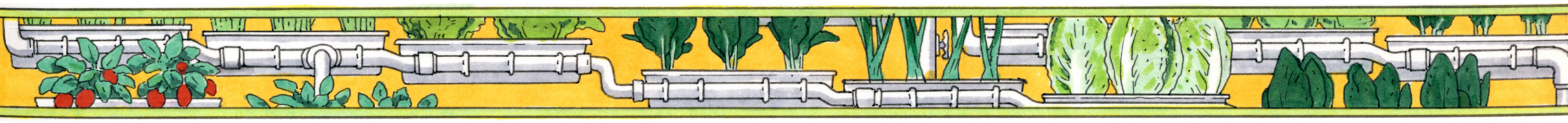

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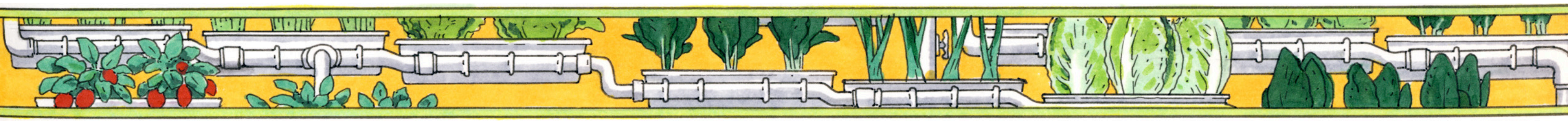
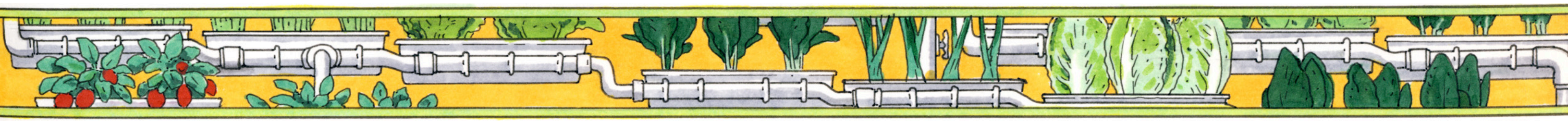


Pilot Sites:

This unit would not be possible without the valuable feedback from our pilot sites!
Center for STEM Education at Northeastern University Boston, MA
Enrichment Zone Livingston, TN
Forest Hills Lutheran Christian School Cornelius, OR
Howard-Winneshiek Community School District Cresco, IA
James L. McKeown Boys & Girls Club of Woburn Woburn, MA
Jones Cove Elementary School Cosby, TN
Knox Trail Junior High School Spencer, MA
Martinez Street Women's Center: Girl Zone San Antonio, TX
Millennium Development Brooklyn, NY
Nashoba Brooks School Concord, MA
NeighborWorks Blackstone River Valley Woonsocket, RI
Saugus Family YMCA Saugus, MA
Vermont Afterschool, Inc. Colchester, VT
YMCA of Metro North Middle School Leaders Program Lynn, MA
YWCA Hamilton Hamilton, OH



Unit Map

Here is an overview of the activities in this unit and how they all fit together.

Prep Activity 1: What is Engineering?

Youth are introduced to engineering as they work in teams to engineer a tower that can support a container of water.

Prep Activity 2: What is Technology?

Youth explore a definition of technology and are introduced to vertical farms and the idea that they will work to engineer a model vertical farm for a place called Greentown.

Activity 1: Window Gardens

Youth engineer a window garden from recycled bottles.

Activity 2: Design a Water System

Youth engineer a water pump system that can deliver water to different locations.

Activity 3: It's Light and Mirrors

Youth design a lighting system to direct light to a specified area.

Activity 4: Create a Vertical Farm

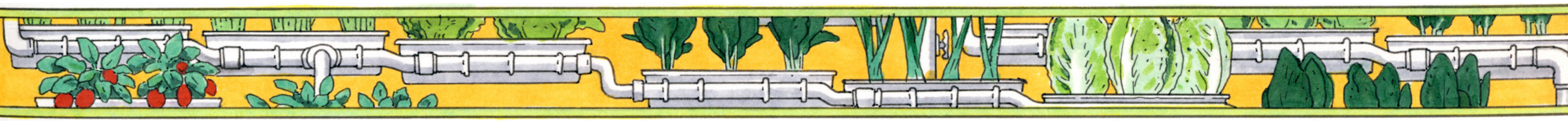
Youth are introduced to their final design challenge: *creating* a room of a vertical farm for Greentown.

Activity 5: Improve a Vertical Farm

Groups *test* and *improve* their vertical farm rooms.

Activity 6: City Council Presentation

Youth *communicate* their work to the Greentown City Council.



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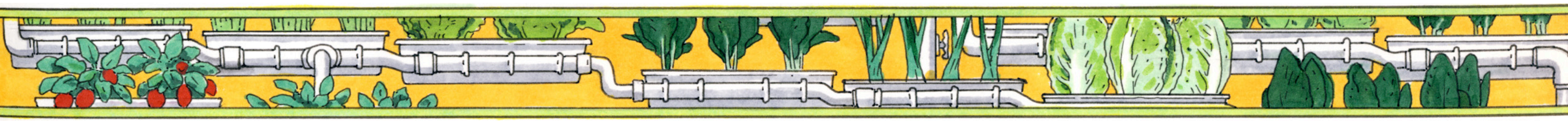


About Engineering is Elementary

Engineering is Elementary® (EiE®) fosters engineering and technological literacy among children. Most humans spend over 95% of their time interacting with technology. Pencils, chairs, water filters, toothbrushes, cell phones, and buildings are all technologies—solutions designed by engineers to fulfill human needs or wants. To understand the world we live in, it is vital that we foster engineering and technological literacy among all people, even young children! Fortunately, children are born engineers. They are fascinated with building, taking things apart, and learning how things work. Engineering is Elementary harnesses children's natural curiosity to promote the learning of engineering and technology concepts.

The EiE program has four primary goals:

- Increase children's technological literacy.
- Increase educators' abilities to teach engineering and technology.
- Increase the number of schools and out-of-school time (OST) programs in the US that include engineering.

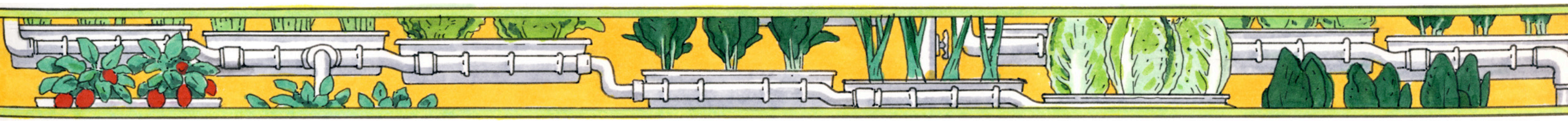
Conduct research and assessment to further the first three goals and contribute knowledge about engineering teaching and learning.

The first product developed by the EiE program was the Engineering is Elementary curriculum series. Designed for use in elementary school classrooms, this curriculum is hands-on, research-based, standards-driven, and classroom-tested. For more information about EiE, visit: www.eie.org.

In 2011, EiE began development of Engineering Adventures (EA), a curriculum created for 3rd–5th grade children in OST environments. EA is designed to provide engaging and thought-provoking challenges appropriate for the OST setting. More information about EA can be found online at: www.engineeringadventures.org.

In 2012 the Engineering Everywhere (EE) curriculum was created. EE is designed to empower middle school-aged children in OST settings to become engineers and solve problems that are personally meaningful and globally relevant. For more information, visit: www.engineeringeverywhere.org.

Engineering is Elementary is a part of The National Center for Technological Literacy (NCTL) at the Museum of Science, Boston. The NCTL aims to enhance knowledge of technology and inspire the next generation of engineers, inventors, and innovators. Unique in recognizing that a 21st century curriculum must include today's human-made world, the NCTL's goal is to introduce engineering as early as elementary school and continue through high school, college, and beyond. For more information, visit: www.nctl.org.



About Engineering Everywhere

The mission of Engineering Everywhere is to create engaging out-of-school time learning experiences for 6th–8th graders that positively impact youth's attitudes about their abilities to engineer. Our goal is to provide youth with personally meaningful and globally relevant challenges that empower them to problem solve, think creatively, and learn from one another.

The main ideas that guide the developers of EE are listed below.

We believe youth will best learn engineering when they:

- engage in activities that are fun, exciting, and connect to the world in which they live.
- choose their path through open-ended challenges that have multiple solutions.
- have the opportunity to succeed in engineering challenges.
- communicate and collaborate in innovative, active problem solving.

Through EE units, youth will learn that:

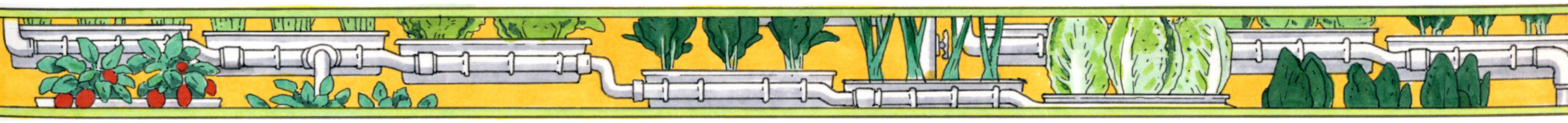
- they can use the Engineering Design Process to help solve problems.
- engineers design technologies to help people and solve problems.
- they have the talent and potential to design and improve technologies.
- they, too, are engineers.

As youth work through their engineering design challenges, they will have the opportunity to build their problem solving, teamwork, communication, and creative thinking skills. Most importantly, this curriculum is designed to provide a fun learning opportunity!

Unit Goals

During this unit, youth will be introduced to engineering and the Engineering Design Process as they work together to engineer a solution to an agricultural engineering challenge. Youth will explore food production problems related to population growth. They will then engineer a model vertical farm as a potential solution to current food production limitations in a fictional location: Greentown. Because vertical farms are still a new concept with only a few prototype examples worldwide, exploring vertical farms provides youth with a chance to *imagine* what the future could bring.

By the end of the unit, youth will be ready to present what they learned about agricultural engineering and the Engineering Design Process to the Greentown City Council and an audience.



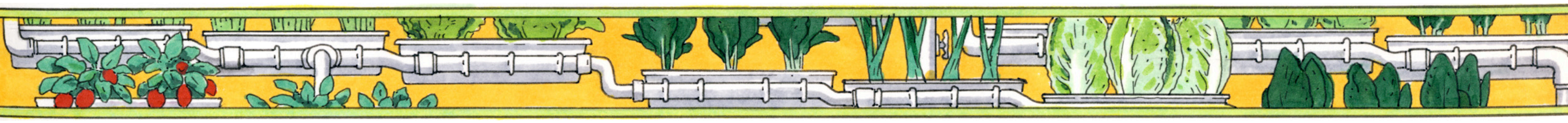
The Engineering Design Process

The Engineering Everywhere Engineering Design Process (EDP) is the backbone of each Engineering Everywhere (EE) unit. It is an eight-step process that guides youth in solving engineering challenges. Our goal for each EE unit is for youth to understand that the EDP can help them solve problems not only in engineering, but also in other areas of their lives.

While there are many versions of the EDP used in academic and professional fields of engineering, we developed an eight-step process that builds on the five-step process used in our elementary curriculum. There are guiding questions throughout the activities for the educator to ask to promote discussion about the EDP. There are also sections in the Engineering Notebook to encourage youth to engage in the process.

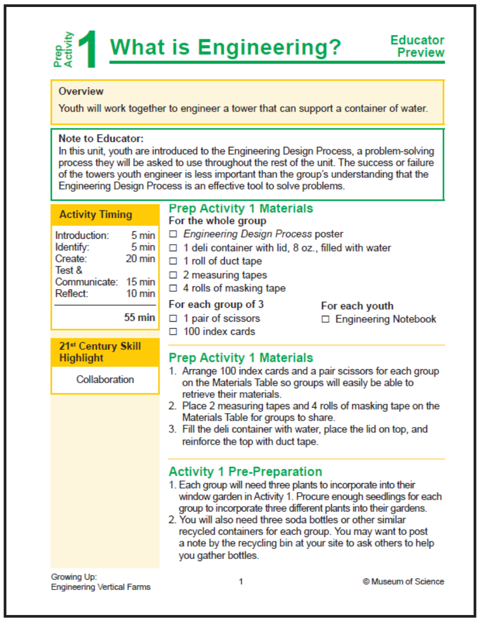
The EDP begins with identifying a problem that needs to be solved and investigating what has already been done. Next, engineers imagine different solutions and plan their designs. Then, they create and test their designs and make improvements based on the test results. Finally, engineers communicate their findings to others. While the process is shown as linear, youth may jump around to different steps as they are engineering. For example, they may need to imagine and plan new designs in order to improve.

To further highlight the EDP throughout the unit, the steps are italicized in this guide. Youth are also provided with an explanation of each step, which can be seen in their Engineering Notebooks. The EDP used in EE units is illustrated to the right.



Teacher Guide Components

An **Educator Preview** with background information, activity timing, key concepts, materials lists, and preparation.



Prep Activity 1 What is Engineering? Educator Preview

Overview
Youth will work together to engineer a tower that can support a container of water.

Note to Educator:
In this unit, youth are introduced to the Engineering Design Process, a problem-solving process they will be asked to use throughout the rest of the unit. The success or failure of the towers youth engineer is less important than the group's understanding that the Engineering Design Process is an effective tool to solve problems.

Activity Timing

Introduction:	5 min
Identify:	5 min
Create:	20 min
Test & Communicate:	15 min
Reflect:	10 min
	55 min

21st Century Skill Highlight
Collaboration

Prep Activity 1 Materials
For the whole group
- ☐ *Engineering Design Process* poster
- ☐ 1 deli container with lid, 8 oz., filled with water
- ☐ 1 roll of duct tape
- ☐ 2 measuring tapes
- ☐ 4 rolls of masking tape

For each group of 3
- ☐ 1 pair of scissors
- ☐ 100 index cards

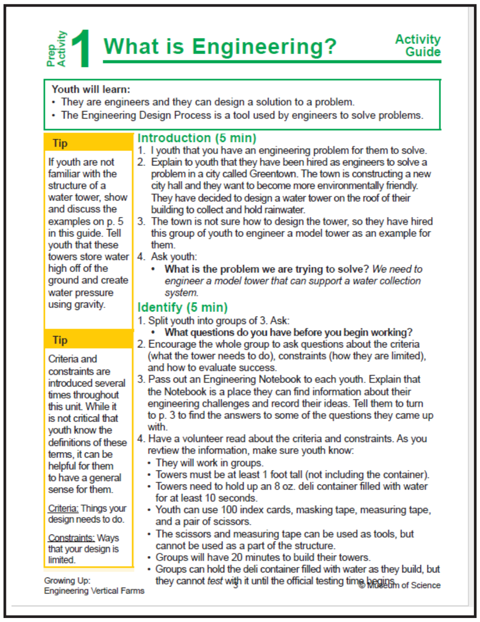
For each youth
- ☐ Engineering Notebook

Prep Activity 1 Materials
1. Arrange 100 index cards and a pair scissors for each group on the Materials Table so groups will easily be able to retrieve their materials.
2. Place 2 measuring tapes and 4 rolls of masking tape on the Materials Table for groups to share.
3. Fill the deli container with water, place the lid on top, and reinforce the top with duct tape.

Activity 1 Pre-Preparation
1. Each group will need three plants to incorporate into their window garden in Activity 1. Procure enough seedlings for each group to incorporate three different plants into their gardens.
2. You will also need three soda bottles or other similar recycled containers for each group. You may want to post a note by the recycling bin at your site to ask others to help you gather bottles.

Growing Up: Engineering Vertical Farms 1 © Museum of Science

An **Activity Guide** with step-by-step instructions, including discussion questions, extension ideas, and tips.



Prep Activity 1 What is Engineering? Activity Guide

Youth will learn:
- They are engineers and they can design a solution to a problem.
- The Engineering Design Process is a tool used by engineers to solve problems.

Tip
If youth are not familiar with the structure of a water tower, show and discuss the examples on p. 5 in this guide. Tell youth that these towers store water high off of the ground and create water pressure using gravity.

Introduction (5 min)
1. I youth that you have an engineering problem for them to solve.
2. Explain to youth that they have been hired as engineers to solve a problem in a city called Greentown. The town is constructing a new city hall and they want to become more environmentally friendly. They have decided to design a water tower on the roof of their building to collect and hold rainwater.
3. The town is not sure how to design the tower, so they have hired this group of youth to engineer a model tower as an example for them.
4. Ask youth:
   - **What is the problem we are trying to solve?** *We need to engineer a model tower that can support a water collection system.*

Identify (5 min)
1. Split youth into groups of 3. Ask:
   - **What questions do you have before you begin working?**
2. Encourage the whole group to ask questions about the criteria (what the tower needs to do), constraints (how they are limited), and how to evaluate success.
3. Pass out an Engineering Notebook to each youth. Explain that the Notebook is a place they can find information about their engineering challenges and record their ideas. Tell them to turn to p. 3 to find the answers to some of the questions they came up with.
4. Have a volunteer read about the criteria and constraints. As you revtiew the information, make sure youth know:
   - They will work in groups.
   - Towers must be at least 1 foot tall (not including the container).
   - Towers need to hold up an 8 oz. deli container filled with water for at least 10 seconds.
   - Youth can use 100 index cards, masking tape, measuring tape, and a pair of scissors.
   - The scissors and measuring tape can be used as tools, but cannot be used as a part of the structure.
   - Groups will have 20 minutes to build their towers.
   - Groups can hold the deli container filled with water as they build, but they cannot *test* with it until the official testing time begins.

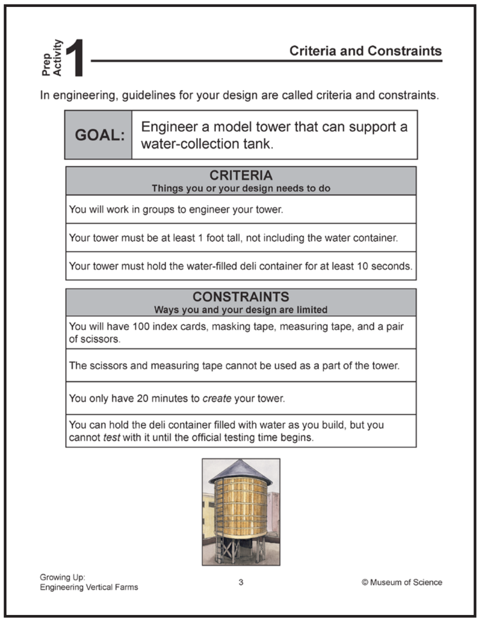
Tip
Criteria and constraints are introduced several times throughout this unit. While it is not critical that youth know the definitions of these terms, it can be helpful for them to have a general sense for them.

Criteria: Things your design needs to do.

Constraints: Ways that your design is limited.

Growing Up: Engineering Vertical Farms 3 © Museum of Science

Engineering Notebook pages that allow youth to record their findings and reflect on their learning.



Prep Activity 1 Criteria and Constraints

In engineering, guidelines for your design are called criteria and constraints.

GOAL:	Engineer a model tower that can support a water-collection tank.

CRITERIA Things you or your design needs to do
You will work in groups to engineer your tower.
Your tower must be at least 1 foot tall, not including the water container.
Your tower must hold the water-filled deli container for at least 10 seconds.

CONSTRAINTS Ways you and your design are limited
You will have 100 index cards, masking tape, measuring tape, and a pair of scissors.
The scissors and measuring tape cannot be used as a part of the tower.
You only have 20 minutes to *create* your tower.
You can hold the deli container filled with water as you build, but you cannot *test* with it until the official testing time begins.

Growing Up: Engineering Vertical Farms 3 © Museum of Science

What You Need to Know Before Teaching an EE Unit

Engineering is Fun

The EE team hears this from many OST educators and youth. Engineering is a way of problem solving—a way of thinking about the world—that is very fun and creative. Any time you need to solve a problem in order to reach a goal, you are engineering.

There are No Right or Wrong Answers

There are often many great ways to solve the same problem. Not only is this a good engineering lesson, it is a good life lesson for the youth in your program.

You are a Guide

As the educator, it is your role to guide youth through these activities by encouraging them to pursue and communicate their own ideas, even if you think they might not work. Every problem has many possible solutions and multiple ways to reach them.

Ask Questions

Throughout the activities, you can ask questions prompting youth to share their prior knowledge, predict what they might find, or remind them of criteria that will help them as they engineer. Asking questions like these sets your youth up to succeed and feel confident in their ability to engineer.

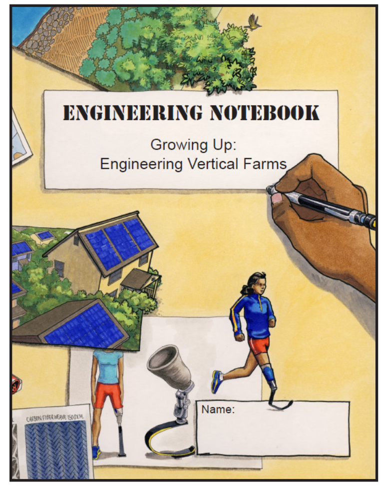
It is Okay to Try It Out

It can be very helpful to try out the engineering challenge yourself—either beforehand or right alongside the youth in your program as they work through the adventures. This can help you understand the challenges they might face.

Support Reflection

Each activity includes 5-10 minutes at the end for youth to communicate with their peers by sharing their work. This gives youth the chance to discuss new ideas, think about their own work and the work of others, and reflect on what was learned. Group reflection can help reduce competition by encouraging youth to support each other as they move through the Engineering Design Process.

Engineering Notebooks



Make a copy of an Engineering Notebook for each youth before you begin working through this Engineering Everywhere unit. Youth will use them as directed in the Educator Guide during every activity.

The Engineering Notebook serves as a central location for youth to record their thoughts and ideas as they move through the unit. Its pages guide youth through the Engineering Design Process, pose questions, and prompt youth to reflect on their engineering work. The time youth spend with their Notebooks during each activity will allow them to create a personalized record of their engineering learning.

There are a few ways you can use the Engineering Notebook. You may want to have groups share one Engineering Notebook as a central recording spot for all group data and findings. This allows group members who enjoy writing and recording to do so. You may also encourage groups to share the responsibility by having group members rotate who records.

Alternate Prep Activities

The two prep activities, “What is Engineering?” and “What is Technology?,” introduce youth to engineering and technology. “What is Engineering?” gives youth the chance to collaborate, experience a mini hands-on engineering challenge, share their designs, and learn about the Engineering Design Process. This activity sets the stage for what they can expect in the rest of the unit.

“What is Technology?” has youth interact with technologies, working with the definition that a technology is anything designed by humans to help solve a problem or meet a need. Most youth think of technology as things that can be plugged into the wall. They do not realize that the items that they interact with every day—including pencils, paper, and water bottles—are also technologies. This activity introduces the definition of technology that they will refer to as they engineer their own technologies to solve the problem presented in the unit.

While the prep activities for Engineering Everywhere are unit-specific, there are alternative prep activities you can use if you would like to reinforce the concepts and vocabulary related to these activities. You can find the alternate activities online at www.engineeringeverywhere.org. If you have questions about these activities, please email engineeringeverywhere@mos.org.

Tips and Tricks for Teaching the Unit

Post a Daily Agenda

Giving youth a sense of the day's activity will help them to plan ahead and manage their time.

Facilitate Teamwork

Being able to work well in teams is an important skill for any engineer. You may want to assign team roles to help youth that struggle with teamwork. Possible roles include: the note taker, the materials gatherer, the tester, and the presenter.

This unit requires a collaborative workspace. Tables, desks, and chairs should be movable. It is a good idea to establish a materials table where you can set up materials for the day. Then, groups can be in charge of gathering their own materials when they are ready.

Invite Others to the Engineering Showcase

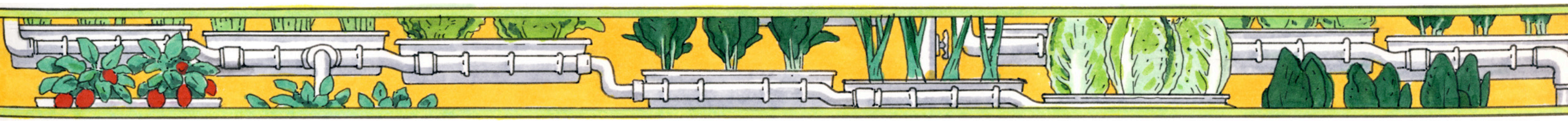
The Engineering Showcase, the last activity in the unit, is a big deal! This is a chance for youth to highlight the engineering they have done and share their accomplishments with others. Consider inviting families, program staff, and other youth to come to the Showcase.

Scheduling the Activities

Each activity requires 55-60 minutes of teaching time. We recommend that you budget at least 8-10 hours in order to complete this unit, as some activities may run longer than expected.

You can schedule this unit in several ways: once a week, several times a week, or daily. It is also possible to group certain activities together. The chart below shows which activities are easily taught together. Use this chart to help you plan your schedule.

Prep Activity 1: What is Engineering? Prep Activity 2: What is Technology?	2-3 hours
Activity 1: Window Gardens	1 hour
Activity 2: Design a Water System Activity 3: It’s Light and Mirrors	2-3 hour
Activity 4: Create a Vertical Farm Activity 5: Improve a Vertical Farm	2-3 hours
Activity 6: City Council Presentation	1 hour



Background

Agricultural Engineering

Agricultural engineering applies science and technology to the cultivation of animals and plants for food and other products used to sustain human life. Agricultural engineers combine their knowledge of animals and plants and mechanical, civil, and chemical engineering principles to solve agriculture-related problems. This broad engineering field encompasses many aspects of agriculture, including the management and conservation of soil and water, experimentation with crop production, and the design of new agricultural machinery.

Vertical Farms

It is predicted that by the year 2050, the global population will increase to 9 billion people. Many experts warn that the earth's current farmland and agricultural practices will not allow the production of enough food to support this growing population. Vertical farms offer a potential solution to the world's limited farmland. Vertical farms, also known as farmscrapers, are farms built within multi-floor buildings and skyscrapers. The vertical orientation of the farm provides more land for crop production on any given footprint. These types of farms would likely be located near urban centers where population density is the highest. Production of crops near cities would decrease the transportation required to deliver food. This could contribute to lower food prices and an increased availability of fresh food to urban populations. While vertical farms are primarily in the prototype stage of development, several small-scale vertical farms have already been built around the world in locations such as Chicago and Singapore. Skeptics of vertical farms question their feasibility and whether energy-efficient systems can be created to sustain the farms. Careful analysis of existing prototypes and advances in energy systems will contribute to the success or failure of vertical farms in the future.

Online Resources

For more information about this and other Engineering Everywhere units, visit:
www.engineeringeverywhere.org

Vocabulary

Agricultural engineering: A branch of engineering that uses knowledge of animals, plants, and agriculture to design technologies and solve problems related to food production.

Constraints: Ways that your design is limited.

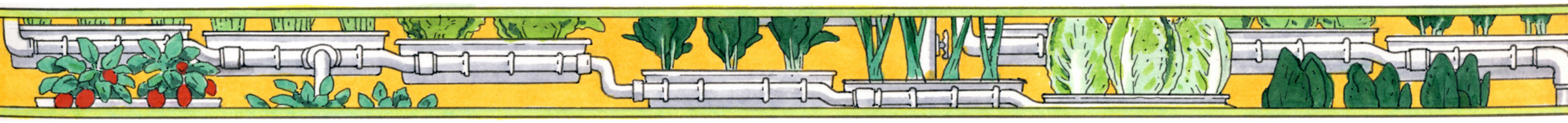
Criteria: Things your design needs to do.

Engineer: Someone who uses his or her creativity and knowledge of math and science to design technologies that solve problems.

Engineering Design Process: The steps that engineers use to design technologies to solve a problem.

Technology: Anything designed by people to help solve a problem or meet a need.

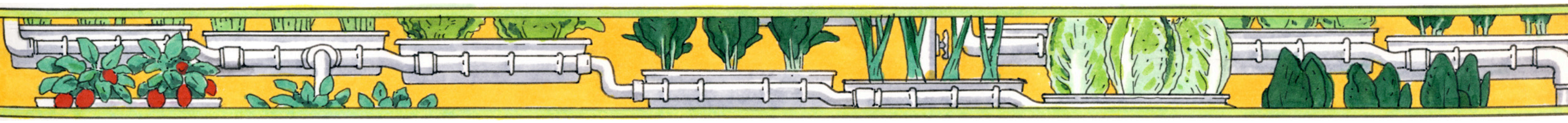
Vertical Farm: A farm built within a multi-story building or skyscraper.



Materials List

This kit is prepared for 8 groups of 3.

Quantity	Item
Non-Consumable Items	
1	*Engineering Design Process* poster
1	hole punch, metal, heavy duty
1	light and moisture meter
1	utility knife
2	measuring tapes
8	aquarium plants, plastic
8	flashlights
8 pairs	scissors
8	water hand siphon pumps
12	hand mirrors
40	storage cube sides, 14” x 14”
Consumable Items	
1 roll	aluminum foil
1 package	modeling clay, 1 lb.
1 pad	sticky notes
1 roll	string
2 rolls	duct tape
4 rolls	masking tape
8	spoons, plastic
8 sheets	construction paper, brown, 9” x 12”
10	deli containers, 16 oz.
16	aluminum trays, 8” x 8” x 1.5”
16	D batteries
16	tubing connectors, 1/4”
16	suction cups with hooks, approximately 2.5”
25	tubing splitters, 1/4”
40	deli containers, 8 oz. (one lid)
100 feet	vinyl tubing, 1/4” diameter
150	craft sticks
200	pipe cleaners
800	index cards



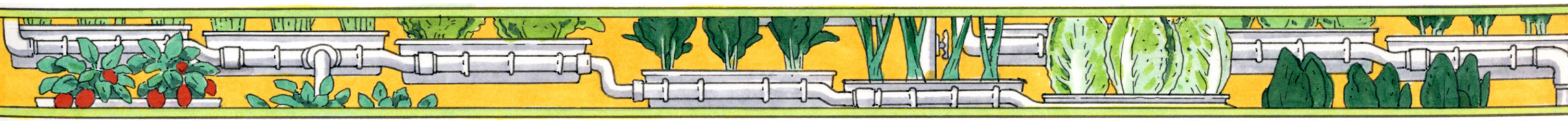
Materials List (cont'd)

NOT INCLUDED IN KIT	
1	chart paper and marker (or whiteboard)
1	computer for playing videos (projector optional)
1	*Engineering Everywhere Special Report* DVD or use the link: http://eie.org/verticalfarms
1 bag	gravel, at least 10 lbs.[1]
1 roll	paper towels
2 bags	potting soil, 32 lbs.[2]
2-4	newspapers
4	pitchers
8+	extra plants[3]
24	markers
24	plants[2]
24	recycled plastic water/soda bottles, 16 oz.

[1] Youth will need at least 10 lbs. of gravel to use throughout the unit. If you choose to use real plants in the final design challenge rather than plastic aquatic plants, you may want to gather additional gardening supplies, particularly if you have a large group and use up most of your potting soil and gravel in Activity 1. You have the option to gather soil and gravel from your backyard, or purchase them at a garden center.

[2] Youth will need at least 16 lbs. of potting soil for their Window Gardens in Activity 1. For the final design challenge, groups will need soil for their model plant (or real plant, if you choose to use them) and to test their water pump system. If groups are using model plants, this soil does not have to be potting soil. You may want to collect soil from outdoors or choose an inexpensive variety as nutrients are not an issue.

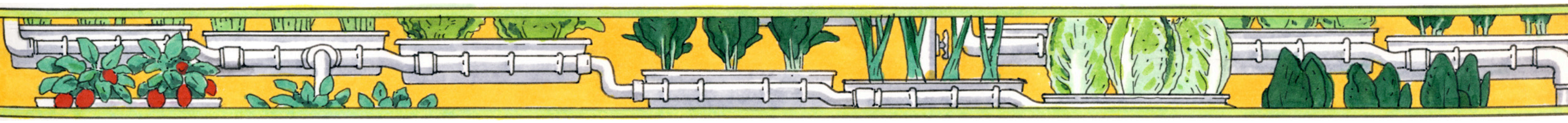
[3] Small plants are required in the Window Garden activity (Activity 1). They can also replace the aquarium plants in the final design challenge if you would like to use real plants (Activities 4, 5, and 6). You may choose to dig up grasses and weeds that naturally grow in your area, or purchase small seedling plants from your local garden center.



National Education Standards

Engineering Everywhere units are written with the goal of teaching engineering skills and critical thinking practices. Many Engineering Everywhere units also touch upon a variety of science topics and principles. The engineering standards taught in this unit and the science topic links in this unit are noted below.

		Prep Activity 1: What is Engineering?	Prep Activity 2: What is Technology?	Activity 1: Window Gardens	Activity 2: Design a Water System	Activity 3: It's Light and Mirrors	Activity 4: Create a Vertical Farm	Activity 5: Improve a Vertical Farm	Activity 6: City Council Presentation
National Science Education Standards	Science as Inquiry								
	Physical Science								
	Life Science			✓			✓	✓	
	Earth and Space Science								
	Science and Technology	✓	✓	✓	✓	✓	✓	✓	
	Science in Personal and Social Perspectives		✓				✓	✓	
	History and Nature of Science								
ITEEA	The Nature of Technology		✓						
	Technology and Society		✓	✓	✓	✓	✓	✓	
	Design	✓		✓	✓	✓	✓	✓	✓
	Abilities for a Technological World	✓	✓	✓	✓	✓	✓	✓	✓
	The Designed World	✓	✓	✓	✓	✓	✓	✓	✓



		Prep Activity 1: What is Engineering?	Prep Activity 2: What is Technology?	Activity 1: Window Gardens	Activity 2: Design a Water System	Activity 3: It's Light and Mirrors	Activity 4: Create a Vertical Farm	Activity 5: Improve a Vertical Farm	Activity 6: City Council Presentation
Next Generation Science Standards	MS-PS4-2 Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various objects.					✓			
	MS-LS1-4 Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants, respectively.			✓					
	MS-LS1-6 Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.			✓		✓			
	MS-LS2-5 Evaluate competing design solutions for maintaining biodiversity and ecosystem services.			✓	✓	✓	✓	✓	✓
	MS-ESS3-3 Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.			✓	✓	✓	✓	✓	✓
	MS-ESS3-4 Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.		✓						
	MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	✓		✓	✓	✓	✓	✓	
	MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	✓		✓	✓	✓	✓	✓	
	MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.	✓		✓	✓	✓	✓	✓	
	MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.	✓		✓	✓	✓	✓	✓	

How to Recognize Success Rubric

How do you know if you are leading these activities successfully? This tool will help you keep track of your youth's successful moments and will ask you to identify how your own actions enabled youth to succeed.

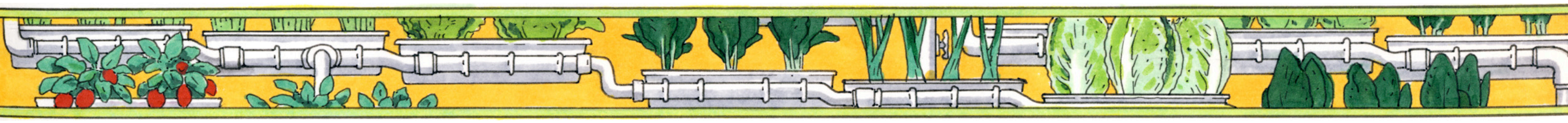
Elements of success	What does this look like?	How does the guide help me facilitate this?
Youth are engaged and challenged by the activity. They persist through difficulties.	• Youth are on-task. • Youth are trying out their ideas. • Youth *identify* what is working well in their designs. • Youth troubleshoot their own work. • Youth *improve* their designs.	• Use the bold prompts to **ask open-ended questions** to help youth troubleshoot their work. • Use the bold prompts to **ask youth about what they think is working well** in their designs and what they would like to improve. This will help youth feel more confident about their problem-solving abilities.
Youth do most of the talking, sharing their ideas with each other during the entire activity.	• Youth bring their own ideas to the activity and are comfortable sharing them. • Youth brainstorm and debate within their groups. • Youth share their designs with others. • Youth talk about how their ideas are changing over time.	• Use the bold prompts in the guide to **encourage youth to share and explain their thinking**. • Have youth **collaborate in groups** so they can brainstorm and *create* a design together. • Use the bold prompts in the Reflect section to **help youth share their new ideas about designs.**
Youth value their engineering work as a process, not just as the end result.	• Youth go beyond talking about their design to talking about how they thought of it and why they designed it. • Youth use the Engineering Design Process to describe their actions.	• Use the bold prompts in the guide to **ask youth how they use the Engineering Design Process.** Spending time talking and thinking about their process will help youth see the value in it. • Use the bold prompts to **ask all youth about *improving*** their designs, even if their designs are working well. • **Encourage youth to reflect individually** in their Engineering Notebooks to give them time for their experiences to sink in and be remembered.

How to Recognize Success Rubric Template

How do you know if you are leading these activities successfully? This tool will help you keep track of your youth's successful moments and will ask you to identify how your own actions enabled youth to succeed.

Date: Activity:

Elements of success	Evidence: Where did I see this during the activity?	What was my role in making this happen?
Youth are engaged and challenged by the activity. They persist through difficulties.		
Youth do most of the talking, sharing their ideas with each other during the entire activity.		
Youth value their engineering work as a process, not just as the end result.		



Dear Family, Date: _________________

We are beginning an engineering unit called *Growing Up: Engineering Vertical Farms*, a curriculum developed by the Engineering is Elementary program at the Museum of Science, Boston. This week, your child will be introduced to engineering and the Engineering Design Process as the group works together to engineer a solution to a biomedical engineering challenge. This unit is set in a real-world context: throughout the unit, your child will work with teammates to respond to a mock outbreak by engineering an antiviral to block a virus model from infecting a cell model.

There are many reasons to introduce children in grades 6–8 to engineering:

- **Engineering projects reinforce topics children are learning in school.** Engaging students in hands-on, real-world engineering experiences can enliven math, science, and other content areas.
- **Engineering fosters problem-solving skills,** including problem formulation, creativity, planning, and testing alternative solutions.
- **Children are fascinated with building and with taking things apart to see how they work.** By encouraging these explorations, we can keep these interests alive. Describing their activities as "engineering" when children are engaged in the natural design process can help them develop positive associations with engineering, and increase their desire to pursue such activities in the future.
- **Engineering and technological literacy are necessary for the 21st century.** As our society increasingly depends on engineering and technology, our citizens need to understand these fields.

If you have expertise in biomedical engineering, responding to an outbreak, or have any general questions or comments about the engineering unit we are about to begin, please let me know.

Sincerely,

If you have any of the following materials available and would like to donate them, I would greatly appreciate having them by the following date: ______________________ . Thank you!

____________________________ ____________________________

____________________________ ____________________________

____________________________ ____________________________

Prep Activity **1**

What is Engineering?

Educator Preview

Overview

Youth will work together to engineer a tower that can support a container of water.

Note to Educator:
In this unit, youth are introduced to the Engineering Design Process, a problem-solving process they will be asked to use throughout the rest of the unit. The success or failure of the towers youth engineer is less important than the group's understanding that the Engineering Design Process is an effective tool to solve problems.

Activity Timing

Introduction:	5 min
Identify:	5 min
Create:	20 min
Test & Communicate:	15 min
Reflect:	10 min
	55 min

21st Century Skill Highlight

Collaboration

Prep Activity 1 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ 1 deli container with lid, 8 oz., filled with water
- ☐ 1 roll of duct tape
- ☐ 2 measuring tapes
- ☐ 4 rolls of masking tape

For each group of 3

- ☐ 1 pair of scissors
- ☐ 100 index cards

For each youth

- ☐ Engineering Notebook

Prep Activity 1 Preparation

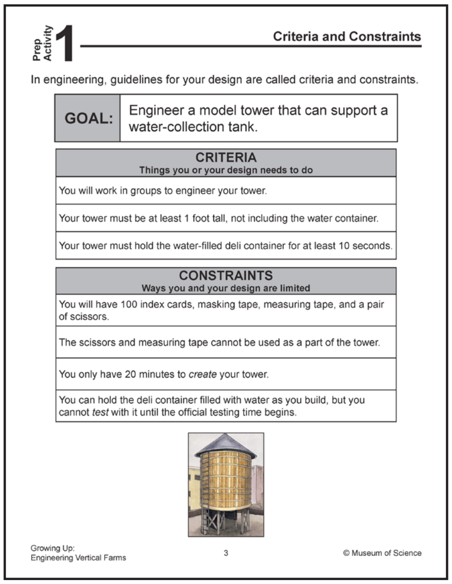
1. Arrange 100 index cards and a pair scissors for each group on the Materials Table so groups will easily be able to retrieve their materials.
2. Place two measuring tapes and four rolls of masking tape on the Materials Table for groups to share.
3. Fill the deli container with water, place the lid on top, and reinforce the top with duct tape.

Activity 1 Pre-Preparation

1. Each group will need three plants to incorporate into their window garden in Activity 1. Procure enough seedlings for each group to incorporate three different plants into their gardens.
2. You will also need three soda bottles or other similar recycled containers for each group. You may want to post a note by the recycling bin at your site to ask others to help you gather bottles.

Notebook Pages for Prep Activity 1

Criteria and Constraints, p. 3



Prep Activity 1 — **Criteria and Constraints**

In engineering, guidelines for your design are called criteria and constraints.

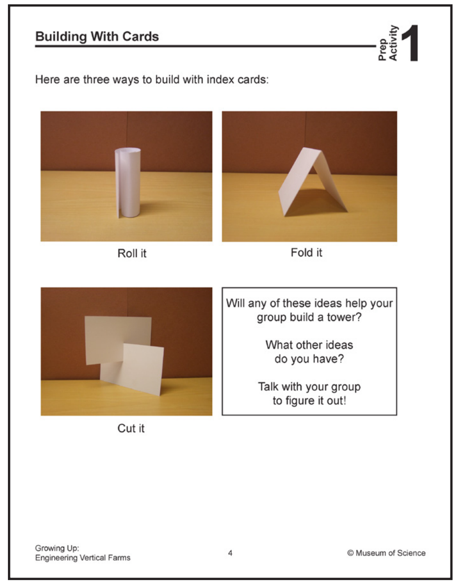
GOAL:	Engineer a model tower that can support a water-collection tank.

CRITERIA Things you or your design needs to do
You will work in groups to engineer your tower.
Your tower must be at least 1 foot tall, not including the water container.
Your tower must hold the water-filled deli container for at least 10 seconds.

CONSTRAINTS Ways you and your design are limited
You will have 100 index cards, masking tape, measuring tape, and a pair of scissors.
The scissors and measuring tape cannot be used as a part of the tower.
You only have 20 minutes to *create* your tower.
You can hold the deli container filled with water as you build, but you cannot *test* with it until the official testing time begins.

Growing Up: Engineering Vertical Farms 3 © Museum of Science

Building With Cards, p. 4



Building With Cards — Prep Activity 1

Here are three ways to build with index cards:

Roll it

Fold it

Cut it

Will any of these ideas help your group build a tower?

What other ideas do you have?

Talk with your group to figure it out!

Growing Up: Engineering Vertical Farms 4 © Museum of Science

Prep Activity 1

What is Engineering?

Activity Guide

Youth will learn:
- They are engineers and they can design a solution to a problem.
- The Engineering Design Process is a tool used by engineers to solve problems.

Tip

If youth are not familiar with the structure of a water tower, show and discuss the examples on p. 5 in this guide. Tell youth that these towers store water high off of the ground and create water pressure using gravity.

Tip

Criteria and constraints are introduced several times throughout this unit. While it is not critical that youth know the definitions of these terms, it can be helpful for them to have a general sense for them.

Criteria: Things your design needs to do.

Constraints: Ways that your design is limited.

Introduction (5 min)

1. Tell youth that you have an engineering problem for them to solve.
2. Explain to youth that they have been hired as engineers to solve a problem in a city called Greentown. The town is constructing a new city hall and they want to become more environmentally friendly. They have decided to design a water tower on the roof of their building to collect and hold rainwater.
3. The town is not sure how to design the tower, so they have hired this group of youth to engineer a model tower as an example.
4. Ask youth:
   - **What is the problem we are trying to solve?** *We need to engineer a model tower that can support a water collection system.*

Identify (5 min)

1. Split youth into groups of 3. Ask:
   - **What questions do you have before you begin working?**
2. Encourage the whole group to ask questions about the criteria (what the tower needs to do), constraints (how they are limited), and how to evaluate success.
3. Pass out an Engineering Notebook to each youth. Explain that the Notebook is a place they can find information about their engineering challenges and record their ideas. Tell them to turn to p. 3 to find the answers to some of the questions they came up with.
4. Have a volunteer read about the criteria and constraints. As you revtiew the information, make sure youth know:
   - They will work in groups.
   - Towers must be at least 1 foot tall (not including the container).
   - Towers need to hold up an 8 oz. deli container filled with water for at least 10 seconds.
   - Youth can use 100 index cards, masking tape, measuring tape, and a pair of scissors.
   - The scissors and measuring tape can be used as tools, but cannot be used as a part of the structure.
   - Groups will have 20 minutes to build their towers.
   - Groups can hold the deli container filled with water as they build, but they cannot *test* with it until the official testing time begins.

Tip

Direct youth to *Building With Cards*, p. 4 in their Engineering Notebooks, if they have difficulty getting started.

Tip

For an additional challenge, you can limit each group's masking tape to anywhere between 1 and 4 feet.

Create (20 min)

1. Pass out 100 index cards and scissors to each group. Have groups share the masking tape and measuring tapes.
2. Set the timer for 20 minutes and have groups begin engineering.
3. As groups work, pass around the container of water so everyone can hold it and get a sense of its weight, but remind youth that they cannot *test* with it yet.
4. As you visit each group, ask questions like:
   - **How did your group come up with this design?**
   - **Why do you think your design will work well?**
   - **What are you doing to the cards to make them stronger?**
5. Every 5 minutes, let groups know how much time they have left.

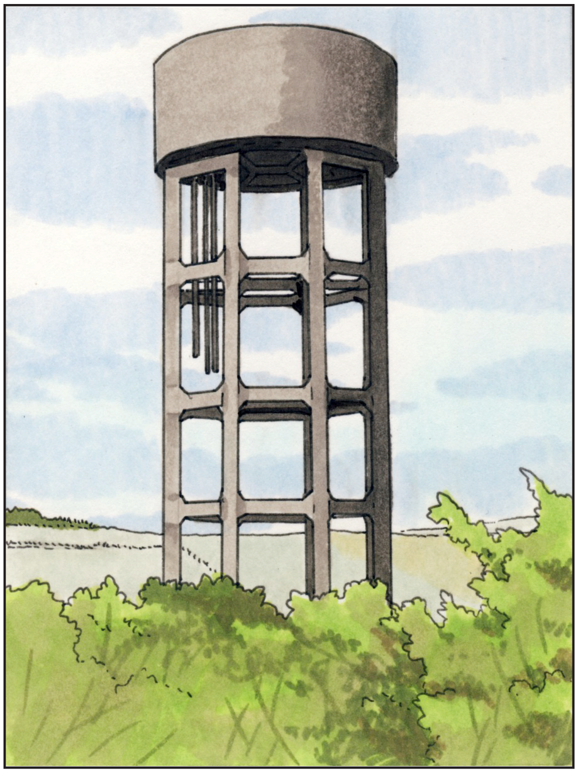
Test & Communicate (15 min)

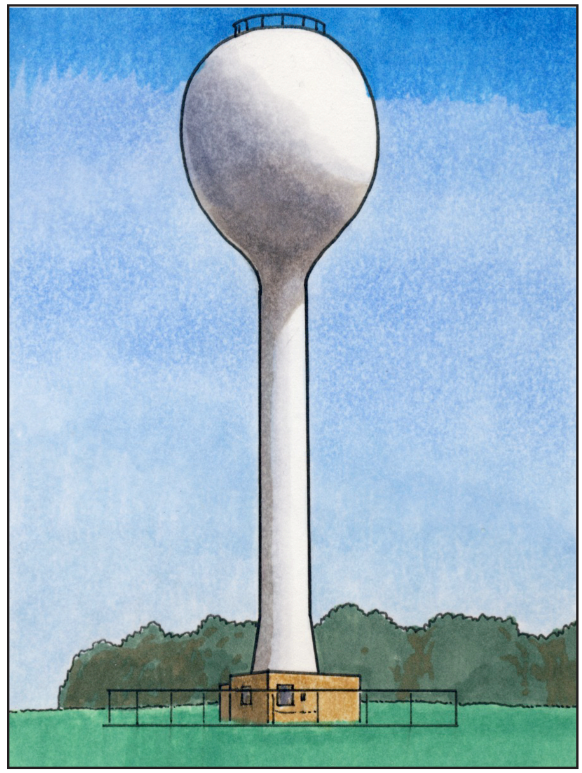
1. When time is up, have groups step away from their designs and observe the structures that other groups have *created*. Ask:
   - **What do you observe is the same about all of the designs? What is different?** *Same materials, shapes, etc. Different ways of using the index cards, different heights, etc.*
2. Point out that every group engineered a different solution to the same problem, and that is great! In engineering, there are always many solutions to the same problem.
3. Have the groups take turns *testing*. Before *testing*, ask:
   - **Tell us about your design. How did you use the materials?**
   - **What do you predict will happen during *testing*?**
4. Allow a group member to measure their tower and then place the water container on top to see if it will hold for at least 10 seconds.
5. Whether or not their design met the criteria, ask each group:
   - **How would you *improve* your design if you had more time?**

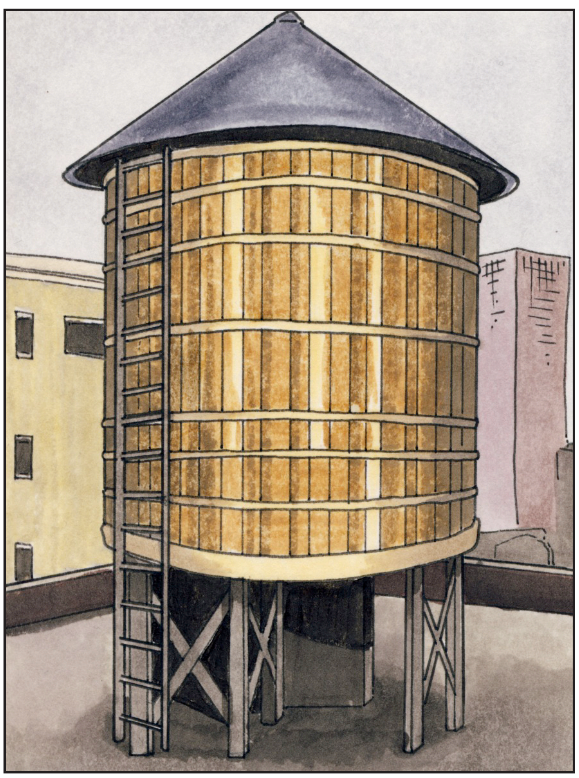
Reflect (10 min)

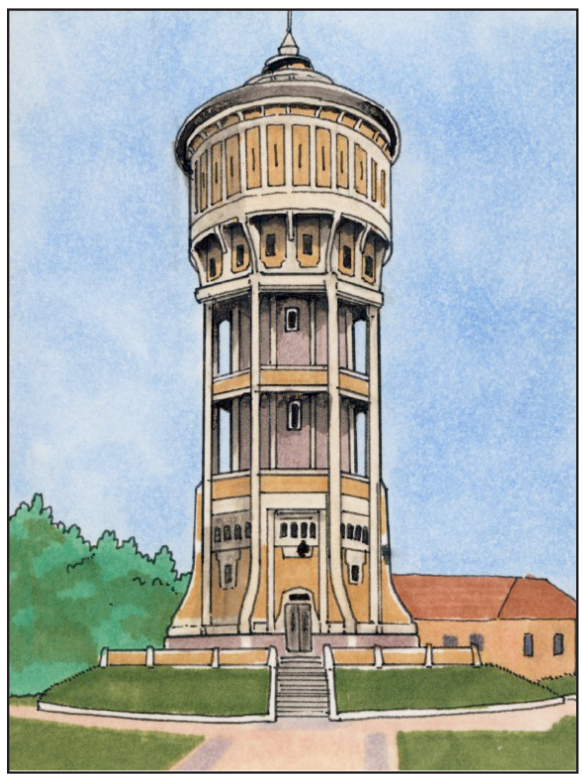
1. Post the *Engineering Design Process* poster.
2. Explain that engineers use a process called the Engineering Design Process to help them solve problems. Ask:
   - **How did your group use these steps, or steps like these, as you engineered your model tower?** *Encourage groups to link specific actions to specific steps, for example: we used the* imagine *step when we brainstormed different designs.*
3. Explain that they will continue to use the Engineering Design Process to guide their engineering work throughout the unit.
4. Tell youth that because they all used the Engineering Design Process, they are all engineers!
5. Let youth know that next time, they will focus on another challenge for Greentown.

Water Tower Examples









Prep Activity

2 What is Technology?

Educator Preview

Overview

Youth will explore a definition of technology and will be introduced to the concept of vertical farms.

Note to Educator:

Many people do not realize that engineers are the people who design technologies. Furthermore, many people only think of technologies as things that require electricity. This activity introduces youth to the idea that technology can be anything created by people to help solve a problem. It also introduces vertical farms as a type of technology intended to solve food shortage problems in urban areas.

Activity Timing

Farmland:	20 min
Vertical Farms:	20 min
Challenge:	15 min
	55 min

21st Century Skill Highlight

Collaboration

Creativity

Prep Activity 2 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ *Engineering Everywhere: Special Report* video
- ☐ chart paper and marker
- ☐ computer and projector

For each group of 3

- ☐ 1 sheet of brown construction paper
- ☐ 1 set of *Food Production Cards*, pp. 13–21, this guide

For each youth

- ☐ Engineering Notebook

Prep Activity 2 Preparation

1. Post the *Engineering Design Process* poster.
2. Make a copy of and cut out the *Food Production Cards*, pp. 13–21 in this guide, for each group. Make sure to separate the cards for each round. There are small numbers printed in the corner of each card to indicate in which round they should be distributed. **Save these cards for future activities.**
3. Watch and prepare to play the video *Engineering Everywhere: Special Report* (9:56): http://eie.org/verticalfarms.

Activity 1 Pre-Preparation

4. Procure enough seedlings for each group to incorporate three different plants into their window gardens.
5. You will also need three soda bottles or other similar recycled containers for each group. You may want to post a note by the recycling bin at your site to ask others to help you gather bottles.

Notebook Pages for Prep Activity 2

Greentown Request for Proposals, p. 5

Prep Activity 2 — **Greentown Request for Proposals**

To: Engineering Everywhere Engineers
From: Greentown City Council
Subject: Request for Vertical Farm Proposals

Dear Engineers,

The City of Greentown is an American coastal city with 500,000 residents. Greentown is not located near any major agricultural centers, so nearly all of the fresh food found in Greentown grocery stores is shipped from other locations. The citizens of Greentown are interested in ways to create local, sustainable sources of fresh fruits and vegetables. The Greentown City Council is requesting proposals from agricultural engineers interested in creating a vertical farm in our city. We are requesting that engineers make models first. If a successful model is engineered, the council would then consider *creating* a real vertical farm.

In order to be considered, engineers must create a model vertical farm of at least three levels and each level must contain and support at least one model plant. Engineers must *create* and *test* working water and light systems for this model to ensure that the plants will have the resources they need to flourish.

Engineers must create a visual presentation to present to the Greentown City Council at the conclusion of their engineering challenge.

Sincerely,

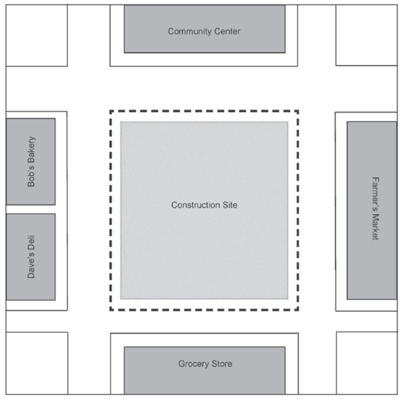
Chairman
Greentown City Council

Growing Up: Engineering Vertical Farms 5 © Museum of Science

Greentown Request for Proposals: Building Site, p. 6

Greentown Request for Proposals: Building Site — Prep Activity 2

Greentown Population: 500,000



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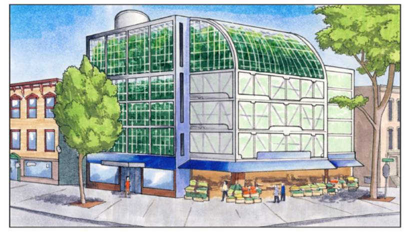
Vertical Farm Prototypes, p. 7

Prep Activity 2 — **Vertical Farm Prototypes**

Look at the two vertical farm prototypes.

Vertical Farm Prototype A



Consider the following questions:

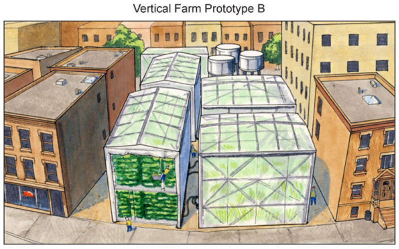
- What are some potential benefits of building a vertical farm near where you live? What are some disadvantages?
- How are the designs of the vertical farms the same? How are they different?
- What surprises you about these designs?
- What elements of these designs could you incorporate into your own vertical farm design?

Growing Up: Engineering Vertical Farms 7 © Museum of Science

Vertical Farm Prototypes, p. 8

Vertical Farm Prototypes — Prep Activity 2

Vertical Farm Prototype B



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My Engineering Profile, p. 9

Prep Activity 2 — **Engineering Profile**

Check off the skills YOU bring to the table.

☐ **Communication**
- I give valuable feedback to others
- I like giving presentations

☐ **Persistence**
- I learn from failure
- I keep trying until I succeed

☐ **Creativity**
- I imagine lots of ideas
- I come up with new ways of doing something

☐ **Teamwork**
- I work well in teams
- I like giving and receiving feedback on my work

☐ **Critical Thinking**
- I solve problems
- I make sense of complicated information

☐ **Technical Skills**
- I make things
- I like working with different materials

☐ **Leadership**
- I lead teams well
- I make sure everyone has a voice

Which skills do you want **to use**?	Which skills do you want **to learn**?

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What is Technology?

Youth will learn:

- Technology is anything designed by people to help solve a problem.
- The amount of farmland available limits the amount of crops that can be produced.
- Engineers envision vertical farms as technologies that can help grow food near densely populated areas and in confined spaces.

Tip

If youth have experience with farming, you may want to have them share their knowledge of how food gets from the fields to a table

Tip

If you think it will be helpful to your youth, consider posting a goal.
Goal: To fit as many crops onto the farmland as possible with no overlap or crop areas falling outside of the farmland.

Tip

There is a small number printed in the corner of each card to indicate which round the card should be distributed in.

Farmland Limitations (20 min)

1. Let youth know that today they will explore farming and food production. Review the previous activity that youth completed. Ask:
    - **What was the engineering challenge you helped Greentown solve during our last session?** *We engineered a model tower in Greentown that could support a water collection tank.*
2. Tell youth that Greentown's population has been growing at an increasingly fast rate and local farmers are having a hard time producing the fresh food that the citizens of Greentown need.
3. Let youth know that they will work in groups to explore how food production in Greentown has changed with the increasing population. The goal is to maximize the amount of crops that can be grown on a limited amount of farmland. Explain that:
    - Each group will be given one plot of land (represented by the sheet of construction paper) that represents the amount of farmland available for Greentown.
    - Each round, groups will be asked to produce a specific amount of crops to support the population of Greentown at a certain point in time. These crops will be represented by the cards you prepared. Groups must arrange the crops on their farmland with no overlap.
    - As the population of Greentown grows and food demands increase over time, youth will be given more crops to produce in the form of additional crop cards. Groups must add these crops to the crops that are already being produced. The plots of crops will have to be rearranged on the available farmland.
4. Break youth into groups of 3, and give each group a sheet of brown construction paper to represent the farmland.
5. Tell youth that when Greentown was first founded their population was small and they only needed to produce a

Tip

For a math extension, have youth measure the footprint area that the crops will take up when laid out horizontally. Then have youth measure the footprint of the area taken up if the crops are stacked vertically.

Tip

Youth may have a challenging time fitting the crops into the farmland in the fourth round. If they are engaged in the activity, give them time to rearrange their crop cards. If they are not engaged, then play this as the final round and move on. Youth should not be able to fit all the crops into the farmland in the fifth round.

Tip

Let youth know that vertical farms are still in a conceptual stage. While a few prototype vertical farms exist around the world, the idea of vertical farms is still very new. The vertical farms described on pp. 7–8 in youth's Engineering Notebooks give an idea of the diverse types of vertical farms that engineers are beginning to envision.

little bit of food. Pass out the first two crop cards to each group. Have them arrange their crops on their farmland. Ask:

- **Is it difficult to grow enough crops for this small population?** *No, there is a lot of available farmland.*

6. Go through the next two rounds of the game, explaining that the population of Greentown has continued to grow. Pass out the cards that represent the growing demand for crops.
7. Pass out the fourth round of crops. Give groups time to arrange their crops on their farmland. Ask:
   - **Is there enough room to plant the crops needed to support Greentown's growing population?** *Barely—our farmland is running out of room.*
8. Pass out the final round of crops for groups to arrange.
   - **Is there enough room to plant the crops needed to feed Greentown?** *No, we cannot fit all of the crops.*
9. Tell youth that Greentown has gotten overpopulated and the farmland is no longer big enough to produce the food needed to feed the growing population. Ask:
   - **What do you think Greentown could do to feed their population?** *Import food, invent faster-growing seeds, etc.*
10. Explain to youth that just like in Greentown, the earth's population is increasing and experts predict the population will grow from 7 billion in 2015 to 9 billion by 2050. Unfortunately, current farmland and agricultural practices will not allow us to grow enough food to support this larger population.

Introduction to Vertical Farms (20 min)

1. Tell youth you would like to share one definition of technology with them. Write the definition of technology on the board or a sheet of chart paper: *Anything designed by people to solve a problem*. Ask:
   - **Does anything surprise you about this definition?** *Reinforce that according to this definition, all human-made items that solve problems are technology, whether they require electricity or not.*
   - **Can you think of any technologies that are used to produce the food you eat?** *Encourage youth to think about the watering and sprinkler systems used on farms, greenhouses, fertilizer, etc.*
   - **Would any of these technologies help Greentown with their food-production problems?**
2. Tell youth that they will now learn about a technology that engineers have *imagined* to produce enough food for a

growing population in a limited amount of space. Ask:

- **What do you think of when you hear the term "vertical farm"?** *Accept all answers.*

3. If youth are unfamiliar with the term, explain that vertical farms are designed to grow crops within skyscrapers or multi-level buildings.
4. Explain that they are going to watch a short video to learn more about vertical farms. Play the video *Engineering Everywhere: Special Report* (9:56): http://eie.org/verticalfarms.
5. Ask:
   - **What are some benefits of vertical farms?** *Vertical farms can produce food in an area with limited space.*
   - **What do you think are some difficulties of designing a vertical farm?** *You have to get a lot of natural resources—water, light, nutrients, etc.—into an artificial environment.*
   - **Do you think a vertical farm is a technology? Why?** *Yes, because it could solve the problem of growing more food in limited space.*

Setting the Challenge (15 min)

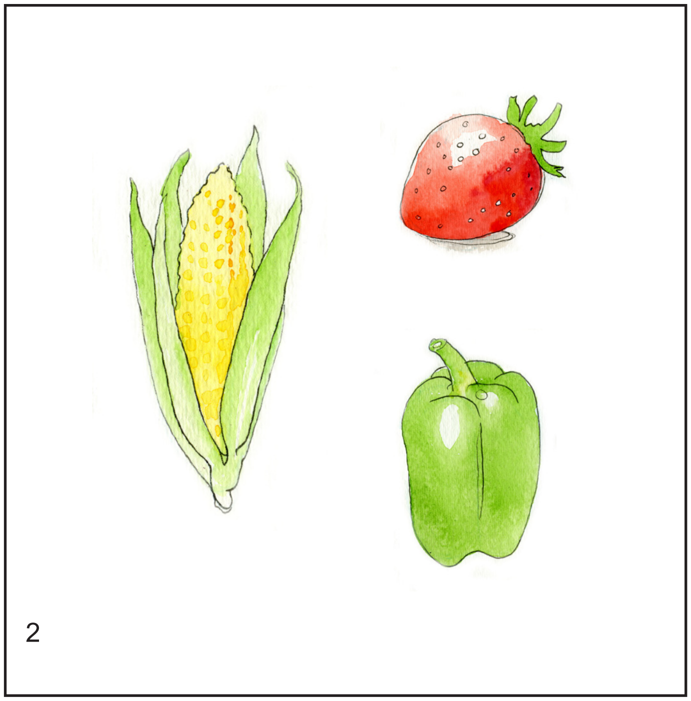
1. Tell youth that their challenge over the next several sessions will be to work as agricultural engineers to design a model vertical farm for Greentown.
2. Have youth turn to *Greentown: Request for Proposals*, p. 5 in their Engineering Notebooks, and have a volunteer read the page. Ask:
   - **What does the vertical farm have to do?**
3. After youth have reviewed the *Request for Proposals*, have them look over the building site plan on p. 6. Ask:
   - **What do you think will be difficult about this project?**
   - **What impact could the vertical farm have on the community?**
4. Point out to youth that there are some vertical farm concept designs and questions in their Engineering Notebooks, pp. 7–8. They may want to look at these as they think about Greentown's vertical farm.
5. Have youth fill out *My Engineering Profile,* p. 9 in their Engineering Notebooks, and reflect on engineering skills that they feel are strengths, and any skills they would like to work on for this challenge.
6. Tell youth that next time they will learn more about the needs of plants and engineer a window garden with live plants.
7. Save the *Food Production Cards* for future activities.

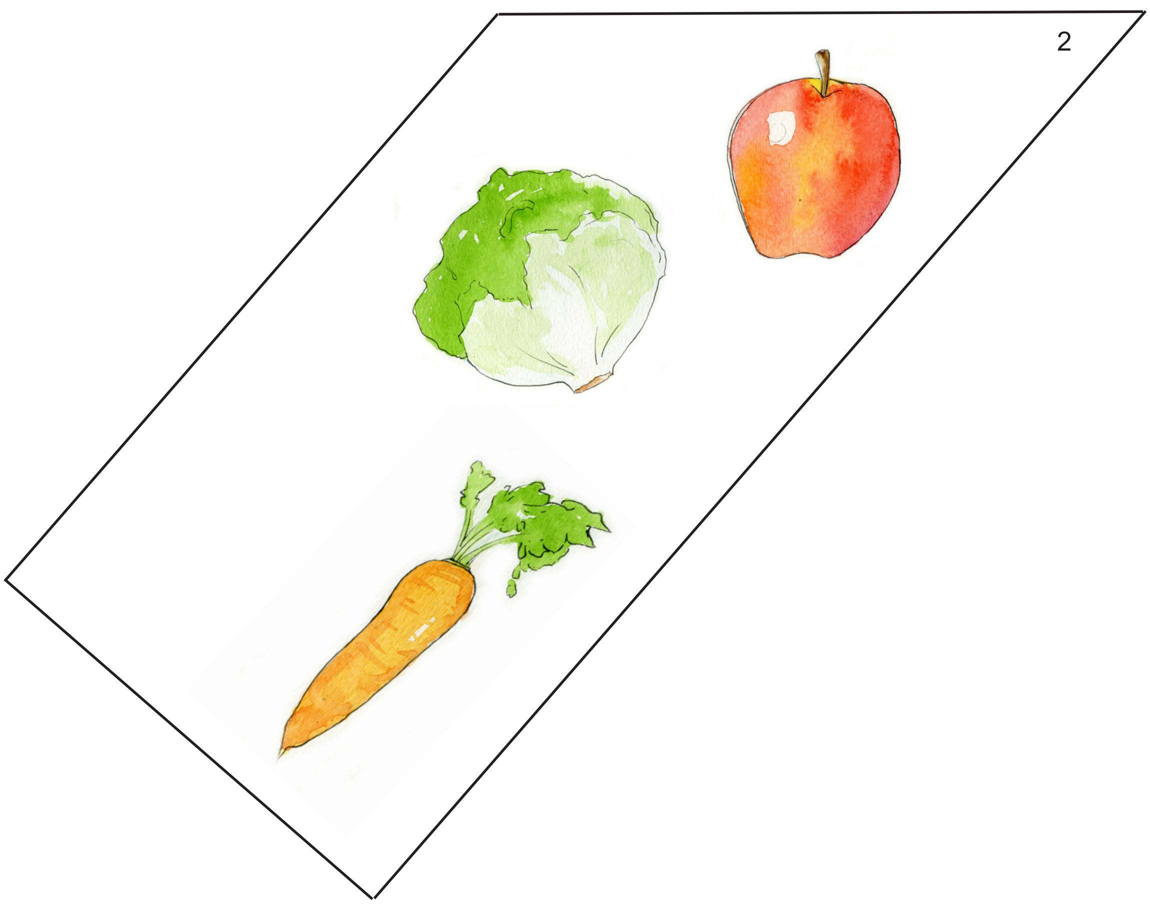
Prep Activity 2 Food Production Cards: Round 1

Each group should get both crop cards shown below during Round 1.

Prep Activity 2 Food Production Cards: Round 2

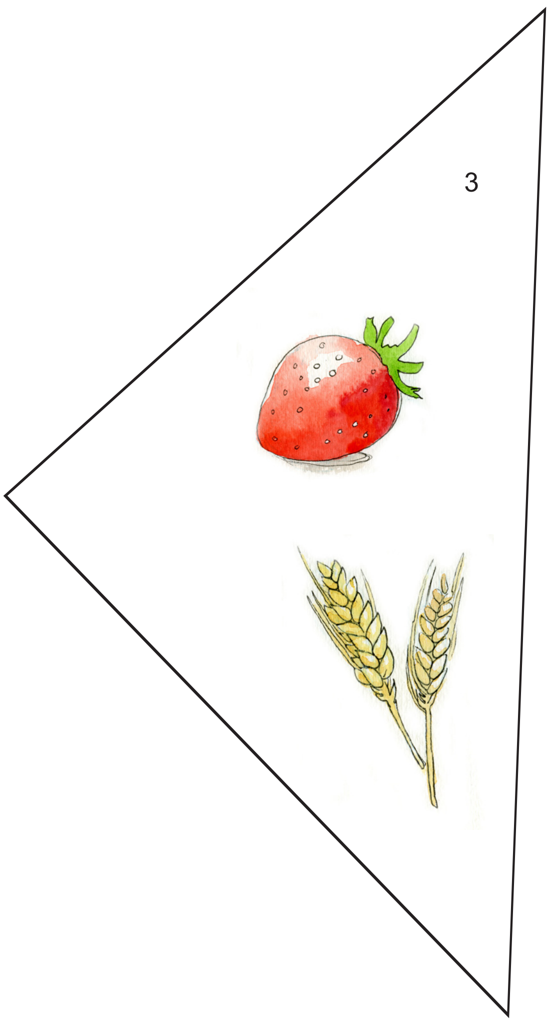
Each group should get both crop cards shown below during Round 2.

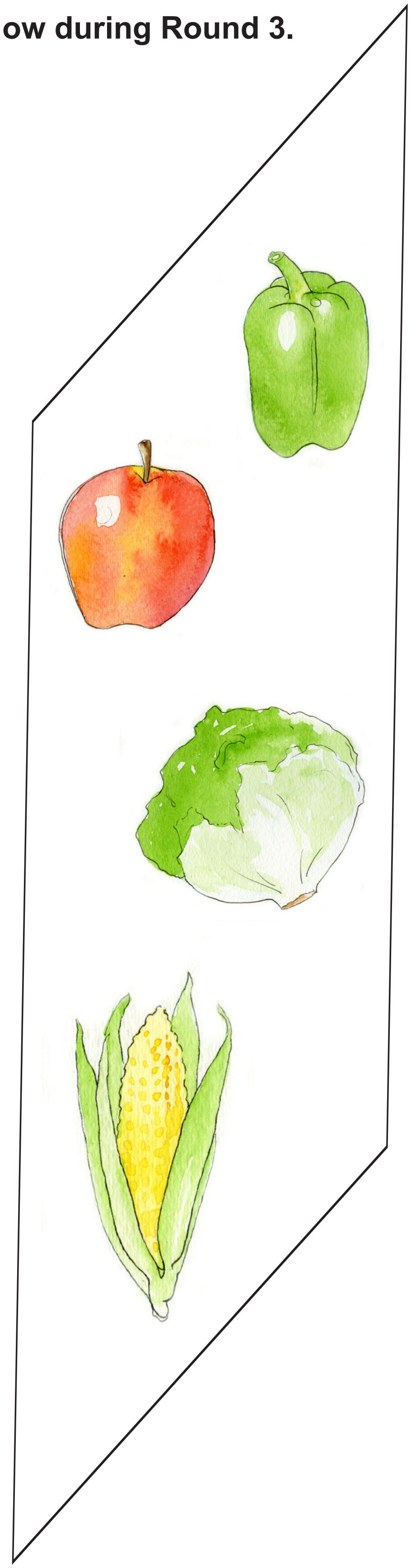




Prep Activity 2 Food Production Cards: Round 3

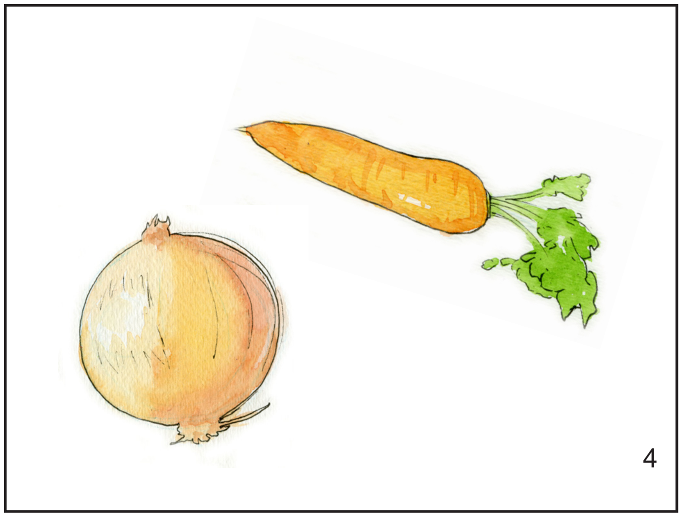
Each group should get both crop cards shown below during Round 3.

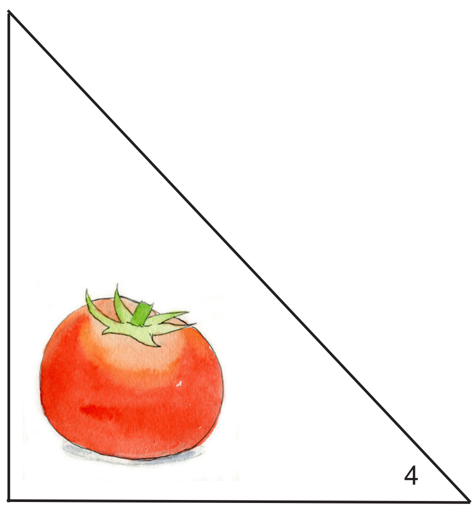




Food Production Cards: Round 4

Each group should get both crop cards shown below during Round 4.

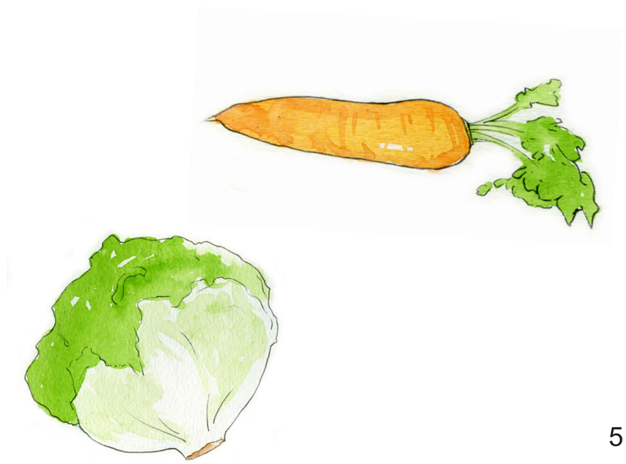




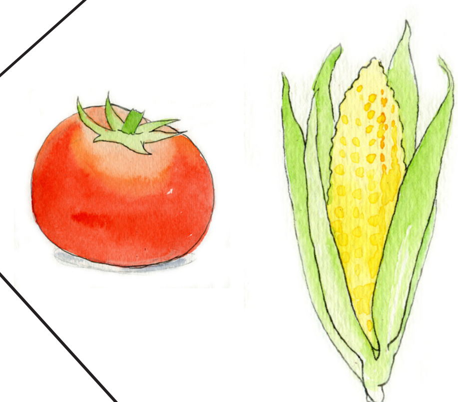
Prep Activity **2**

Food Production Cards: Round 5

Each group should get both crop cards shown below during Round 5.



5



5

Activity 1 Window Gardens

Educator Preview

Overview

Youth will engineer a window garden using plastic bottles.

Note to Educator:
Youth will need to hang their window gardens from suction cups on a pane of glass, the ceiling, a sturdy hook, a curtain rod, or a coat rack. Make sure you identify a way to support youth's window garden systems before the activity begins.

Activity Timing

Introduction:	10 min
Create:	30 min
Plant:	10 min
Test & Communicate:	10 min
	60 min

21^{st} Century Skill Highlight

Collaboration
Creativity

Activity 1 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ chart paper
- ☐ colored markers
- ☐ newspaper
- ☐ 1 bag of gravel, 10 lbs.
- ☐ 1 bag of potting soil, 16 lbs.
- ☐ 1 hole punch
- ☐ 1 roll of paper towels
- ☐ 1 roll of string
- ☐ 2 deli containers, 16 oz.
- ☐ 2 feet of 1/4" tubing
- ☐ 2 rolls of duct tape
- ☐ 4 pitchers
- ☐ 16 suction cups, 2.5"
- ☐ 50 craft sticks
- ☐ 1 utility knife (for educator use)

For each group of 3

- ☐ 1 pair of scissors
- ☐ 1 plastic spoon
- ☐ 3 plants
- ☐ 3 plastic bottles, 16 oz.

For each youth

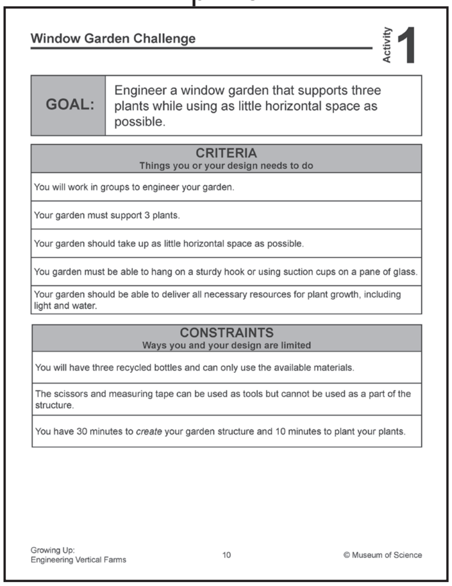
- ☐ Engineering Notebook

Preparation

1. Post the *Engineering Design Process* poster.
2. Lay out the newspaper on the tables to contain the mess.
3. Prepare the materials for constructing the window gardens on the Materials Table.
4. On a separate table, lay out the plants, gravel, and potting soil. Place one plastic deli container next to the bag of gravel and the other next to the potting soil to be used for scooping. Lay out the plastic spoons, which groups can use to dig and plant.
5. Fill up each pitcher with water.
6. Prepare the location you identified for youth to hang their window gardens (see Note to Educator above).

Notebook Pages for Activity 1

Window Garden Challenge, p. 10



Window Garden Challenge Activity 1

GOAL:	Engineer a window garden that supports three plants while using as little horizontal space as possible.

CRITERIA Things you or your design needs to do
You will work in groups to engineer your garden.
Your garden must support 3 plants.
Your garden should take up as little horizontal space as possible.
You garden must be able to hang on a sturdy hook or using suction cups on a pane of glass.
Your garden should be able to deliver all necessary resources for plant growth, including light and water.

CONSTRAINTS Ways you and your design are limited
You will have three recycled bottles and can only use the available materials.
The scissors and measuring tape can be used as tools but cannot be used as a part of the structure.
You have 30 minutes to *create* your garden structure and 10 minutes to plant your plants.

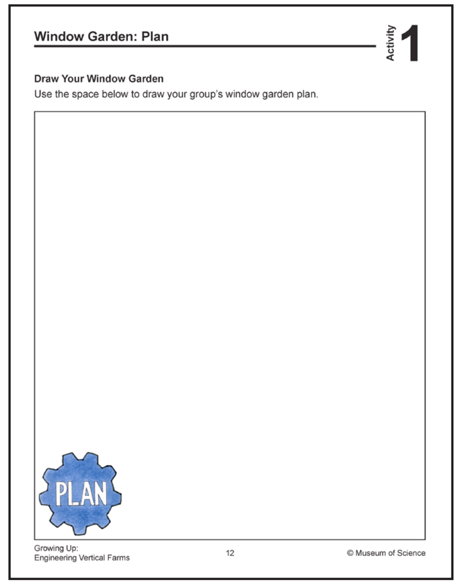
Growing Up: Engineering Vertical Farms 10 © Museum of Science

Window Garden Examples, p. 11

Activity 1 Window Garden Examples

Growing Up: Engineering Vertical Farms 11 © Museum of Science

Window Garden: Plan, p. 12



Window Garden: Plan Activity 1

Draw Your Window Garden

Use the space below to draw your group's window garden plan.

Growing Up: Engineering Vertical Farms 12 © Museum of Science

Window Gardens

Youth will learn:
- Plants have numerous requirements that must be met in order for them to survive.
- Engineers must consider the needs of plants when designing vertical farm systems.

Challenge Introduction (10 min)

1. Have youth reflect on the last activity. Ask:
   - **What is the problem that Greentown is facing?** *They do not have enough space to grow the amount of food they need to support their population.*
2. Tell youth that today they are going to *investigate* the resources plants need in order to survive, so that they can engineer ways to deliver these resources in their vertical farms.
3. Hold up a plant and ask youth:
   - **What does this plant need to stay healthy?** *Accept all answers. Youth will likely say light and water. They may also say air, carbon dioxide, and nutrients.*
4. Explain to youth that their challenge for today will be to engineer a small window garden, which is a way to grow plants that are stacked vertically so they take up very little space. Window gardens are similar to vertical farms in that they use the vertical space along a window instead of horizontal space along the ground.
5. Tell youth that their garden will need to hold three different plants (each in a different plastic bottle) while also being able to deliver all of the necessary resources for the plants. Hold up a 16 oz. soda bottle. Ask youth:
   - **How can you *imagine* reusing soda bottles like this one to make a garden in our window?** *Accept all answers.*
   - **How can you minimize the horizontal area of your window garden?** *Youth can stack the bottles on top of each other instead of spreading them out horizontally. This is similar to the way that vertical farms have a reduced footprint.*
   - **If the bottles are stacked on top of each other, how can you deliver water to your plants?** *Youth can either deliver water to each bottle or pour water in the top and allow the unused water to drip down to lower bottles.*
6. Have youth review the criteria and constraints for the challenge on *Window Garden Challenge*, p. 10 in their Engineering Notebooks.
7. Tell groups they will have 30 minutes to *plan* and *create* the skeleton of their system (meaning the base of their system with no plants in it). Then, they will have 10 minutes to plant their plants.

Tip (optional)

If youth are not familiar with the needs of plants, play the video *Photosynthesis* (4:51): http://tinyurl.com/n3magvj.

Tip

For a math extension, have youth measure what the footprint area of their containers would be if they were placed horizontally, and then compare the measurement to the area of the footprint when the plants are placed vertically.

Tip

If you think it will be useful to your youth, post the goal for the activity on the board or chart paper. **Goal**: Engineer a window garden that supports three plants using as little horizontal space as possible.

Tip

To guide youth to think about how to fill their containers without leaking soil from the bottom of their bottles, encourage them to think about layering the rocks and soil.

Tip

Youth can put newspaper under their window gardens while planting to contain any mess.

Tip

If youth are interested in seeing a window farm in action, show them the short video *The Window Farms Project* (3:43): http://tinyurl.com/o7lvh3l.

Tip

Youth can learn more about window farms and download free window farm plans online at: http://our.windowfarms.org.

Create (30 min)

1. Break youth into groups of 3.
2. Give groups a few minutes to *plan* their designs. Tell youth that they can reference *Window Garden Examples*, p. 11 in their Engineering Notebooks, for inspiration.
3. Allow youth to visit the Materials Table to explore the types of materials that they will have available to them during this challenge. They should not take any materials yet.
4. Tell groups that they should sketch their designs on *Window Garden Plan*, p. 12 in their Engineering Notebooks.
5. Once youth have sketched out their plans, allow them to collect their materials from the Materials Table. Remind youth that they do not need to worry about filling the containers or planting their plants during this part of the activity. They should focus on constructing their window garden structure.
6. Give youth 30 minutes to *create*. As groups work, circulate around the room and ask:
   - **How do you *imagine* your window garden will work?**
   - **How will you deliver water to your window garden?**

Plant (10 min)

1. Once youth have finished their designs, allow them to hang their designs in the space you designated.
2. If the structure does not work as they *imagined*, encourage youth to keep working to *improve* their designs.
3. If their designs work as they intended, allow groups to visit the Materials Table and collect their plants and any planting materials they would like.
4. Give youth 10 minutes to plant their plants and complete their designs. As youth plant, ask:
   - **How are the needs of the plants being met in your design?**

Test & Communicate (10 min)

1. Have each group water their window farm and then participate in a gallery walk to observe the other designs. Ask:
   - **How did you engineer your window garden to hang above the ground?**
   - **Does water reach all of the plants in your window garden?**
   - **How much space would you need if you planted these plants on the ground in a row compared to the space needed for the window garden?**
2. Congratulate youth on completing their first agricultural engineering challenge. Tell youth that next time they will explore how to deliver water to plants in vertical farms.

Activity 2 Design a Water System

Overview

Youth will engineer a water pump system that can deliver water to different locations.

Note to Educator:

Make sure to familiarize yourself with the water pump before the activity. You will need the water pump, the two pieces of associated tubing, and a water reservoir. The hole closest to the hand pump is the intake and sucks in the water. The hole farthest from the hand pump is the outtake and expels the water. You may want to label the intake and outtake holes on the pumps for youth.

Activity Timing

Introduction:	5 min
Investigate:	10 min
Create:	30 min
Test & Communicate:	10 min
	55 min

21st Century Skill Highlight

Collaboration
Creativity

Activity 2 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ newspaper
- ☐ 1 roll of paper towels
- ☐ 1 utility knife (for educator use)
- ☐ 2 rolls of duct tape
- ☐ 4 water pitchers
- ☐ 16 tubing connectors
- ☐ 25 tubing splitters

For each group of 3

- ☐ 1 aluminum tray
- ☐ 1 pair of scissors
- ☐ 1 plastic deli container, 16 oz.
- ☐ 1 water pump
- ☐ 3 feet of tubing, 1/4”
- ☐ 5 plastic deli containers, 8 oz.

For each participant

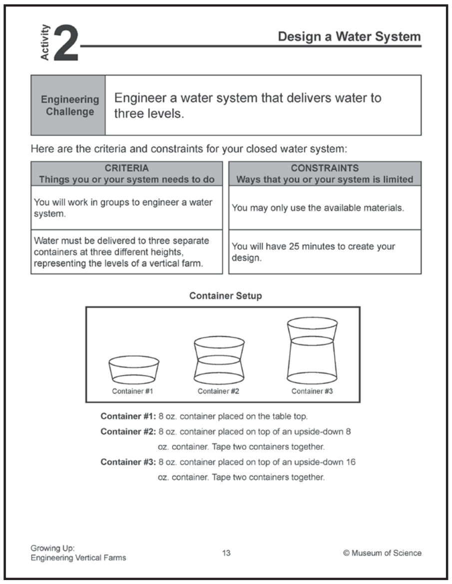
- ☐ Engineering Notebook

Preparation

1. Post the *Engineering Design Process* poster.
2. Cut a 5-inch piece of 1/4” tubing for each group.
3. Prepare an example of the container setup required for this challenge. An explanation and schematic of this setup can by found on p. 31 in this guide.
4. Fill an aluminum tray halfway with water for each group. Youth can use their water pitchers to fill the pan higher if needed.
5. Collect newspaper to be put under the pump systems to contain spilled water.
6. Test the water pump and become familiar with how it works.

Notebook Pages for Activity 2

Design a Water System, p. 13



Activity 2 — Design a Water System

Engineering Challenge	Engineer a water system that delivers water to three levels.

Here are the criteria and constraints for your closed water system:

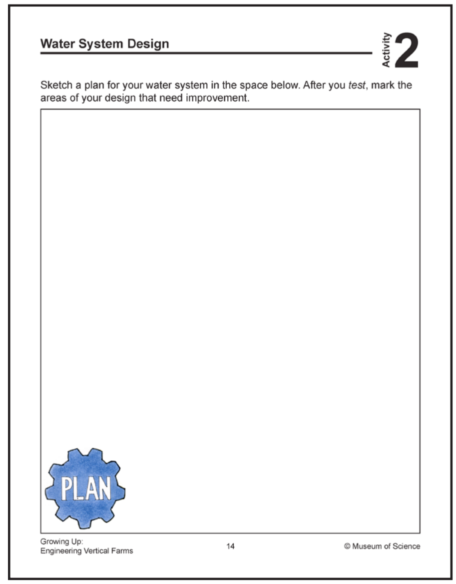
CRITERIA Things you or your system needs to do	CONSTRAINTS Ways that you or your system is limited
You will work in groups to engineer a water system.	You may only use the available materials.
Water must be delivered to three separate containers at three different heights, representing the levels of a vertical farm.	You will have 25 minutes to create your design.

Container Setup

Container #1: 8 oz. container placed on the table top.
Container #2: 8 oz. container placed on top of an upside-down 8 oz. container. Tape two containers together.
Container #3: 8 oz. container placed on top of an upside-down 16 oz. container. Tape two containers together.

Growing Up: Engineering Vertical Farms 13 © Museum of Science

Water System Design, p. 14



Water System Design — Activity 2

Sketch a plan for your water system in the space below. After you *test*, mark the areas of your design that need improvement.

Growing Up: Engineering Vertical Farms 14 © Museum of Science

Design a Water System

Youth will learn:

- Water can be delivered to crops on different floors of a vertical farm using a pump system.
- They can engineer a system that can deliver water to different plants.

Introduction (5 min)

1. Review with youth what they discussed last time. Ask:
   - **What do plants need to survive and grow?** *Water, sunlight, air.*
2. Tell youth that today they will focus on providing water to plants. Their challenge is to engineer a system to deliver water to three containers on three levels of a model vertical farm. Ask:
   - **Can you *imagine* how to deliver water to different levels of a vertical farm?** *Accept all answers. Youth may suggest dripping water from above or pumping water from below.*
3. Have youth turn to *Design a Water System*, p. 13 in their Engineering Notebooks, to learn more about their challenge. Make sure youth know:
   - They will work in groups of 2-3.
   - Water needs to be delivered to three different containers at three different heights (representing the levels of a vertical farm).
   - Each group will get a pump; a reservoir of water; and any tubing, accessories, and tools they need.
   - They will have 25 minutes to *create*.
4. Show youth the container setup they will use to simulate the 3 different levels of a vertical farm. A schematic of this setup can be found on *Water System Tutorial*, p. 31 in this guide. One 8-oz. container should be placed on the table, the second 8-oz. container should be taped to an upside-down 8-oz. container, and the third 8-oz. container should be taped to an upside-down 16-oz. container.
5. Briefly demonstrate how the pump works. Fill a reservoir with water and place the intake tubing into the water. Tape the output tubing to the side of the reservoir, so that the end is not in the water (so you can see water being pumped out). Pump the pump a few times to demonstrate the water flowing out of the reservoir, through the pump, and then back into the reservoir.
6. Tell youth that they will be given additional tubing to pump the water to the containers. They will need to tape the smaller 1/4” tubing to the pump’s tubing.

Tip

This activity can be messy, so make sure to keep paper towels and newspaper on hand to contain any spills.

Tip

Youth may want more direction as to the amount of water to deliver. If so, they can either set their own water delivery goals or you can decide as a group if you want more precise water delivery criteria.

Tip

Tell youth that the setup of the containers is more horizontal than it would need to be in a vertical farm, but it still meets the goal of this activity (to practice using a system to move water to different places).

Tip

Youth can put newspaper down under their water systems to soak up any spilled water.

Tip

Youth may not want to engineer a system to deliver unused water back to the reservoir, like the loop schematic depicted on p. 31 in this guide. This is fine. Support youth in their designs. Ask questions like "How could you reuse excess water?" to guide them to think about recycling the water in their system.

Tip

If youth have difficulty coming up with ideas, you may choose to copy *Possible Schematics of Delivery Systems*, p. 32 in this guide, and share the examples with youth.

Tip

If you have extra time, encourage youth to mark areas for improvements on *Water System Design*, p. 14 in their Engineering Notebooks.

Investigate (10 min)

1. Break youth into groups of 3. Give each group a pump, corresponding tubing, and an aluminum roasting pan of water.
2. Tell youth to spend 5 minutes exploring how they can manipulate the pumping of the water. As youth *investigate*, circulate around the room and ask:
   - **What happens when you raise the end of the tubing too high?** *The water flow stops.*
   - **What happens when you raise the middle of the tubing high but leave the end of the tubing low?** *The water flows normally.*
3. Pass out a small piece of the 1/4" tubing, a tubing connector, and a tubing splitter to each group. Tell groups to spend a few minutes *imagining* how they could use each of these materials in their design.
4. After youth have had time to brainstorm, ask:
   - **How do you *imagine* you could use the tubing connectors?**
   - **How do you *imagine* you could use the tubing splitters?**

Create (30 min)

1. Tell youth to spend a few minutes *planning* their water system design. They can sketch their plans on *Water System Design*, p. 14 in their Engineering Notebooks.
2. After groups have a plan, allow them to collect their materials and begin. If the tubes and tube connectors do not fit tightly together, youth may use duct tape to close any gaps.
3. Give groups 25 minutes to *create* their design. As groups work, circulate around the room and ask:
   - **How does your design deliver water to the different levels of the model vertical farm?**

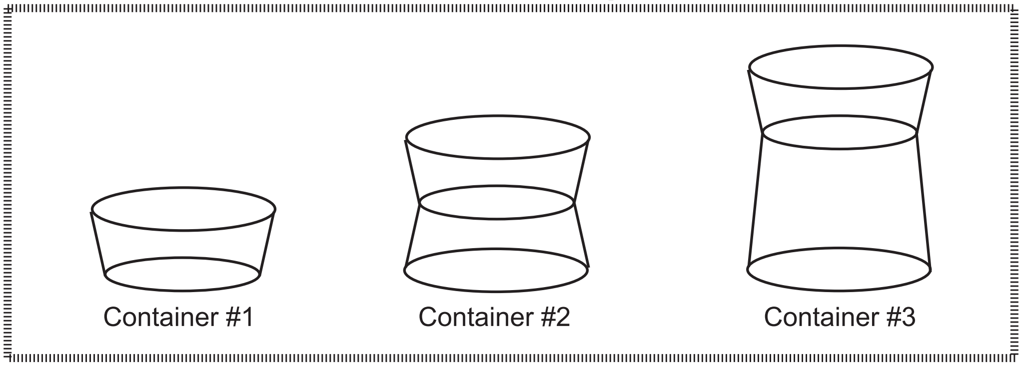
Test & Communicate (10 min)

1. Have each group test their water pump and then participate in a gallery walk to observe the other designs. Ask:
   - **How does your design deliver water to each of the levels of the model vertical farm?**
   - **How could you *improve* upon this design?**
2. After all of the groups present, ask:
   - **Which steps of the Engineering Design Process did you use today?**
   - **How could you incorporate your designs and what you learned today into a vertical farm?**
3. Tell youth that next time they will consider how engineers deliver light—another important resource—to plants in a vertical farm.

Activity 2

Water System Tutorial

Container Setup

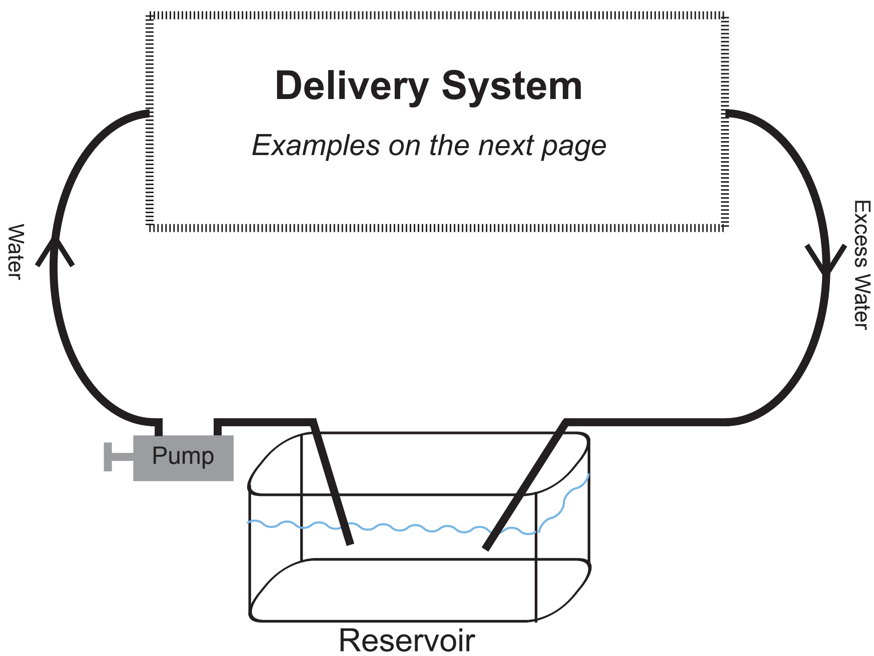


Container #1: 8-oz. container placed on table top. Tape to table.

Container #2: 8-oz. container placed on top of an upside-down 8-oz. container. Tape two containers together. Tape to table.

Container #3: 8-oz. container placed on top of an upside-down 16-oz. container. Tape two containers together. Tape to table.

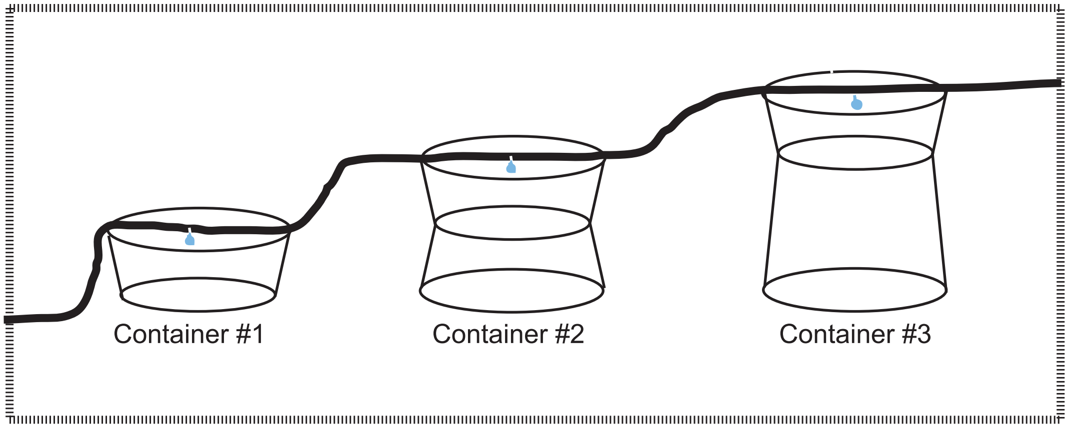
Possible schematic of water delivery system setup



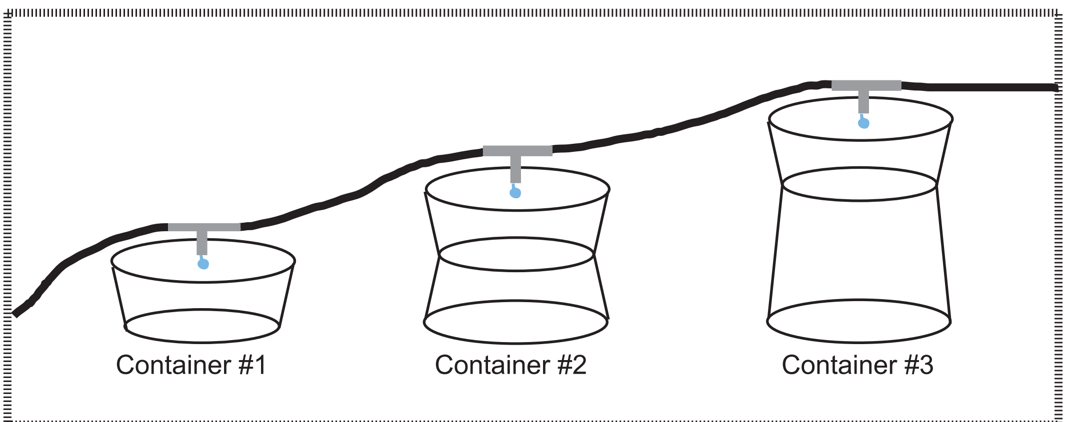
Note: This is one possible example of a system setup youth may design. Groups may not want to engineer a system to deliver unused water back to the reservoir, like the loop schematic depicted here. This is fine. Support groups in their designs. Ask questions like "How could you reuse excess water?" to guide them to think about recycling the water in their system.

Activity 2 Water System Tutorial

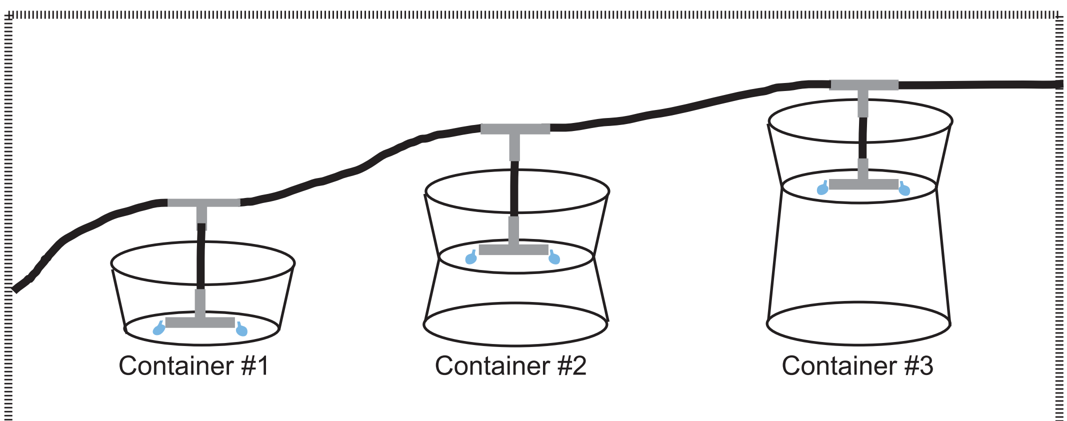
Possible Schematics of Delivery Systems



Water is delivered directly out of holes in the tubing.



Water is delivered through in-line splitters.



Water is delivered through in-line splitters. The water streams are split using additional splitters.

Activity **3** # It's Light and Mirrors

Educator Preview

Overview

Youth will design a lighting system to direct light to plants located in the shaded areas of a room.

Note to Educator:
The goal of this activity is to encourage youth to consider how engineers who design vertical farms manipulate and direct light to ensure that plants receive energy from the sun. The cubes groups make for this activity are the same as those that will be used as the vertical farm rooms in the final design challenge.

Activity Timing

Identify:	10 min
Investigate:	10 min
Create:	30 min
Test & Reflect:	10 min
	60 min

21st Century Skill Highlight

Collaboration
Creativity
Critical Thinking
Problem Solving

Activity 3 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ chart paper
- ☐ colored markers
- ☐ computer and projector
- ☐ 1 light and moisture meter
- ☐ 1 package of modeling clay
- ☐ 1 sheet of construction paper
- ☐ 2 rolls of duct tape
- ☐ 2 rolls of masking tape
- ☐ 12 mirrors
- ☐ 30 craft sticks
- ☐ 30 pipe cleaners

For each group of 3

- ☐ 1 flashlight
- ☐ 1-2 Food Production Cards from Prep Activity 2
- ☐ 5 storage cube sides
- ☐ 8 pipe cleaners

For each participant

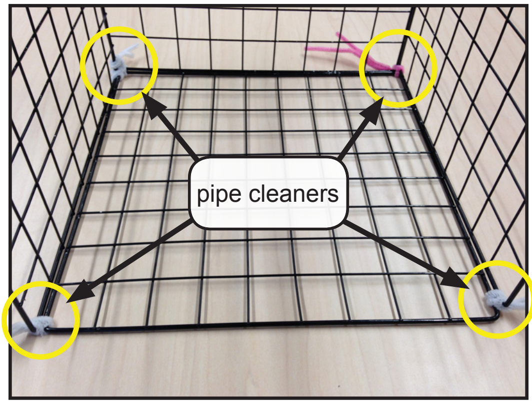
- ☐ Engineering Notebook

Preparation

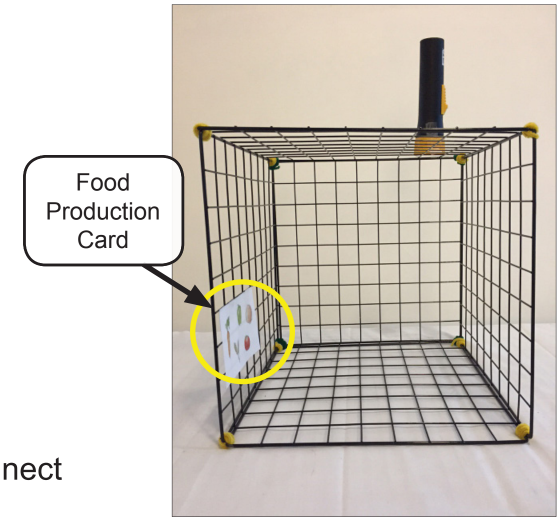
1. Post the *Engineering Design Process* poster.
2. Prepare 1 room as an example for the group. Construct the room using pipe cleaners to secure the joints. Leave 1 face open (see p. 34).
3. Place the flashlight face down on the top of the room in the back right corner. You may want to use tape to secure the flashlight in place.
4. Tape a *Food Production Card* to the inside of the room in the front left corner.
5. Optional: If you choose to facilitate the extension activity, make a copy of *Light Meter Investigation*, p. 39 in this guide, for each group.

Preparation Instructions: Building Room Cube

Bottom View



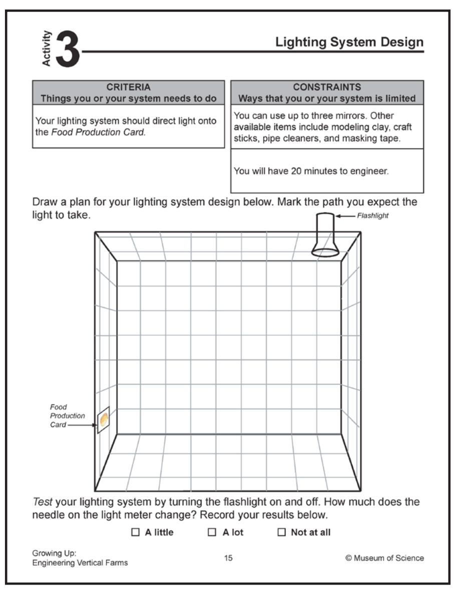
Front View



Construct the room using pipe cleaners to connect the walls to the base and ceiling.

Notebook Pages for Activity 3

Lighting System Design, p. 15



Activity 3 Lighting System Design

CRITERIA Things you or your system needs to do	CONSTRAINTS Ways that you or your system is limited
Your lighting system should direct light onto the *Food Production Card*.	You can use up to three mirrors. Other available items include modeling clay, craft sticks, pipe cleaners, and masking tape.
	You will have 20 minutes to engineer.

Draw a plan for your lighting system design below. Mark the path you expect the light to take.

Test your lighting system by turning the flashlight on and off. How much does the needle on the light meter change? Record your results below.

☐ A little ☐ A lot ☐ Not at all

Growing Up: Engineering Vertical Farms 15 © Museum of Science

Activity 3 # It's Light and Mirrors

Youth will learn:

- Light can be directed in different ways using mirrors.
- They can engineer solutions that provide light to plants that would otherwise not receive direct light.

Identify (10 min)

1. Explain that youth will design a lighting system for a vertical farm today. Ask:
   - **Why is it important to make sure the plants receive enough sunlight?** *Plants need sunlight in order to carry out photosynthesis, grow, and remain healthy.*
2. Show youth the cube you prepared. Explain that the cube represents one room of a vertical farm. Place the flashlight face down on top of the room in the back right corner (see the image in the Preparation section). Turn on the flashlight and explain that the light represents the sun. Point out the *Food Production Card* and tell them that this card represents the spot designated for the first batch of plants. Ask:
   - **Do you think this light source currently does a good job of reaching the plants? Why?** *No, the light mostly hits the bottom of the room.*
3. Explain that their challenge today is to design a lighting system that directs as much light as possible to the *Food Production Card*. Ask:
   - **Do you have any ideas about how we could direct more light to the plants?** *We could use mirrors to redirect the light.*
4. Have youth read the criteria and constraints for the challenge on *Lighting System Design,* p. 15 in their Engineering Notebooks, to learn about the materials they will have to make their lighting system.

Investigation (10 min)

1. Break youth into groups of 3.
2. Hold up a mirror. Tell groups that they will have 5 minutes to investigate. They should shine the light from the flashlight off of the mirrors onto a flat surface and observe what happens.
3. Give each group a flashlight and a mirror. As groups are working, ask:
   - **How does the mirror affect the beam of light?** *It changes the direction of the light.*

Tip

If youth are particularly interested in how different colors of light impact plants, refer them to the article *Plant Responses to Light*: http://tinyurl.com/nkcw5am.

Tip

For best results, run this activity with as little light in the room as possible. If it is still too light when you shut off the lights and cover the windows, place a sheet or blanket over the designs and test with the flashlight and light meter underneath.

Tip

To begin, groups should assess their lighting system by observing whether more light hits their *Food Production Cards*. Later in the activity, they will be introduced to a light meter that will allow them to quantify their results.

Tip

If your schedule allows, give youth more time to experiment with the flashlight and mirrors.

Tip

The flashlight on top of the room can easily tip over. It is important that the light remains in the same place as youth work to place their mirrors to accurately direct the light. You can mark the exact location the flashlight should be placed by taping it or creating a loop using a pipe cleaner and securing it to the top of the cube.

Tip

The light meter is not very sensitive, so it may not show any change with a small increase in light. To help increase the sensitivity of the meter, conduct the tests in a very dark room or place a blanket over the design as it is being tested.

Tip

If time permits, have youth complete the *Extension Activity*, p. 37 in this guide, to further explore the light meter.

4. Encourage groups to *imagine* and *plan* how they will design their lighting system. Let youth know that they can sketch their designs on *Lighting System Design,* p. 15 in their Engineering Notebooks.

Create (30 min)

1. Give each group five storage cube sides, eight pipe cleaners, a 12” piece of tape, and a *Food Production Card* (from Prep Activity 2). Show them the example room you prepared in advance and instruct them to build their own room.
2. Once their room is complete, allow groups to collect the materials for their lighting system from the Materials Table and begin *creating* their designs.
3. As groups work, circulate around the room. Ask:
   - **Which materials are you using in different areas? Why?**
   - **Why do you think your system will work well?**
4. If groups *create* a lighting system that successfully lights up their *Food Production Card*, give them another card to place in a different location of their room. Challenge groups to *create* a lighting system that can direct light to both cards at the same time.

Test & Reflect (10 min)

1. Let groups know that they will now share their designs. They will also have a chance to *test* their designs with a tool called a light meter.
2. Hold up the light meter and explain that it is a tool that measures the amount of light it receives. Demonstrate how they will use the light meter to run their test. Place the meter in front of the *Food Production Card*, ensuring that the clear light sensors point toward the interior of the cube. Start by covering the lighting design system with a sheet of dark construction paper. Turn on the flashlight and observe how much light reaches the card without the lighting design in use. Then, uncover the mirrors and observe whether the needle on the light meter moves.
3. Have each group share their design. Then, have them *test* their design with the light meter. Ask:
   - **What about your design worked well?**
   - **What would you change if you had more time?**
   - **What impact do you think a lighting system like this could have on plants in a vertical farm?** *Getting plants more light can help with photosynthesis and lead to*

healthy plants.

- **Which steps of the Engineering Design Process did you use?**

4. Tell youth that next time they will use what they have learned about delivering water and light to plants by starting to engineer their model vertical farm for Greentown.
5. Have youth take apart their designs, but leave the storage cubes constructed for use in the final three activities.

Extension Activity

1. Make a copy of *Light Meter Investigation*, p. 39 in this guide, for each youth.
2. Split youth into two teams. Encourage them to come up with team names that are related to agricultural engineering and what they have learned thus far.
3. Hand a light meter to one member of each team.
4. Tell youth that they have 5 minutes to use the light meters to identify eight places in the room that have different readings on the light meter (A - H). Have youth record their results on *Light Meter Investigation,* p. 39 in this guide.
5. After 5 minutes is over, gather youth together to share their results. Ask:
   - **Which area of the room had the most light?**
   - **Which area of the room had the least light?**
   - **How did the light meter react when you moved the sensor closer to a light source? Why?**
   - **Would this room make a good vertical farm floor? How do you think we could engineer technologies to *improve* it?**

Light Meter Investigation

Identify eight locations in your environment that each register a different reading on the light meter. Record your results in the blank spaces below.

A ____________________

B ____________________

C ____________________

D ____________________

E ____________________

F ____________________

G ____________________

H ____________________

Activity **4** # Create a Vertical Farm

Educator Preview

Overview

Youth will be introduced to their final design challenge. They will work through several steps of the Engineering Design Process (*identify, investigate, imagine, plan*, and *create*) to design one room of a model vertical farm.

Note to Educator:

During this activity, your role will be to support groups as they take charge of their designs. Encourage groups to push their thinking and ask good questions. Each group will be working on one room of the vertical farm. Remind groups as they are working that their room will be combined with the others, so that may affect their design.
As written, this activity calls for model plants. If you would like to give youth real plants, be sure to provide at least one per group.

Activity Timing

Introduction:	5 min
Greentown's Farm:	15 min
Imagine & Plan:	10 min
Create:	25 min
Reflect:	5 min
	60 min

21st Century Skill Highlight

Collaboration
Creativity
Critical Thinking

Activity 4 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ colored markers
- ☐ 1 paper towel roll
- ☐ 1 sticky notepad
- ☐ 1 utility knife (for educator use)
- ☐ 1 light and moisture meter
- ☐ 2 measuring tapes
- ☐ 2 rolls of duct tape
- ☐ 2 rolls of masking tape
- ☐ 4 pitchers of water

For each group of 3

- ☐ 1 plastic aquarium plant
- ☐ 1 flashlight
- ☐ 1 pair of scissors
- ☐ 1 set of *Food Production Cards*
- ☐ 1 room (storage cube) created during previous lesson

For each youth

- ☐ Engineering Notebook

Materials Store

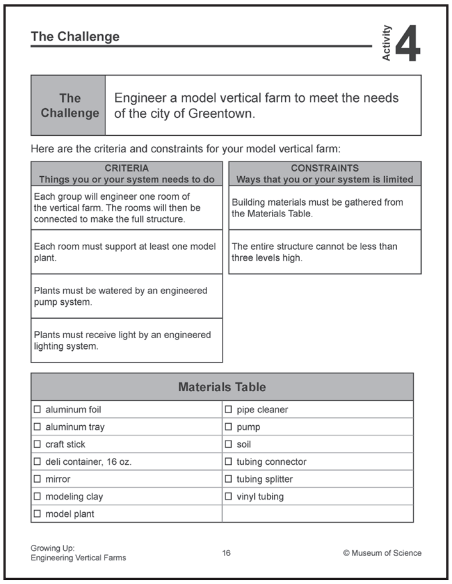
- ☐ 1 roll of aluminum foil
- ☐ 1 package of modeling clay
- ☐ 8 water pumps
- ☐ 12 mirrors
- ☐ 12 tubing connectors
- ☐ 12 tubing splitters
- ☐ 16 aluminum trays
- ☐ 16 deli containers,16 oz.
- ☐ 16 lbs. soil
- ☐ 80 ft. of vinyl tubing, 1/4 in.
- ☐ 100 craft sticks
- ☐ 100 pipe cleaners

Preparation

1. Post the *Engineering Design Process* poster.
2. Gather about 16 lbs. of soil. If you are using the aquarium plants, it does not have to be soil specific for growing plants.
3. Lay out supplies for the Materials Store.
4. Set aside materials for each group.
5. Review *Materials Store Extra Challenge*, p. 47 in this guide, and decide whether you would like to include a budget requirement for your group.

Notebook Pages for Activity 4

The Challenge, p. 16



The Challenge — Activity 4

The Challenge	Engineer a model vertical farm to meet the needs of the city of Greentown.

Here are the criteria and constraints for your model vertical farm:

CRITERIA Things you or your system needs to do	CONSTRAINTS Ways that you or your system is limited
Each group will engineer one room of the vertical farm. The rooms will then be connected to make the full structure.	Building materials must be gathered from the Materials Table.
Each room must support at least one model plant.	The entire structure cannot be less than three levels high.
Plants must be watered by an engineered pump system.	
Plants must receive light by an engineered lighting system.	

Materials Table	
☐ aluminum foil	☐ pipe cleaner
☐ aluminum tray	☐ pump
☐ craft stick	☐ soil
☐ deli container, 16 oz.	☐ tubing connector
☐ mirror	☐ tubing splitter
☐ modeling clay	☐ vinyl tubing
☐ model plant	

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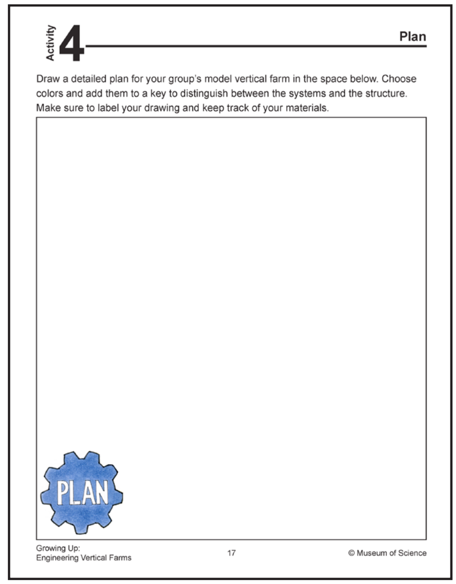
Plan, p. 17



Activity 4 — Plan

Draw a detailed plan for your group's model vertical farm in the space below. Choose colors and add them to a key to distinguish between the systems and the structure. Make sure to label your drawing and keep track of your materials.

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Activity

4 Create a Vertical Farm

Activity Guide

Youth will learn:
- The Engineering Design Process can help guide them to a successful solution.
- Designs do not always work the first time and they, as engineers, can learn from mistakes.
- Working as a team is an important part of engineering.

Tip

Lead a discussion about the benefits of using models to engineer new designs, like vertical farms. Make sure youth understand that models can help to test whether a design will work before full-size construction occurs.

Tip

The vertical farm building should be no more than four rooms tall to prevent the structure from tipping over.

Introduction (5 min)

1. Tell youth that they are now ready to begin their final design challenge.
2. Have youth form groups of 3 that they will remain in for the rest of the unit. Have youth turn to *The Challenge*, p. 16 in their Engineering Notebooks. Review the challenge and the criteria and constraints as a group, as well as the materials they will have available. Ask:
   - **What is the Greentown City Council asking us to engineer? Why?** *A model of a vertical farm that can supply food to the citizens of Greentown.*
3. Explain that each group will make one room of the vertical farm, and those rooms will be combined to form a vertical farm structure. This design will be presented during the City Council Presentation, the last activity of the unit.

Greentown's Vertical Farm (15 min)

1. Explain that the whole group will now decide how the rooms of the vertical farm will be arranged to form one complete vertical farm building. Let youth know that the building must be at least three rooms high, as stated by Greentown's City Council.
2. Give each group a sticky note and have them write their names on it. This will represent their room of the vertical farm.
3. As a group, have youth decide how the rooms will be stacked by rearranging the sticky notes until an agreement is reached. When the arrangement is finalized, tape the notes together and display them somewhere in the classroom where youth can refer back to them.
4. Have youth stack their empty rooms in the arrangement they decided upon. They should not attach them yet. Ask:
   - **What do you notice about the location of your room?**
   - **Where can light enter your room?**
   - **Where will your water reservoir be located? How much tubing will you need to reach your water**

reservoir?

5. Tell youth that they will now decide where the light source (flashlight) will be located. The flashlight must be located on the outside of the room with the light projecting in. Each group should decide where the light would likely be coming from given their room's position. Rooms on the top level may have light coming in from the top or sides, while rooms in the first two layers can only have light coming in from the sides.
6. Give each group a pipe cleaner. Tell groups to decide where their light source will be located. They should form a circle out of the pipe cleaner and tape it to the location where the flashlight will be held. This will ensure that the flashlight will be tested at the same position throughout the remainder of the challenge.

Tip

If you would like youth to have an additional challenge, consider adding a budget. Suggestions can be found on p. 47. If youth are using the budget, they should add the cost of the materials to their materials list.

Imagine and Plan (10 min)

1. Have youth read through *Test,* p. 18 in their Engineering Notebooks, to review how their models will be tested.
2. Let youth know that today they will work in their groups to *imagine, plan,* and *create* their room of the model vertical farm for Greentown. They can visually assess how their systems are working as they *create,* but they will officially *test* the light and water systems in the next activity.
3. Show groups the materials they will have available for their designs.
4. Give group 5 minutes to *imagine* and *plan* their designs. Let youth know that they can *plan* their vertical farm designs on *Plan,* p. 17 in their Engineering Notebooks.
5. As groups are finalizing their plans, circulate and ask:
   - **How did you decide on this design and these materials?**
   - **What do you think will work well about your design?**

Tip

If you feel that it will be overwhelming for your group to have access to all of the materials during this lesson, consider holding back the soil and water until the next activity.

Create (25 min)

1. Have groups visit the Materials Store to collect their supplies.
2. As groups work, rotate among them, encouraging what they are doing and asking them to explain how they are engineering. Ask questions like:
   - **Which parts of your design are working well?**
   - **What aspects of your design have you modified since you started? Why?**
   - **What do you predict will happen when you *test* your design?**
3. If groups would like an additional challenge, encourage them

to use one or multiple *Food Production Cards* from Prep Activity 2 and place them somewhere in their vertical farm room. They should make sure that these model plants also receive adequate light.

4. When time is up, have youth clean up their materials and tell them that they will *test* their designs in the next activity.

Reflect (5 min)

1. Gather youth around the *Engineering Design Process* poster. Point to each step of the Engineering Design Process and ask:
   - **How did you use this step today?** *We* planned, created, *and* tested *designs, and made* improvements.
2. Let youth know that next time they will combine the rooms of the vertical farm to create the model for Greentown. Ask:
   - **How did the original design you *planned* change as you were *creating* your model vertical farm room?**
   - **What challenges do you think you will face when combining multiple systems into a single vertical farm model?** *There is limited space; it can get complicated; the more connections you make, the greater chance there is for something to go wrong.*
   - **Why do you think using models before building is helpful for engineers?** *Encourage all answers. Youth may say that it saves materials and time, the model can help you see potential problems, designs need to be approved by the client, etc.*

Tip

If groups have access to both soil and water, their soil may become saturated with water as they design and test. Have dry soil available to replace wet soil. Spread out wet soil so that it can dry and be reused during the next activity.

Tip

If youth are interested in seeing an example of a vertical farm that was built within an existing building, show them the Plant, a vertical farm in Chicago that was built in what used to be a pork packing facility: http://www.plantchicago.com/.

Activity 4 Materials Store Extra Challenge

1. If you wish to increase the difficulty of the challenge, add the following constraint to the criteria and constraints chart:

CONSTRAINTS
Groups may not spend more than $100,000.

2. Copy the information from the chart below onto a piece of chart paper or individual price tags and instruct youth to keep track of their budgets.
3. Assign a volunteer to play the role of the Materials Store Clerk. Instruct groups to show their completed *Plan* and *Materials List* pages to the clerk in order to receive their supplies.
4. Tell youth to reserve 25% to 50% of their budget for future improvements.
5. In Activity 5, if youth are frustrated that they exhausted all of their original budget, you may grant them the ability to exceed their budget by a certain amount. If you have time, you can hold mini-challenges to gain access to extra funds.

Cost Chart

MATERIAL	AMOUNT	COST
pump	1	$20,000
parabolic mirror	1	$7,500
aluminum tray	1	$5,000
flat mirror	1	$5,000
model plant	1	$4,000
deli container, 16 oz.	1	$2,000
modeling clay	1 sq. in.	$1,000
vinyl tubing	1 ft.	$1,000
soil	8 oz.	$500
tubing connector	1	$500
tubing splitter	1	$500
pipe cleaner	1	$250
aluminum foil	1 ft.	$100
craft stick	1	$100

Activity 5 Improve a Vertical Farm

Educator Preview

Overview

Youth will work through the *test* and *improve* steps of the Engineering Design Process to make changes to their model vertical farm designs.

Note to Educator:

Encourage youth to focus on *improving* their systems. Your role is to facilitate whatever stage of the Engineering Design Process they are working on. Make sure to provide encouragement and reinforce their identities as successful engineers. In the next activity, youth will share their vertical farm with Greentown's city council. You may want to ask a few people in advance if they would like to take on city councilor roles.

Activity Timing

Combine the Rooms:	10 min
Test:	15 min
Planning Improvements:	5 min
Improve:	25 min
Reflect:	5 min
	60 min

21st Century Skill Highlight

Collaboration
Creativity
Critical Thinking
Problem Solving

Activity 5 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ colored markers
- ☐ *Materials Store* items (see Activity 4 Materials)
- ☐ 1 light and moisture meter
- ☐ 2 rolls of duct tape
- ☐ 2 rolls of masking tape
- ☐ 4 pitchers of water

For each group of 3

- ☐ 1 model vertical farm room
- ☐ 1 flashlight
- ☐ 1 pair of scissors
- ☐ 1 sticky note or scrap paper

For each youth

- ☐ Engineering Notebook
- ☐ *City Council Presentation Invitation*, p. 53 in this guide

Preparation

1. Post the *Engineering Design Process* poster.
2. Organize supplies on the Materials Table.
3. Print out *City Council Presentation Invitations*, p. 53 in this guide, for youth to share with family and friends.

Notebook Pages for Activity 5

Test, p. 18

Test — Activity **5**

Follow the testing procedures below to determine how well your model vertical farm directs water and light to the model plant. Record your data in the table.

Water System Testing Procedure

1. Set the meter to the moisture setting. Place the probe into the soil at the base of the testing plant.
2. Mark the starting position of the water meter needle on the data table.
3. Turn on the water pump and run the system for one minute.
4. Mark the new position of the water meter needle on the data table.
5. Did you observe water reaching the plant? Record your observations on the data table.

Light System Testing Procedure

1. Set the meter to the light setting. Put the sensor at the base of the testing plant. Be sure the side with the sensor is facing in the direction the light is coming from.
2. Cover the first mirror in the lighting system. Turn on the flashlight and mark the starting position of the light meter needle on the data table.
3. Uncover the mirror.
4. Mark the new position of light meter needle on the data table.
5. Did you observe light from the flashlight on the plant? Record your observations on the data table.

Water	1 2 3 4 5 6 7 8 9 10 Did water reach the plant? ☐ Yes ☐ No
Light	A B C D E F G H Did light reach the plant? ☐ Yes ☐ No

Which system will you focus on improving?

☐ **Water** ☐ **Light**

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Improve: New Plan, p. 19

Activity **5** — **Improve: New Plan**

Draw a detailed plan for the improvements your group intends to make to one system of the model vertical farm. Add new colors to the key used in the last activity. Make sure to label your drawing and keep track of new materials you use.

You may want to **continue to test your design** as you *improve* it. Use the tables below to record data from additional trials.

	Test 1	Test 2	Test 3
Water	1 2 3 4 5 6 7 8 9 10 Did water reach the plant? ☐ Yes ☐ No	1 2 3 4 5 6 7 8 9 10 Did water reach the plant? ☐ Yes ☐ No	1 2 3 4 5 6 7 8 9 10 Did water reach the plant? ☐ Yes ☐ No
Light	A B C D E F G H Did light reach the plant? ☐ Yes ☐ No	A B C D E F G H Did light reach the plant? ☐ Yes ☐ No	A B C D E F G H Did light reach the plant? ☐ Yes ☐ No

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Improve a Vertical Farm

Youth will learn:
- The Engineering Design Process can help guide them to a successful solution.
- Designs do not always work the first time.
- Engineers learn from their failures.
- Working as a team is an important part of engineering.

Tip

If you have a large group and are concerned about youth struggling to work on their room while all of the rooms are combined into one building, you may want to have youth stack, but not attach, their rooms together. They can see what they need to change so the room fits within the larger building, and then take their room to work on it separately. You will need to provide time at the end of the activity for groups to combine the rooms. The cubes can still be undone when they are held together with pipe cleaners, but it may destabilize the structure a bit.

Combine the Vertical Farm Rooms (10 min)

1. Explain to youth that they will start by combining the rooms of the vertical farm based on the arrangement they decided upon in the last activity. Tell youth that they will use pipe cleaners to secure the rooms together.
2. Assist youth as they combine the rooms. When the farm is constructed, give groups a few minutes to rearrange the systems within their rooms if they changed when the cubes were combined.

Test (15 min)

1. Tell youth that they will now *test* their model vertical farm room designs. Some groups may have *tested* their light or water systems during the last activity. Today, all groups should *test* both systems. This step is important because it will provide them information on whether their model plant is receiving the resources that it requires.
2. Have youth turn to *Test,* p. 18 in their Engineering Notebooks, and review the testing procedures together as a group.
3. Review the testing procedure for the light and moisture readings.
4. Have each group explain their design, and then *test* their lighting and water systems. Ask questions like:
   - **What is working well about your lighting and water systems?**
   - **What changes might you make?**

Planning Improvements (5 min)

1. Let groups know that they will now focus on *improving* at least one system in their rooms. They should use the data from their testing to determine which system needs the most improvement and work on that first. Encourage this thinking by asking questions like:
   - **Is your design working like you *imagined* it would?**
   - **What is working well about your design?**
   - **Which parts need to be *improved*?**
2. Have youth identify the system they will focus on *improving*

Tip

Encourage youth to check in and get advice from other groups if they are having trouble *improving* their designs.

Tip

As youth *improve* and *test* their water systems, their soil may become saturated with water. Have dry soil available to replace wet soil. Spread out wet soil so that it can dry and be reused during the next activity.

Tip

If youth successfully *improve* one of their vertical farm systems, challenge them to *improve* the other.

Tip

If you have extra time, you may want to show your group a real life example of a class in New York City who started the Green Bronx Machine. This project introduces gardening, including vertical farms, into classrooms. Find information and resources at www.greenbronxmachine.org.

first on *Test*, p. 18 in their Engineering Notebooks.

3. Remind youth that the *improve* step is a very important part of the Engineering Design Process. Let youth know that this is their last chance to engineer before they share the final model vertical farm design with the Greentown City Council.
4. Ask groups to spend about 5 minutes discussing the changes they would like to make to the system they identified.
5. Encourage youth to record their *improved* designs on *Improve: New Plan,* p. 19 in their Engineering Notebooks.

Improve (25 min)

1. Have groups collect any supplies they need from the Materials Store and begin *improving* their designs.
2. As groups work, rotate among them, encouraging what they are doing and asking them to explain how they are engineering. Ask questions like:
   - **How are you *improving* your design?**
   - **Are your *improvements* having the effect that you planned?**
3. Encourage groups to *test* their designs as they *improve.* Let groups know that they can record new testing data on *Improve: New Plan,* p. 19 in their Engineering Notebooks.
4. As youth finish up, congratulate them on completing the last improvements to their model vertical farm.
5. If there are groups who finish up very quickly, consider having them draw sketches of what they would like the exterior of the vertical farm structure to look like.

Reflect (5 min)

1. Have youth gather around the *Engineering Design Process* poster. Ask:
   - **Which steps of the Engineering Design Process did you use as you were engineering your model vertical farms?** *All of them!*
2. Tell youth that in the next activity, they will develop a presentation designed to convince the Greentown City Council to adopt the vertical farm design. Ask:
   - **Which steps of the Engineering Design Process do you think you will use as you create a presentation for the Greentown City Council?** *Communicate.*
3. Tell youth to start thinking about how they want to present their designs to the city council.
4. Congratulate youth on the excellent engineering and design work they did today!
5. Hand out *City Council Presentation* invitations for youth to share with family and friends.

You're Invited...

City Council Presentation

WHERE:

WHEN:

WHAT:

Come support your local engineers as they share their vertical farm designs!

Activity 6 City Council Presentation

Educator Preview

Overview

Youth will make a presentation to share their work with the Greentown City Council.

Note to Educator:
The Greentown City Council presentation is an opportunity for youth to share the engineering work they have completed over the course of the unit. Invite parents, peers, and other staff members to play the roles of the City Council members and to see what youth have engineered.

Activity Timing

Planning How to Present:	15 min
Presentation Preparation:	10 min
Presentation:	25 min
Reflect:	5 min
	55 min

21st Century Skill Highlight

Collaboration
Creativity
Communication

Activity 6 Materials

For the whole group

- ☐ *Engineering Design Process* poster
- ☐ chart paper
- ☐ colored markers
- ☐ model vertical farm
- ☐ 1 light and moisture meter
- ☐ 2 flashlights

For each participant

- ☐ Engineering Notebook
- ☐ *Engineering Certificate*, p. 59 in this guide

Preparation

1. Post the *Engineering Design Process* poster.
2. Invite several volunteers from outside of your course to play the roles of Chairman Higgins and the Greentown City Council at the Vertical Farm Proposal Presentation.
3. Print out an *Engineering Certificate*, p. 59 in this guide, for each youth in the group.
4. Write each youth's name on an *Engineering Certificate*. You may choose to write notes of encouragement on the back that describe how each youth made progress over the course of the unit. This document can be a very powerful memento!

Notebook Pages for Activity 6

Communicate, p. 20

Communicate Activity **6**

During your presentation, you will get to share information about your engineering challenge with the Greentown City Council. What are some things you might want to tell them about engineering a vertical farm in their community?

COMMUNICATE

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Engineering Vertical Farms 20 © Museum of Science

Activity 6 City Council Presentation

Youth will learn:

- The *communicate* step is an important component of the Engineering Design Process.
- They have valuable knowledge to share about the problem they have solved.

Tip

If you are unable to enlist other members of the community to attend the presentations and play the roles of the Greentown City Council, you can play the role of Chairman Higgins yourself or split the group in half and have youth prepare two proposals to present to each other.

Tip

Instead of giving youth a structure for their group presentation, have them come up with interesting ideas of their own. They may want to show a video or act out different roles in their presentations. As long as they have the inclination and the time, allow them to structure their own presentation.

Planning How to Present (15 min)

1. Tell groups that today they will present their vertical farm proposals to Chairman Higgins and the Greentown City Council.
2. Tell youth that they will first make a whole-group presentation highlighting the important ideas they learned about vertical farms to the council. Afterwards, the council will inspect the vertical farm and groups will present their individual rooms and answer questions.
3. Lead a discussion about how youth will create the whole-group presentation for the Greentown City Council. There are several ways that youth could structure the sharing of the work they have done in this unit. Ask:
   - **What important ideas do you think we should present?**
   - **Do you have ideas about how we might structure our presentation?**
4. If youth are having trouble deciding how to present to the Council, recommend that the Showcase be split into three parts. First, the whole group can explain the challenge and the Engineering Design Process. Then, each group can share their light and water system designs. After that, visitors can have an opportunity to explore the vertical farm model and speak with them about their designs.
5. Volunteers will need to fill certain roles in the first part of the presentation. Write some possible roles on the board for groups to review:
   - Describe the problem.
   - Explain the design challenge and the Engineering Design Process.
   - Describe some of the benefits of their vertical farm for the community of Greentown.
   - Describe what resources plants need to survive and be productive in a vertical farm.
   - Describe how they *investigated* different aspects of vertical farms, specifically water and light.
6. Encourage youth to add additional presentation topics to the list.
7. Have youth decide which part their group would like to present, and assign them their roles.

Tip

The presentations should be a time for youth who enjoy presenting, or those who would like to work on this skill, to take a lead role. It is not necessary for all youth to present, though everyone should take part in the preparation of presentations.

Tip

If you do not have an opportunity to sufficiently brief the visitors playing the City Councilors before this activity, have one or more youth provide a synopsis of Greentown, its needs, and the challenge.

Tip

By carefully observing the presentation, you should be able to assess which concepts youth took away from the unit.

Presentation Preparation (10 min)

1. Tell youth that they can prepare notes for their presentations on *Communicate*, p. 20 in their Engineering Notebooks.
2. Pass out markers and chart paper and encourage youth to create visual aids for their presentations.
3. Give groups 5 minutes to prepare their part of the whole-group presentation. Groups will need to decide exactly what they will say, which Engineering Notebook pages they might want to show, and who among them will do the talking.
4. After youth have finished preparing for the whole-group presentation, have them work with their original engineering groups to prepare individual presentations highlighting their particular room of the vertical farm.
5. As groups are preparing, rotate among them asking questions and providing support. The process of sharing should be fun and exciting, not stressful.

Presentation (25 min)

1. When all groups are ready, invite the members of the community playing the roles of the Greentown City Council, and any additional audience members, to come in and watch the presentation.
2. Have youth present what they have prepared for the whole-group presentation, then answer any questions from the city councilors.
3. When the whole-group presentation is complete, invite the city councilors to inspect each room in the model vertical farm.
4. Have each group present their model vertical farm room and then answer any questions from the city councilors.
5. When presentations are finished, be sure to congratulate your group on doing a great job with the *communicate* step of the Engineering Design Process and on being engineers throughout the unit. Have youth thank the council and audience members before adjourning the council meeting.

Reflect (5 min)

1. Gather youth around the *Engineering Design Process* poster. Ask:
   - **Which steps of the Engineering Design Process did you use to engineer your vertical farm?**
   - **Which step did you enjoy the most? Which did you not enjoy?**
   - **What will you engineer next?**
2. Use the remaining time to hand out Engineering Certificates and have youth reflect on their engineering experience by sharing what they will take away from the unit.

Certificate of Merit

For engineering excellence
and outstanding effort,
this certificate is granted to:

____

on: ________________ by: ________________